TECHNOLOGICAL DEVELOPMENT, STRATEGIC BEHAVIOR, AND GOVERNMENT POLICY IN INFORMATION TECHNOLOGY INDUSTRIES

BY

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Submitted to the Department of Political Science
in Partial Fulfillment of
the Requirements of the Degree of
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ABSTRACT

This thesis examines the competitive dynamics of the United States semiconductor and computer industries, their performance in international competition, and the effects of alternative government policy initiatives upon the future of these sectors and the U.S. economy. Through the empirical analysis of these issues, the thesis also seeks to further our general understanding of the sources of, and relationships between, several attributes of corporate strategy, government policy, sectoral dynamics, and national competitive advantage, particularly in technology intensive industries.

My principal empirical conclusions are that the U.S. semiconductor and computer industries are in technological and competitive decline, particularly relative to Japan; that this decline derives in large part from institutional and strategic forces not captured in traditional economic models; that further decay could have serious economic and political consequences for the United States; and that such decline will continue unless significant structural and policy changes, some of them rather unconventional in character, are introduced into the U.S. system.

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CHAPTER ONE

STRATEGIC BEHAVIOR AND HIGH TECHNOLOGY COMPETITIVENESS

1. A General Introduction

This essay examines the competitive dynamics of the United States semiconductor and computer industries, their performance in international competition, and the effects of alternative government policy initiatives upon the future of these sectors and the U.S. economy. Through the empirical analysis of these issues, the essay also seeks to further our general understanding of the sources of and relationships between corporate strategy, government policy, sectoral dynamics, and national competitive advantage, particularly in technology intensive industries. My principal empirical conclusions are that the U.S. semiconductor and computer industries are in technological and competitive decline, particularly relative to Japan; that this decline derives in large part from institutional and strategic forces not captured in traditional economic models; that further decay would have serious economic and political consequences for the United States; and that such decline will continue unless significant structural and policy changes, some of them rather unconventional in character, are introduced into the U.S. system.

To some extent the essay can be read as a traditional industry study. While its subject is a sector of unusually high economic, military, and geopolitical importance, and the study comes to some rather strong
conclusions, it often uses categories such as structure, technology, competitive strategy, government policy, and market performance. However, the implications of these traditional variables are changed by simultaneous consideration of others less traditional, and the explanation of industry behavior I finally propose is somewhat heterodox, at least from the standpoint of economics.

This nontraditional argument is related to the manner in which the essay also seeks to illuminate two other, far wider issues, with respect to both of which traditional explanations are insufficient. One is the general but still empirical question of the American economy's declining performance relative to earlier time periods and/or other nations; the second is the performance of the neoclassical competitive equilibrium paradigm itself relative to newer, nondeterministic, theories. These matters are of course related. To the extent that the argument driving the sectoral analysis presented here can be applied to other parts of the economy, it may to some extent explain why microeconomic industry analysis and macroeconomic growth accounting have been unable to describe recent U.S. performance satisfactorily.

My analysis suggests that competitive success and aggregate rates of industrial progress, particularly where continuous technological improvement is an issue, are strongly tied to strategic and institutional forces. In particular, aggregate behavior depends heavily upon long term, but local (in the sense of small and specific) strategic interactions between employees, firms, and governments (for example, their propensity to cooperate with each
other). The outcomes of these strategic processes are in turn strongly conditioned by time horizons, by the incentives, rules and/or norms of behavior which govern arenas such as markets and trade negotiations, by feasible choices with respect to cooperative versus adversarial strategies, and by appropriability considerations.

Indeed in the semiconductor / computer case, such "strategic" and "evolutionary" forces emerge as comparable in importance to traditional economic categories such as factor endowments, the terms of trade, or well developed markets. Sometimes strategic forces negate the impact of economic variables such as interest rates; in other cases, they greatly magnify them. In fact under some conditions the specifically strategic effects of economic policies such as interest rate management (e.g., via the effect of discount rates upon the propensity to risk future retaliation for hostile strategic actions) will vastly overshadow their purely traditional effects, such as changes in the rate of capital accumulation or investment. This proposition has potentially strong implications for both description and policy.

On this "strategic" view, for example, optimal policy with respect to long run industrial competitiveness would necessarily involve more than conventional analyses and economic measures such as macroeconomic adjustments, R&D commitments, adequate investment, and education. Analysis and policy measures which contemplate time horizons and the strategic conduct of individuals, firms, industries, and other interest groups would also be required. Frequently, it might prove optimal to employ highly specific policies tailored to sectoral conditions. In the United States of
the present day, the general thrust of such measures might include reducing the effective discount rates of institutions, shifting incentives towards domestic productivity growth (versus consumption and distributional conflict), changing the regions of (and boundaries between) cooperative versus adversarial behavior, and recognizing the importance of government policy in shaping international strategic interactions, particularly between the American and Japanese strategic systems.

And finally, the empirical argument presented here bears upon a yet larger, more theoretical issue. Both as an intellectual technology and as a body of substantive propositions, neoclassical economic theory appears to face significant limits. The shared assumptions of most models continue to neglect demonstrably important variables such as strategic effects, the impact of information costs and uncertainty, technological dynamics, and government policy. Relatedly, neoclassical models generally emphasize product market behavior while neglecting other domains of action such as technological or political cooperation and competition. Moreover, even within the narrow common ground shared by the major neoclassical models, the range of permissible alternative assumptions (e.g. with respect to the nature and extent of market imperfections) is sufficient to generate a wide range of divergent results. Consequently stylized, artificial assumptions are often required to generate "determinate" theoretical results, making the relationship between theory and reality fairly tenuous.

Similarly, many economic models are driven or constrained by the tractability limits associated with mathematical analytics or numerical
estimation techniques. Deterministic equilibrium models seem not to lend themselves well to the analysis of situations in which history, incomplete information, or strategic interdependence play major roles; nor do analytic or econometric models exploit recently developed techniques of computer simulation. Once again, the correspondence between theory and observation is weakened and rendered, ironically, highly indeterminate.

Some of these characteristics of economic theory may be sociologically derived. Many facets of neoclassical theory seem rooted in an earlier, less internationalized period in which economic activity was more frequently dominated by laissez faire systems, and by physical assets more than technology and information; a period also in which technological change, time pressures, learning effects, and strategic interactions were generally less intense, and in which elegant mathematics was the research technology of preference.

But whatever their source, these limits appear serious, and so it is pertinent to ask whether alternative models might yield improved theoretical descriptions of modern industrial dynamics. I will argue that at least if the information technology sector is any guide, an emerging theory of nondeterministic dynamics holds great promise for improved analysis. This discipline comprises models of interaction and dynamics which explicitly include local interactions, nonlinear dynamics, instabilities, and uncertainty. Its methodology relies heavily upon nonlinear mathematics, stochastic processes, and the intensive use of computer simulation to explore both qualitative behaviors and the robustness of results relative to
parameters such as discount rates and alternative strategic choices.

Such nondeterministic or evolutionary models include chaos theory; hysteresis models such as catastrophe theory; fractal theory and related models of diffusion-limited aggregation; simulated annealing; and perhaps most importantly for economics, analyses of iterative stochastic and/or strategic processes. While these models are being developed and applied by a wide array of disciplines - ranging from computer science to evolutionary genetics to political economy - the most prominent analyses devoted principally to social science are the strategic models pioneered by Thomas Schelling and Robert Axelrod. In the body of this essay, I will compare neoclassical explanations of semiconductor industry behavior with a model based upon a generalization of Axelrod's model of iterated strategic choice. In an appendix, I review and contrast these two theoretical approaches (the deterministic equilibrium models of economics versus nondeterministic evolutionary strategics) in a somewhat more general, theoretical way.

2. The Empirical Argument

The case I use to explore these questions is an arena which encloses the semiconductor and computer systems industries. The information technology arena, as I will sometimes call it, is a large industrial complex which has recently become the object of intense, internationalized strategic competition and of equally intense policy debates in several nations. (By the term "arena" I mean a domain of interaction, competition, and/or interdependence, for example a market or a set of business-government
relationships.) This arena, or system of arenas, includes the semiconductor industry, its associated capital equipment industry, the information systems sector (particularly computers), their consumers, and several other institutional structures, particularly government policy establishments and several related input and asset markets (e.g. for capital, technology, skilled labor, and corporate control).

The direct sectoral analysis traces the history of the Japanese and American industries, their characteristics, and their respective fortunes. The two national industries, it turns out, have developed along divergent structural and strategic paths. By virtue of their early institutional and technological particularities, the American semiconductor and computer industries developed quite different patterns from each other and from their principal Japanese competitors. In large part because semiconductors were initially commodity components, because early U.S. semiconductor markets were predominantly military, and because (IBM aside) many established firms in the U.S. computer and consumer electronics industries showed early indications of stagnation, few large U.S. firms invested successfully in semiconductor technology. (IBM and AT&T were major exceptions, but AT&T was precluded by its antitrust agreements from open market semiconductor sales between 1956 and 1982, and IBM also refrained from such sales for strategic reasons.)

Left to itself, the U.S. semiconductor industry remained fragmented and developed a chronic pattern of shortsightedness, instability, noncooperative behavior, and entrepreneurialism. The industry then institutionalized this
regime because incremental decisions made from within it rationally assumed it to be a fact of life: any individual agent was an arena taker, unable to shape the environment but required to adapt to it. As a decentralized infrastructure developed, a strategy of short term reliance upon it became less expensive relative to long term cooperation or vertical integration; and as we shall see, powerful strategic forces opposed firms acting against this tendency.

Conversely, the U.S. computer industry rapidly became and until quite recently remained a concentrated oligopoly dominated by IBM. Over the past decade, however, the gradual stagnation of the established industry and the emergence of novel systems markets opened opportunities for new entrants, and the newer portions of the U.S. computer sector increasingly resemble the semiconductor industry in their fragmentation and instability. As a consequence, the Japanese computer industry's efforts increasingly resemble the Japanese industry's strategy in semiconductor markets.

The result was a fragmented, unstable U.S. arena structure and, with a few exceptions, strategic norms of shortsighted, parochial, noncooperative behavior. As I will argue in detail below, this pattern of structural instability and strategic noncooperation constituted a strategic fragmentation trap analogous to a liquidity trap in macroeconomics. It was a suboptimal but stable equilibrium from which participants could not escape because it was not individually rational to try, and because no individual actor could overcome the centripetal force of the system. Only collective action or policy imposed from above could break the systemic incentives
which perpetuated the problem. This stable pattern of noncooperative fragmentation in turn generated competitive inefficiency. With the arrival of foreign competitors embedded in more favorable strategic systems, this inefficiency led to rapidly declining competitiveness, particularly in the semiconductor sector.

And the Japanese industry was, in fact, embedded in a more favorable strategic system, albeit one dependent in part upon the absence of U.S. retaliation in response to predatory Japanese behavior. But the Japanese industry was not structured in a manner which accords with traditional economic prescriptions. The Japanese electronics industry became and has remained a stable, highly concentrated oligopoly of roughly half a dozen giant, diversified, vertically integrated firms closely linked to even larger industrial groups and financial institutions. Moreover, these firms often cooperate extensively with each other and with the Japanese government, which prevented foreign competition and sometimes encouraged the formation of domestic consortia or cartels. Yet despite this structure the Japanese industry has not displayed the stagnation and rent harvesting deemed typically "cartellistic" by neoclassical models. To the contrary, Japanese industry has employed extensive strategic coordination primarily in furtherance of farsighted, technologically progressive strategies, and has displayed ferociously aggressive growth and competition.

The analysis thus concludes that the American semiconductor industry lost its competitive advantage primarily through strategic and institutional processes which shortened its time horizons, facilitated Japanese predation,
and favored consumption and distributional conflict relative to cooperation or long-term investments in productivity growth and institutional sophistication. Though previously more concentrated and stable, the U.S. computer industry has begun to exhibit similar dynamics, albeit not yet to the same degree as the semiconductor sector, and faces a potentially similar trajectory of decline. Structural, strategic, and government policy changes would therefore be necessary though perhaps not sufficient conditions for retention of the long-run technical and competitive strength of these industries. And while some portion of these industries' behavior can assuredly be attributed to traditional economic forces, the most important effect of economic variables (particularly factor costs) may have been to raise the effective discount rates of U.S. actors, thereby lessening their propensity to engage in long-run reciprocity and productive cooperation. In a capital intensive high technology industry with strong economies of scope and integration, the inefficiencies caused by suboptimal levels of communication and cooperation can easily dwarf the traditional allocative effect of factor cost differences.

The advent of major scale economies and increasing economies of vertical coordination associated with Very Large Scale Integration added further to these strategic processes and accelerated U.S. competitive decline. By the late 1970s, increases in scale requirements, computer-based automation, and device integration levels implied that semiconductor production would become a capital intensive, systems intensive industry of great strategic importance to downstream electronics sectors. The diversified, vertically integrated, capital rich Japanese industry acted
accordingly by importing U.S. technology, investing heavily, and mounting a strong competitive challenge to the fragmented, entrepreneurial U.S. semiconductor industry. The result was rapid U.S. decline and, frequently, an intensification of shortsighted strategic contention within the American arena, rather than the rationalization demanded by long term technological and market trends.

The computer industry, conversely, initially suffered less. The industry was relatively sheltered from both internal distributional conflict and from foreign attack, in large part as a consequence of IBM's early dominance and the switching costs imposed by the compatibility requirements of computer users. Even inefficient computer vendors were protected from precipitous decline by virtue of the effectively captive market consisting of their installed base. Hence within the computer industry, instability and Japanese technology licensing were initially confined to declining second tier firms such as Honeywell and Amdahl. (One result, however, was large scale Japanese intellectual property theft.)

However, with the exception of IBM (which became the world's largest semiconductor producer in order to meet its own needs), U.S. computer producers came to depend primarily upon the open market semiconductor industry for their commodity devices, though they developed small "captive" (i.e. internal) operations to supply themselves with special purpose circuits. Eventually, the presence of the merchant semiconductor infrastructure, the open market availability of powerful VLSI devices, and the U.S. tax system's subsidies to venture capital based startups diffused
the regime of unstable entrepreneurialism and fragmentation further downstream, into new markets for personal computers, peripherals, advanced workstations, digital switches, multiprocessors, supercomputers, and fault-tolerant machines. The behavior of the new firms in these markets strongly resembles that of the merchant semiconductor industry. As I indicate below, this facilitates Japanese technology extraction and competitive entry. In addition, the increasing dependence of most U.S. computer vendors upon Japanese semiconductor technology increasingly provides a source of leverage for Japanese computer vendors, one already evident in arrangements between Hitachi and Unisys, Fujitsu and Amdahl, and NEC and Honeywell.

The continuation of this regime would eventually destroy most of the U.S. semiconductor industry and, in part by threatening the technological competitiveness of captive semiconductor production, also represents a major strategic threat to the U.S. computer industry. Indeed the fragmentation of new U.S. computer markets, the increasing dependence of U.S. electronics firms upon semiconductors supplied by Japanese competitors, the increasing frequency of licensing arrangements with Japanese producers, and the lack of backward integration by the U.S. computer industry can be regarded as both indicators of, and contributors to, the emergence of competitive decline and distributional conflict in downstream U.S. industries similar to that observed already in semiconductor production. While some recent events suggest that the U.S. industry is learning how to cooperate (e.g. agreements between Sun and AT&T, DEC and Apple), the net trend would appear to be negative. The U.S. has already become a $4 - 5 billion net importer of computers relative to Japan (versus parity in 1982, and a net exporter
previously), and the U.S. worldwide trade surplus in computers has declined steadily since 1981, from a peak of roughly $7 billion to less than $3 billion presently.

In addition, increasing U.S. competitive difficulties in the semiconductor and computer industries have progressed in tandem with a more general internationalization of high technology competition, a process resulting in the formation of globally integrated (though far from homogeneous) competitive arenas. As a consequence of the fragmentation, insecurity, short time horizons, and absence of internal cooperation which characterize the U.S. regime, the United States is being integrated into this emerging global system on strategically unfavorable terms. Increasingly, the U.S. arena occupies a subordinate position as an institutionally fragmented provider of marketized services to strategically cohesive, vertically integrated foreign competitors. Partly as a consequence, the U.S. is becoming a major net exporter of its expertise, technology, and human capital, while increasingly an importer of commercial products developed with them. Foreign firms with favorable strategic arrangements and efficient manufacturing capabilities thereby appropriate many of the social returns to U.S. technology-related expenditures. In aggregate terms, this appears to constitute a process of U.S. societal disinvestment which brings a one-time windfall to the present generation at the expense of its successors.

Whether the U.S. regime can be changed sufficiently to arrest this decline is unclear, and depends heavily upon prospective U.S. industrial
coordination, national politics, and Federal policy. However, policies which do not recognize these strategic and institutional forces may be ineffective or even counterproductive. The U.S. structure, and its competitive weaknesses, may owe as much to these strategic forces as to cost or market forces of the sort typically described by neoclassical economic theory, including newer models which incorporate simple oligopolistic interactions and learning effects. Hence in addition to providing resources, successful U.S. policy interventions would necessarily also change the incentive structures which govern U.S. corporate strategy. Policy must lengthen the time horizons of industrial actors, encourage vertical cooperation, and favor enduring productivity gains rather than distributional conflict or the pursuit of short term profits.

The prediction of further U.S. decline thus raises the prescriptive question of policy alternatives and their consequences. The empirical argument suggests that the economic importance of competitive information technology sectors is large. In addition to serving as a test case for theoretical models, the industrial complex comprised of the semiconductor, computer, and related sectors is important on its own terms. Semiconductor and computer technologies are diffusing widely; the technological and competitive position of the United States is declining; and the sectors in question are strategic in virtually every sense. Microelectronics and computer systems are rapidly growing industries increasingly critical to each other and to other major sectors including telecommunications, aerospace, robotics, automobile, defense, and financial services.
Semiconductors and Computers As High Technology Sectors

In fact, microelectronics is at the core of an industrial revolution driven by rates of technical progress quite literally unprecedented in economic history. The sectors which powered or benefited from earlier industrial revolutions exhibited rates of growth and technical progress ranging from five to fifteen percent annually. During the first industrial revolution of the late 18th century, for example, British cotton consumption grew 6.7% annually, and the cost of cotton yarn fell by about 1% per year. During the second industrial revolution of the late 19th century, the combined steel production of Britain, Germany, France, and Belgium grew 10% to 15% annually. Through the same period, the lethality and cost/performance indices of armaments grew about two orders of magnitude, a compound annual growth rate of less than 5%.

In contrast, the contemporary revolution in information technology has displayed rates of growth and technological change ranging from fifteen to forty percent per year for about thirty years, and is expected to continue this trajectory for another twenty years or more. World computer shipments have grown 20% annually in revenue terms over the past decade; semiconductor shipments have grown 15% per year for the last twenty years; the price per bit of semiconductor memory has decreased 40% per year since 1971, while consumption has grown 25% annually in dollar terms; world software shipments are growing about 30% per year; total installed computer functionality doubles about every three years; and new 32-bit personal computers are more powerful than the largest, most expensive mainframes of
thirty years ago.

Recently, however, the American information technology sector has deteriorated sharply relative to foreign competitors. This has been most evident in the semiconductor industry. In the past decade, Japan's share of world semiconductor markets has nearly doubled to almost 50%, while the U.S. industry's world market share has declined from about 60% to 40%. Japan has overtaken the U.S. in some measures of innovation as well; between 1975 and 1982, Japan's share of world integrated circuit patents rose from 18% to 48%, while America's share declined from 43% to 27% in the same period. In the computer industry U.S. decline has thusfar been less severe, but it is already noticeable. In 1982, the United States became a net importer of computers relative to Japan. Imported computers (including peripherals, and including imports from foreign IBM plants) now hold about 30% of the U.S. market, Japanese firms are constructing major U.S. factories, and it is anticipated that the United States will become a net importer of computers by the late 1980s. And if the analysis I advance below is correct, the future - absent major structural and policy changes - will show further U.S. decline, particularly relative to Japan and South Korea.

The consequences of this transformation are potentially vast. Over the next thirty years, the cost / performance ratios of information systems will improve another hundredfold, and the production of digital systems, already a $200 billion industry, will become one of the world's largest industrial sectors. Information technology industries such as semiconductors, computers, and software are high-wage, high value-added sectors thought to
generate unusually large economic benefits to host nations. Their output will be responsible for a substantial portion of future productivity gains in many other industries. Moreover, digital technology is becoming increasingly critical to military power, so that the competitive and technical performance of relevant national industries may have substantial geopolitical and national security consequences. Hence the condition of U.S. information technology sectors has recently become the focus of intense policy debates.

These sectoral events have unfolded concurrently with two other processes relevant to this essay. The first is the more widespread and continuing deterioration of American economic performance, including productivity growth and competitiveness. Over the past quarter century, U.S. productivity growth has declined from over 3% annually to less than 1% annually, and a seventy year long trade surplus became an enormous trade deficit. In several major industrial activities (e.g. steelmaking, automobile production, machine tool production, and the use of flexible automated manufacturing systems), the absolute or physical productivity of U.S. industry has come to lag best world practice by large margins - in some cases, by a factor of two or more.

The same period has witnessed increasing contention between the academic disciplines which seek to understand economic behavior. This tension is found, for example, in the sharpening competition between various schools within neoclassical economics, and between neoclassical theory generally and other schools of thought competing to explain economic
behavior and to structure the terms of policy debate. These competing models include traditional neoclassical economics, emphasizing determinate cost variables and competitive markets; new neoclassical models based upon learning effects and imperfect competition, but which are usually still determinate equilibrium, perfect information, noncooperative models; population ecology models; and finally, the fundamentally different new models based upon long run strategic and evolutionary processes, developed from within several disciplines including evolutionary genetics, management, and political science.

The differences between these competing theoretical visions, though they may seem academic in the perjorative sense, may be of some importance to economic policy. The economic effects and policy requirements generated by American competitive decline, for example, depend fairly heavily upon whether self-adjustment is automatic, and upon whether and how strategic processes have a role in this decline. If American industry's performance is the best possible given existing macroeconomic conditions, and if its competitive decline is caused by high capital costs and macroeconomic instabilities such as exchange rate shifts, then responses to these conditions might be necessary and/or sufficient.17

But if strategic effects are important and strategic problems are severe, matters are more complex. For example, conventional forms of assistance may not help, because they might be wasted in strategic conflict. Inefficiencies generated by dysfunctional strategic processes could be so large that changing the arena's strategic incentives would be necessary.
and/or sufficient to produce substantial improvement in U.S. performance. I argue that such strategic processes, both productive and destructive, are quite important in the semiconductor and computer cases. They have interacted with traditional economic variables such as capital costs, wage costs, and economies of scale and scope in such a way as to nullify initial American technological advantages and to magnify American disadvantages in factor costs.

Indeed, one implication of strategic analysis is that certain attributes of U.S. factor markets - high labor mobility, high capital costs, and the extreme liquidity and arm's length relationships which characterize U.S. financial markets - may be substantially more detrimental than traditional neoclassical models would suggest. Suppose, for example, we accept that U.S. capital costs are higher than Japan's. On a purely neoclassical analysis, this would simply depress investment by the U.S. semiconductor industry by some fraction. But on the more strategic view, high capital costs would also have another important effect: they would raise the discount rate used in evaluating strategic interactions, shortening the shadow of the future and shifting firms towards adversarial strategic postures. For example, firms will avoid long term cooperative relationships, particularly any which involve initial risks; if breaking a commitment offers a short term gain, the commitment will be broken even if it damages future relations with the other firm; and firms will tend to become free riders in situations which include public goods dilemmas. In other words cooperation, trust, and reciprocity are favored proportionately to the extent that the future is valued.
Similarly, if U.S. capital markets are characterized by liquidity and high costs, investors will rationally have short time horizons as well, and will avoid long term cooperation in their own way - by withholding funds from temporarily troubled firms or during cyclical recessions. This will raise the cost of funds to these firms yet further, thereby endangering them even more. While it might well be in the collective, long term interest of the populace to assure these firms a steady supply of capital, it is in the individual, short term interest of any single capital supplier to act otherwise. This expectation of "defection" by investors will oblige firms to be more risk averse and to shorten their time horizons yet further, affecting their propensity to cooperate with their own employees, with other firms, and so forth.

For complementary reasons, I will argue later that it is neither surprising nor coincidental that Japanese banks own stock in the firms in their group to which they lend money, that these firms often own stock in the bank, and that Japanese electronics firms have extremely close long term relationships with suppliers and customers. The point in both cases is that a traditional economic parameter (the risk-adjusted interest rate) has a nontraditional role, namely that of regulating the degree of cooperation in which agents are rationally willing to engage. If such cooperation and information sharing are important, this strategic issue could overwhelm the traditional allocative effect of altering investment at the margin. Much theoretical research in strategic processes is therefore devoted to elucidating the determinants of effective time horizons and of levels of
cooperation exhibited by self-interested actors.

And, in fact, I will argue that the strategic behavior and performance of American information technology arenas, and perhaps others as well, have come to be much influenced by short term calculations of narrowly individual self-interest. The environment in which firms operate - an environment which is in part their collective creation through their strategic choices - has shortened the time horizons of actors (individuals, firms, sometimes coalitions or interest groups) and led them to seek individual advantage through collectively dysfunctional distributional struggles rather than by competing within structural conditions and strategic norms which engender maximum long run productivity growth. The evolution of arrangements which would have yielded superior long run performance, while probably affected by macroeconomic and aggregate factor supply considerations, has thus also been impeded by strategic dilemmas and incentive structures which reduce the individual attractiveness of those actions which would generate optimal long run productivity gains.

Hence, background conditions of arena conduct led to individual optimizations which lessened aggregate efficiency and also exposed the U.S. arena to external strategic predation. These noncooperative, shortsighted decisions then reacted back on the general environment, intensifying tendencies towards shortsighted individualism. When the effects of this regime showed later in deteriorating performance, this deterioration rendered effective long range action yet more difficult as lifeboat ethics has spread, and as remaining U.S. actors seek individual security -
protectionism, alliances with foreign predators - in order to survive.

Similar strategic considerations also, in my view, increase the economywide impact of U.S. decline in specific sectors, including semiconductors.

Therefore the empirical arguments regarding the strategic nature of digital information systems competition have implications both for real economic policy and for general theories of political / economic dynamics. I argue that long run strategic processes are a significant force in conditioning structure and performance, that they interact closely with economic variables such as capital investment and labor quality, and that any policy capable of reversing American decline must take these strategic forces into account. And policy changes, I conclude, are indeed necessary. Unless effective policy measures are undertaken, U.S. open market semiconductor production will largely disappear by the mid-1990s, and much of the digital systems sector will enter a serious, possibly irreversible decline.

3. Implications and Generalizations

As already indicated, this sectoral and policy analysis is in turn used to illuminate two more general issues: the declining relative performance of the American economy, and the nature of theoretical models which might best explain variations in the structure, strategic behavior, and performance (say, productivity growth and/or competitiveness) of national industrial sectors. The principal theoretical focus is upon comparing neoclassical analyses and recent "population ecology" models with
evolutionary strategic models, both as descriptive accounts of industrial
dynamics and as prescriptive guides to decisionmaking. (Appendix 1 contains
a moderately lengthy theoretical comparison of these models.) My conclusion
is that neoclassical and population ecology explanations are useful but
limited, while emerging models of strategic evolutionary processes offer
considerable promise for improved understanding of microeconomic dynamics,
economic performance, and the political economy of industrial competition.

Neoclassical and Population Ecology Models

The underlying theme of neoclassical analysis is that the forces of
supply and demand, usually though not necessarily expressed in explicit
markets, provide fairly determinate, optimum economic outcomes. In the
microeconomic context, market structures and prices reflect optimal
responses to technology, cost, and demand conditions. In the macroeconomic
and international context, production and trade patterns follow factor
endowments and comparative advantage, while national growth paths follow
capital accumulation, aggregate technological change, and perhaps domestic
capture of increasing returns. In the most extreme version of a perfectly
competitive system, the only potentially useful roles for a government are
the regulation of pathological cases (e.g. natural monopolies), the
provision of public goods, and perhaps measures to regulate aggregate
macroeconomic incentives to save, invest, and consume.

At least implicitly, the neoclassical outlook hence presumes not only
that markets work when they exist, but that there is an implicit, yet
efficient market for the production of markets and market structures themselves. In other words, when there is a need for markets they arise, and their structure is appropriate to economic efficiency. For example, Nancy S. Dorfman's 1987 analysis, "Innovation and Market Structure," discusses traditional microeconomic parameters of the U.S. semiconductor and computer industries in relation to Schumpeter's innovation hypothesis. (Japan is mentioned perhaps ten times in 250 pages, and Korea and Taiwan are entirely absent.) In this and other neoclassical analyses, features of market structure (such as concentration, the success of small versus large firms, levels of entry and exit, dominance of innovation by established firms or entrants, and vertical integration) are explained as natural reflections of technology, cost structures, and demand. The underlying assumption and/or conclusion is that forces of supply and demand are sufficiently strong that only efficient forms of behavior can survive. Therefore observed market structures and strategic behaviors are individually rational, relatively determinate, and collectively optimal.

Inefficiencies, if and when they occur, are chiefly the result of excessive market power, government interventions, or both. Therefore microeconomic sector studies, ranging from Almarin Phillips' "Market Structure and Technological Change" (concerning aircraft production) to the National Security Council's economic analysis of the semiconductor industry, are principally concerned with how market behavior reflects technology, demand, and/or distortions caused by interventions. The extant analyses of the IBM and AT&T antitrust cases, and more generally of the computer and telecommunications industries, are principally concerned with such
questions. Brock and others have argued that IBM and AT&T possessed market power; Fisher and others argued they did not.

Similarly, neoclassical treatments of international competitiveness and trade patterns seek to explain patterns of production and trade through reference to comparative economic endowments and international market conditions, often as affected by government policies (such as exchange rate manipulation or currency controls). Robert Z. Lawrence's "Can America Compete?" and C. Fred Bergston & William Cline's "The United States - Japan Economic Problem," for example, both cite such factors as exchange rates, net savings rates, macroeconomic policy, and the Federal deficit as the determinants of variation in competitiveness, the sources of relative U.S. decline, and the correct foci of remedial action. In these and other traditional economic analyses, politically generated macroeconomic distortions are often held responsible for problems in otherwise roughly competitive market processes which, if left alone, would generate more satisfactory outcomes.

The more traditional neoclassical vision was predominantly restricted to static analyses; and in international economics, most models and thinking assumed perfect competition. For reasons of both formal and empirical inadequacy, these models have now been partially superceded from within economics. Recent neoclassical analysis has expanded into models involving learning effects and network externalities in microeconomic behavior, and the presence of increasing returns in international industries. This new emphasis upon "imperfect" competition has given rise to a new neoclassical
economics, including but not restricted to so-called strategic trade theory. These more recent neoclassical models, and the empirical analyses drawing upon them, certainly widen the scope of economics to include some important forms of strategic interaction. However, the additions are incremental rather than qualitatively new. Important forces remain unexamined, and many questions of industrial behavior - e.g., why industrial structure, strategy, and performance vary over time and across nations - remain unanswered.

In particular, international competitiveness - even at the level of firms, but particularly at the level of industries or complexes of related industries - appears to depend heavily upon multiple, concurrent, iterated strategic processes. The aggregate outcomes of these processes depend upon long run strategic behaviors which, in turn, derive from domestic as well as international norms, institutions, and incentive structures. Hence models which omit politics, or the interplay between national specificity and internationalized activity, or the nondeterministic, evolutionary character of much strategic decisionmaking, are unlikely to provide satisfying models of international competition. For such reasons, the "strategic" models of the new international economics 19 offer only modest improvement over the traditional theory of comparative advantage. For example, strategic trade theory at present considers the effects of international strategic interactions upon national industries without, generally, considering how they might affect or be affected by domestic strategic interactions specific to those national industries. Nor do they generally leave much room for historical conjunctures which, in the presence of increasing returns, might have substantial long term consequences.
Yet a number of sector studies, including my analysis of the semiconductor and computer industries, suggest that such processes are both important and tightly coupled to international competitive, and specifically to strategic, interactions. A number of considerations suggest that this situation is more the rule than the exception. For example, the determinants of the effective time horizons and strategic incentives facing firms, and therefore in large measure their strategic propensities and perhaps their long run competitiveness, are often found in incompletely traded arenas (e.g. flows of venture capital, information, skilled labor), government policies, or in nationally specific industry structures. The strength and qualitative nature of various nations' responses to foreign competition are therefore potentially, and also actually, quite different as a consequence of domestic differences in structure and strategy.

More recently, "population ecology" models of market dynamics have been developed in an attempt to explain distributions of organizational types and sizes, and particularly nonuniform distributions which include niche firms, over time and across industries. In these models, the adaptability of various classes and populations of organizations to external environmental conditions, and to changes in these conditions, determines arena-level outcomes such as industry structure. While these models are of some interest, in their current form they have limits (perhaps surprisingly) similar to those of neoclassical economics. For example, "the environment" is usually exogenously specified, and the potential importance of multiple, continuing strategic interactions among players is left unaddressed.
To put it more generally, existing models—traditional neoclassical models, the new neoclassical economics, population ecology models—largely continue to omit from consideration a variety of arenas, forces, and forms of interaction which, while perhaps mathematically inconvenient, outside the purview of economic theory and management science, and/or as yet incompletely understood, are often critical to understanding actual industrial conduct.\textsuperscript{21} There is increasing agreement that there exist learning effects, system economies of scale, public goods dilemmas, opportunities for cooperation, and other strategic interdependencies in many industrial activities—ranging from R&D to capacity rationing, relationships with suppliers, personnel policy, lobbying the government, assessing technologies, and, finally, traditional product market competition. But, under some conditions, such interdependencies imply the importance of several other issues relatively foreign, so to speak, to the fields of economic theory and strategic management.\textsuperscript{22}

Two related examples of such issues are (a) the weight of increasing returns, for example via the effect of sunk costs upon incremental decisions and (b) the impact of uncertainty about the future upon the nature of strategic decisionmaking. In the presence of learning effects and system economies of scale, investments made at a given time and in a given way will reduce the relative costs of continuing along that path in the future, and therefore increase the costs of switching to any other. But this implies that initially small effects arising from chance, uncertainty, or local market imperfections can yield eventually major divergences—between
different firms, different national industries or arenas, and/or between optimal and actual practice. And while in traditional economic models the assumption of increasing returns has been applied only to production (through scale and/or experience effects), there is little reason to believe it does not hold elsewhere as well. Firms can gain experience benefits in R&D, competitive assessment, supplier relationships, political strategies, and strategic styles as well as in cumulative output. And, therefore, cooperation and information sharing between institutions with complementary experience endowments and information might prove highly valuable.

Analogously for uncertainty. In the presence of unpredictable change, actors may be unable or unwilling to make irreversible, risky strategic commitments. Consequently strategic behavior will take the form of repeated, short term decisions which can be revised in subsequent interactions as a function of new information. But the new information will include the strategic decisions made by others - such as whether they cooperate or compete, or whether they have adhered to, or defected from, prior strategic practices. Those with long time horizons will care more about how others respond in future rounds of competition, and interdependent actors will be able to cooperate most efficiently under such conditions. Thus, paradoxically, long time horizons with respect to strategic interactions may be most important when the ability to predict the future in any specific way is very limited. This, for example, may explain Japanese contracting practices which many U.S. businessmen have found puzzling. Often, Japanese firms simply reach a vague agreement that one will develop a product for the other. Because the firms involved typically have a variety
of strong, long term interdependencies, there is little need for detailed contracts covering unforeseen contingencies; both parties have confidence that difficulties will be resolved cooperatively. (As we shall see, however, Japanese - American technology licensing agreements are rarely blessed in the same way.)

One common result of situations involving long term interactions under conditions of uncertainty appears to be the development of identifiable "regimes" of competition and cooperation through an evolutionary process, the result of repeated strategic interactions and signaling. The characteristics of these regimes - the degree of cooperation versus adversarialism which come to dominate them, their average performance levels, the kinds of strategies which succeed best - are precisely the questions studied by Axelrod and others. The simplest and best-understood formulation of the strategic problem is a symmetric, 2-player, iterated prisoner's dilemma. More complex, less understood cases involve other, asymmetric games such as "Chicken;" N-player games; and processes involving multiple, concurrent, interdependent games.

Evolutionary Strategic Models

Such iterated strategic interactions - even in their simplest forms - are now known to yield results quite different than those associated with the assumptions and models of neoclassical economic theory, including recent but still largely deterministic "new wave" or "strategic" models. For example Axelrod's mathematical analyses and computational simulations of
iterated symmetric prisoner's dilemmas suggest that the existence and characteristics of long run strategic processes are major determinants of the levels at which public goods will be provided. Under some conditions iterated processes give rise to widespread cooperation and positive sum interactions, while under other structural conditions the result tends to be pervasive defection and nonproductive distributional conflict.

Furthermore, the first, still very recent, attempt (by Fader and Hauser) to use an evolutionary strategic model to simulate microeconomic competition (an n-player pricing game) suggest that strategies which recognize, respond to, and encourage coalition behavior exhibit greatly superior long run performance relative to other strategies competing in the same arena. Somewhat surprisingly, this was true even in quite "nasty" environments in which friendly overtures had a two-thirds probability of meeting with immediate betrayal. To be sure, the sensitivity of this result to variations in individual and arena-wide discount rates was not analyzed. But even so, absolute performance (both individual and collective) was substantially degraded by widespread nastiness relative to nicer arenas.

In many kinds of long run strategic interactions, behavior can change over time; Axelrod provides both historical and synthetic (i.e. computer generated) examples, including the development and destruction of the "live and let live" system in trench warfare during the first world war. This system, in which opposing armies spontaneously evolved informal truces via strategic signaling but without explicit coordination, was broken by higher
commanders' introduction of, in effect, predatory entry: unpredictable attacks and rotations of soldiers which eliminated the individual benefits of long run cooperation. Hence while the warfare remained a long run strategic process in the aggregate, with the rise of defection caused by personnel shifts and predatory attacks it became impossible for opposing armies and even individual soldiers to develop a history of strategic signaling, or to count upon any cooperative response to their own restraint. Hence the arena disintegrated into widespread defection, i.e. renewed real warfare, just as the high command wished. 26

One recently noted form of strategic interaction, involving multiple linked games, deserves mention because it suggests an evolutionary, strategic version of increasing returns and strategic lock-in: a process whereby one strategy or form of behavior drives out others and persists even when other, potentially superior, strategies are available. In a recent article Axelrod investigated the evolution of norms, conceived roughly as behaviors enforced by decentralized action rather than by law or central authority. A single "norms game" produced indeterminate behavior; sometimes a norm spread, but sometimes nobody heeded it. But then Axelrod introduced an additional "metanorms game," which made the decision to sanction or not sanction defectors from the norm into a separate and parallel strategic process. When both games were played simultaneously, the evolution of the arena uniformly produced lock-in: the norm always became universal. 27

While the particular game Axelrod chose is of questionable economic relevance, a larger point is clear. If players must interact in several
strategic arenas simultaneously and their decisions are linked, strategies and actors are rapidly forced into mutually exclusive equivalence classes, and switching costs can be exceptionally high. Anyone who cannot afford to pay those costs is locked in, and shortsighted actors will be least inclined to pay them. Early events thus come to have large structural impact, and strategic interactions can produce extreme behavioral rigidities.

That, I will argue, is exactly what happened to the American semiconductor industry. More generally, our understanding of behavior under conditions of repeated strategic interaction by now suggests that an industry’s efficiency and long run competitiveness might be substantially affected by its strategic processes, and in a potentially wide variety of ways. The behavioral and performance outcomes of these processes, it seems, in turn depend upon the structure of arenas, the presence or absence of rules enforced by a central authority, the nature of these rules or incentives if they do exist, the effective time horizons of participants, their subjective preferences, their strategic histories and behavioral patterns, and the levels of information available to them. I will argue below that precisely these factors – particularly time horizons and the strategic forces affecting them – are critical to understanding the long run problems of American high technology industry.

For example, the effects of so-called “strategic” trade policy as described by the new neoclassical economics (i.e., national protectionism designed to shift scale economies and experience to domestic producers in order to give them advantages in foreign markets), far from being determined
in advance by nations' eternal, fixed "reaction functions," would in fact depend upon whether such a policy would evoke foreign retaliation, the response to such retaliation, et cetera. The effect of such a policy would similarly and simultaneously also depend upon whether, in the presence of national protection, the domestic industry's strategic arrangements would give rise to productivity growth, as opposed to rent-harvesting with cartellistic stagnation. This in turn depends upon whether the home government would penalize such cartellistic behavior, upon the interactions between international and domestic strategic forces, and upon the specific nature of the strategic regime governing individual industries in each nation. Hence "strategic" protection of an industry may yield vastly different results in the United States than elsewhere, and protecting some industries may yield different results than protecting others. Nor is the traditional criterion of cartellistic tendency, namely horizontal concentration in product markets, very useful for the purpose of distinguishing industries which would invest a windfall (in creating future productivity gains) from those industries which would consume or waste it. Assuming rational behavior, the most critical parameters would be time horizons and the nature of the strategy played by the government.

I argue below that the specific strategic system which evolved in the U.S. merchant semiconductor industry, superficially a model of efficient market behavior, entrepreneurialism, and vigorous competition, in fact discourages long range, collectively efficient investments relative to consumption, distributional conflict, waste, and even direct transfers of expected revenue streams to foreign competitors. This strategic pattern
derives, I believe, from structural conditions and long run strategic processes of the sort described above. For example, U.S. subsidization of entrepreneurial new venture formation led to high rates of defection which could not be effectively deterred by existing firms through any legal form of strategic behavior. Personnel defection and firm-level instability reduced cooperation and time horizons, which in turn led to reduced aggregate efficiency and to individually rational, but shortsighted and collectively self-destructive, technology sales to Japanese competitors.

Even during the period of U.S. dominance which endured until the early 1980s, these strategic patterns increased the costs of the U.S. industry, in part by consumption (e.g., increasing the wealth of its professionals and executives) and in part through waste (e.g., suboptimal levels of procompetitive technical cooperation). But whereas in the earlier period U.S. firms competed only against each other, which permitted them to impose their inefficiencies upon consumers, their inefficiencies and strategic deficits severely disadvantaged them in competing against the Japanese industry. Since the U.S. domestic regime remains largely intact, the utility of either conventional policy remedies (e.g. increased R&D funding) or strategic protectionism of the new neoclassical sort is questionable. Indeed, such measures might worsen U.S. decline unless they were accompanied by other measures which altered strategic behavior.

Consequently the utility of instruments such as strategic trade policy, to either Japan or the United States, depends upon an understanding of linkages between international and domestic forces, upon preexisting
domestic norms of strategic behavior, upon the results of repetitive rather than one time interactions, upon interactions in arenas other than product markets, and upon the ability of national policy and/or domestic industry to generate appropriate incentive structures and patterns of strategic behavior. Nor is strategic trade policy alone in this regard; analogous statements hold for national educational and science policies, the political strategies of firms, levels and routes of market entry and exit, the governmental regulation of investment flows, the formation of relationships between competitors, the development of norms of strategic conduct within industries, or the relationships between firms and their employees.

All of these domains involve long run strategic processes with potentially major effects upon long run economic efficiency, and in all cases these processes and their efficiency consequences can at least in principle be affected both by government policy and private strategic choice. Some of the appropriate measures might be highly general, say in the nature of tax-based policies to lengthen organizational time horizons; others might be highly specific as a consequence of historical, national, and technological particulars.

In a typical industry many interactions occur concurrently, and involve the same set of actors. The same firms interact in seeking supplies, technological advantage, skilled labor, distribution channels, political favors, profits from current sales, and access to future global markets. They may compete intensely, or cartelize, or adopt many behaviors between those two extremes, in each of these regions of interaction. They may agree
to stay out of politics, or to enter the political arena only to seek
industrywide "public" goods, or they may compete viciously for individual
political favors. They may compete for long run technological advantage via
large R&D commitments while avoiding severe short term price competition, or
they may engage in unsustainable episodes of destructive competition which
leave even the survivors unable to finance future R&D. They might compete
directly by producing general purpose products targeted to the same large
market, or they may implicitly cooperate by engaging in more limited
monopolistic competition by carving out niches, thus producing specialized
products which compete with each other only at the margin.

All firms may employ the same strategy, or there may be a spectrum of
strategic behavior within a single industry. Some firms may respect the
niches of competitors, while others may attack competitors directly. Some
firms may respond ferociously to such attacks, while others may migrate away
to other niches. Firms may view the various areas in which they participate
strategically as being distinct, independent arenas, or they may view them
as comprising a single strategic environment. Hence some firms may respond
to a product market attack solely with a market counterattack, while others
might respond with an all-out assault in product markets, sourcing,
headhunting of competitor personnel, and political lobbying. The degree of
linkage between strategic behavior in various arenas therefore constitutes
yet another, and significant, variable in making strategic calculations.

Potentially, therefore, the spectrum of strategic behavior is extremely
wide. However, an industry's strategic environment, and the particular
choices made by actors within it, may lead to industrywide or arena-wide regularities in strategic behavior, either in individual strategic interactions such as product market competition, or in the entire collection of strategic behaviors exhibited within an arena. For example, such regularities might take the form of reciprocity in certain areas, or industrywide bargaining with suppliers, or cartellization combined with predatory pricing attacks on new entrants, or avoidance of shortsighted optimization in favor of long term technological competition, or the existence of generally respected guidelines regarding permissible versus impermissible competitive conduct. As a function of various regulatory, structural, and competitive conditions, these aggregate strategic characteristics might be extremely stable, or might evolve gradually, or might possibly be highly unstable. For example an established but voluntary norm of industrywide public goods provision, for instance by the participants in a concentrated oligopoly, might be stable and sustainable only in the absence of entry by predatory free riders who would enjoy the benefits of sectoral public goods without contributing to their provision.

Strategic Regimes As Alternative Behavior Paths

To the extent that considerations such as these prove important or interesting, they suggest the need for new variables and units of analysis in the study of industrial dynamics. In particular, I will describe the course of Japanese - American competition in information technology in terms of arenas in which there have evolved distinct strategic "systems" or "regimes." By subarenas or arenas, I mean some collection of regions of
interaction or potential cooperation and/or contention, such as economic or political markets together with the incentive structures associated with them. Some of these incentives might derive from microeconomic structure: dominant firms or Stackelberg leaders have different incentives than followers or new entrants. Some might derive from policies established by a central authority such as a government: the tax system might subsidize entry or discourage it, or might favor either taking of current profits or long term reinvestment for growth.

Hence by a "strategic regime" I mean an identifiable distribution of strategic behaviors, including industrywide strategic norms if any, which evolve as actors compete, cooperate, enter, fail, merge, lobby the government, and so on in the many subarenas in which their actions potentially affect each other. At any given time, any given arena will have a regime specified by the strategy vectors of its members. The principal question is whether, under conditions of repeated interaction which correspond to actual industrial behavior, regimes obey laws or exhibit regularities which have material effects upon individual and industrywide structure, conduct, and performance. My argument will be that the answer is yes. Indeed, I would contend that arenas and strategic regimes roughly at the level of national industry systems (e.g. individual sectors, complexes of industries, business-government relationships, international markets) are the units of analysis most appropriate to the understanding of contemporary international competition.

Indeed, I would even venture to argue that national industrial sectors
with similar factor endowments might evolve (as a function of policy, incentive structures, and/or historical accident) very different strategic regimes, and that differences in strategic arrangements can have major, long run effects upon an industry's long run productivity growth and competitiveness. Some arrangements promote productivity growth, strategic exploitation of other systems, and stability in the face of external strategic attack. Others promote distributional conflict, are quite fragile, and in the face of attacks give rise to individual strategies of lifeboat diplomacy which, collectively, actually transfer resources to the attacker. And indeed, the competitive success of firms may, frequently, be determined in large measure by the nature of, and interactions between, the national strategic regimes in which they are embedded.

In the case of the semiconductor and computer industries, for example, I will distinguish a "traditional" period in which there existed parallel but largely independent Japanese and American systems, within which in turn there existed several sectoral strategic regimes (e.g., a merchant industry regime). For several decades, these systems evolved quasi-independently, the primary interaction between them being Japanese technology imports (some legal, others not). Since the late 1970s, however, the two systems have begun to interact (and compete) more intensely. Technological and strategic forces are causing a progressive interpenetration of the two national regimes, gradually resulting in the emergence of a single, international strategic regime (albeit one with many remaining nationally specific elements). In discussing these matters, I will distinguish regimes of shortsighted and unrestrained distributional conflict from regimes in which
competition is structured, or conforms to norms, such that long run productivity growth results. (As the treatment in Appendix I indicates, much of this intellectual structure derives from the evolutionary strategic models of Robert Axelrod, Kenneth Oye, Robert Keohane, and Duncan Snidal.)

These notions might be summarized by saying that strategic systems have four major elements: the preferences (e.g. discount rates) of participants; the structure of the arena (such as its concentration in the microeconomic sense, and whether entry is permitted); the incentive structure facing participants (induced by structure, by technological conditions, by demand, and by regulations imposed by central authority); and the nature of strategic behavior characteristic of the system (i.e. its strategic regime). These may change over time or they may not, depending upon the case; one clear lesson from the present study is that the velocity and predictability of technological change are important variables in the stability of strategic regimes. Hence the economically pertinent features of the strategic systems I will consider here include but are not limited to the traditional features of markets in neoclassical analysis: firms and market concentration, factor costs and technology, levels of entry and exit, the structure of payoffs to various alternative strategies and responses, the strategies actually employed. They are richer than the neoclassical conception of an industry or market, however, in several respects.

First, industrial strategic systems include institutions and agents other than firms; governments, universities, and individuals are important as well. Often their importance derives from aspects of their behavior
which are governed by rules imposed by law, government policy, or industry associations; these rules are part of the system as well. Second, these strategic systems include many forms of iterated strategic interaction not typically considered in neoclassical analyses, such as whether firms within an industry engage in, or voluntarily refrain from, headhunting or hostile takeovers. These systems also include the subjective goals and time horizons of actors, and the strategic norms which have evolved in various arenas - i.e. the behavioral resolutions of the long run strategic dilemmas that actors face. These dilemmas include such matters as whether or not firms buy from or sell to their competitors; whether takeovers, headhunting, or defection to form new ventures are permitted; and whether firms share technology or contribute to public goods provision.

This conception (that an important unit of economic analysis consists in systems of institutions engaged in multiple long run strategic processes) again raises the possibility that in questions of industry-level and/or national competitiveness, the whole is quite different than the sum of the parts. Industrial systems with multiple, concurrent, continuous strategic interdependencies may behave, compete, and perform in ways which reflect not only specific strategic processes but relationships between them. For example, the Japanese industrial system is frequently described as relatively closed, in contrast to the more open U.S. system. Much of this difference arises not from protection or explicit coordination, but rather from national differences in structure, incentives, and strategic behavior. These divergent strategic practices range from investment strategy to the nature of potential or actual markets for personnel, technology, capital,
goods, and corporate control. Taken together, they result in distinct national strategic environments. Moreover, some of these various alternative strategic regimes interact more or less gracefully with high rates of technological change. In some regimes, opportunities for cooperation are exploited; in others, strategic conditions combined with technologically generated instability to give rise to widespread defection and betrayal.

My argument, essentially, will be that features of the Japanese strategic system confer upon the Japanese semiconductor and computer industries major long run advantages not captured by the U.S. regime, and not accounted for in traditional economic models. These advantages are in the nature of long time horizons, the relatively secure appropriability of the returns to long term investments, even if they potentially generate externalities to domestic competitors, freedom from many forms of zero-sum distributional conflict, strong incentives to engage in external predation against foreign industries and markets, and a strong bargaining position relative to foreign organizations acting from within less cohesive national strategic environments. Conversely the U.S. strategic system produces behavior largely of the opposite kind: dysfunctional strategic patterns and inadequate, suboptimally allocated investment flows caused by severe appropriability dilemmas, distributional conflicts, internal predation, and short time horizons. Hence, for example, the U.S. semiconductor industry declined rapidly beginning in the late 1970s despite an initially large advantage in its total stock of assets, technology, and experience relative to its Japanese competitors.
To the extent that this conclusion is generalizable to the U.S. economy, it suggests that much of the decline in U.S. growth and international competitiveness involves iterated strategic processes at microeconomic levels (such as firm-level investment licensing policies, or the evolution of sectoral behavioral norms in price competition or technology exchange) which are heavily conditioned by time horizons. While under appropriate structural conditions such strategic processes may be generated by economywide forces, including conventional macroeconomic effects, they differ in fundamental ways from the variables and mechanisms modeled by traditional economic theory. These processes are determined not by factor prices and market clearing behavior per se, but rather by incentive structures, in which traditional economic variables may of course play a role. Aggregate behavior is the long run result of many iterations of individual strategic decisionmaking.

Such micro-level processes, under some incentive structures, might conceivably produce long run, large scale results strikingly at variance with neoclassical economic theory. These may include the competitive failure and/or stagnant productivity of industrial sectors or complexes of related sectors. Alternatively, concentrated industries displaying high levels of strategic collusion can be more productive than fragmented, competitive industries under some strategic conditions. For example the presence of a strategically active, independent central authority and an environment which favors long time horizons might shift oligopolists' incentives towards future performance rather than current profits. If this
view is correct, it follows that government policies, incentive structures, strategic processes, and institutional arrangements are more important to industrial performance than current economic models generally imply. The argument also suggests the potentially large value of developing a more complete theory of nonequilibrium (and particularly strategically driven), nondeterministic evolutionary processes and their role in political economy.

4. Outline of the Essay

The essay is divided into six chapters, roughly in four parts. In addition, the main body of the essay is followed by three appendices. The first part of the essay consists of this introductory chapter. The second is the substantive analysis of the semiconductor industry, including associated sectors such as semiconductor capital equipment production. Chapter 2 covers the development of the American semiconductor industry, the institutionalization of its strategic dynamics, and the quasi-independent development of the Japanese industry. Chapter 3 considers the destabilization of these quasi-independent national arrangements by the arrival of VLSI technology, and the decline of the U.S. industry upon the arrival of Japanese competition. Chapter 4 discusses the logic governing this process, and the relative explanatory power of neoclassical as opposed to strategic models.

The third part of the essay considers the computer industry; the gradual formation of a system including the semiconductor, computer, and other information technology sectors; and the possible emergence of a global
strategic regime general to high technology industries. This analysis begins, analogously to the semiconductor discussion, with the evolution of the computer industry. I then discuss the destabilization of the industry's traditional U.S. oligopoly by new technology and cost structures, Asian competition, and the spread of fragmentation and entrepreneurialism into the U.S. systems sectors. I explain these developments, and the U.S. industry's declining relative performance, in large measure through reference to the same strategic processes described in the semiconductor case. I then argue that this argument applies to high technology industries generally. As these industries shift towards cost structures dominated by initial knowledge and engineering investments whose returns are appropriable only through open market sales, the United States is being integrated into a global strategic regime on unfavorable terms.

The last part of the essay, Chapter 6, considers the implications of the sectoral analyses for U.S. economic performance and policy. I conclude that the social costs of continued decline would be large, that remedial government policy measures could reduce these social costs, but that these measures must be designed explicitly to interrupt the strategic processes which have emerged as the dominant basis of U.S. economic and political action in these sectors. Indeed the promotion of long run cooperation within industry, and between industry and government, must now be counted as a major policy goal unto itself.

Appendix I discusses the theoretical debate concerning industrial dynamics, its relation to the manner in which I explore it here, and my
conclusion that strategic processes (at both domestic and international levels) are critical to understanding the information technology sectors. I provide a very broad, perhaps even schematic, characterization of traditional neoclassical economics, and then of newer neoclassical models which emphasize imperfect competition and mechanisms such as learning economies, various externalities, and strategic trade policy. These neoclassical views are compared with an emerging model of evolutionary arena dynamics which takes iterated strategic processes as the continuing, pervasive rule rather than as one-time, isolated events. This discussion draws heavily upon the work of Robert Axelrod among others.

Appendix 2 contains a highly technical discussion of relationships between semiconductor capital equipment and materials, semiconductors, and computer systems. These relationships, together with the comparative structure of the U.S. and Japanese industries, indicate that strategic technology denial by Japanese firms is a likely consequence of U.S. decline, a proposition discussed throughout the essay in less technical detail.

Appendix 3 discusses the sources and methodology employed in the research, particularly its reliance upon personal observation, confidential interviews with participants, and market research firms such as Dataquest, ICE Corp., and VLSI Research as opposed to more conventional statistical sources.
NOTES TO CHAPTER ONE


2. Ibid.


5. For U.S. shipments, see "U.S. Industrial Outlook," annual; for Japanese shipments, "Japan Electronics Almanac," annual; for comprehensive estimates see Dataquest Corporation's Semiconductor Industry Service.

6. Dataquest.

7. Ibid.


11. Japan Electronics Almanac, 1986, p. 38; see also p. 91, p. 95.


13. For one set of estimates, see "U.S. Industrial Outlook," 1986, p. 28-8, which estimates world computer markets including software at $155 billion, not including embedded systems. Dataquest estimates the world semiconductor market at roughly $30 billion.


18. For a theoretical analysis of the importance of time horizons to cooperation, see articles by Oye and by Axelrod & Keohane in "Cooperation Under Anarchy."


21. For example, I quote from Helpman and Krugman, p. 34: "...The theory of cooperative behavior in oligopolistic industries is not well developed, however. Thus in this book we will restrict ourselves to an analysis of markets where the participants behave noncooperatively." Thus do strategic interactions and sectoral policies disappear.

22. For example, as Richard Samuels recently noted in his survey "Research Collaboration in Japan" (MIT Japan Science and Technology Program, 1987), the standard text on industrial organization (Scherer) does not even mention collaboration, except in discussion of cartels.

23. Thomas Schelling and Robert Axelrod have provided seminal analyses of these issues. See the discussion in Appendix 1.


29. In his recent article "An Evolutionary Approach to Norms," Axelrod provides two examples by computer simulation in which an arena characterized by iterated prisoner's dilemmas evolved into either of two opposite
strategic regimes (one with a norm, one without) as a function of minor and accidental variations in initial conditions. Brian Arthur's work on urn processes makes essentially the same point using a somewhat different model, one with randomness plus increasing returns, rather than strategic indeterminacy, as the generator of instability in results.

CHAPTER TWO
THE EVOLUTION OF THE SEMICONDUCTOR INDUSTRY

1. Introduction

Until the late 1970s, the U.S. and Japanese semiconductor industries evolved quasi-independently. Japan imported U.S. technology and capital equipment,\(^1\) restricted both import penetration and direct investment by U.S. semiconductor firms,\(^2\) produced for the Japanese domestic market (particularly the consumer electronics industry), but largely refrained from export drives directed at either the United States market or the U.S. industry.\(^3\) The U.S. industry sold technology and capital equipment to Japan, generally acquiesced to closure of the Japanese market, but also controlled the rest of the world market. At the apparent height of its success in the late 1970s and early 1980s, the U.S. industry held 95% of its domestic market, half of Europe’s, and over 60% of the world market - but only a quarter of Japan’s.\(^4\)

The Japanese and U.S. national industries also diverged structurally. The Japanese industry became a relatively stable oligopoly of diversified, vertically integrated firms\(^5\) protected from foreign competition both by the industry’s structure and by national government policy. Imports were controlled, and direct foreign investment was effectively prohibited. Semiconductor production was dominated by six enormous firms for whom semiconductors accounted for 5 to 25 percent of total revenues.\(^6\) These firms used roughly a quarter of their semiconductor production internally,
and collectively sold roughly another quarter to each other, for use in the electronics products which constituted their principal businesses. They also dominated Japanese semiconductor capital equipment production and maintained close, enduring relationships to their suppliers, the Tokyo city banks, the national government, and often each other. Frequently these relationships included substantial equity cross-ownership and transfers of personnel between firms.

Japanese firms also cooperated in R&D and pre-commercialization standardization activities, even while simultaneously competing intensely in both domestic and foreign product markets. Entry into the Japanese semiconductor industry was relatively rare and came only through the diversification efforts of other large industrial complexes (Kawasaki, Sanyo, Sharp, Nippon Steel), rather than through the creation of independent firms dedicated to semiconductor production. The industry also followed typical Japanese personnel practices such as lifetime employment, reliance upon entry-level hiring, and refusal to hire defectors from other firms, so employee turnover was consequently low.

In the United States, by contrast, there evolved a different and more fragmented industry. Semiconductor production itself was divided between "captives" and "merchants." The few major and relatively stable "captives," such as IBM and AT&T, produced for their internal use but refrained from market competition. Conversely the open-market "merchant" industry, which at its peak accounted for 70% of U.S. production and dominated the world market, evolved into a less stable, more fragmented, highly entrepreneurial
arena.\textsuperscript{9} Most U.S. merchant producers were young, relatively small firms whose semiconductor sales represented at least 40%, and often the entirety, of their total revenue.\textsuperscript{10} Market leadership, employee loyalties, and supplier relationships were transitory; many semiconductor and capital equipment producers rose and fell rapidly, and employee turnover averaged 20% across the industry.\textsuperscript{11} For twenty years this pattern of instability, frequent mobility, and new venture formation was considered a critical factor in the industry's success,\textsuperscript{12} though by the mid-1970s the performance of IBM, AT&T, and the Japanese industry should have suggested otherwise.\textsuperscript{13}

Equally striking, and analogous, is the contrast between the two nations' semiconductor capital equipment, materials, and services sectors. Once again, the Japanese industry is dominated by a relatively small number of large, diversified firms, including the major semiconductor producers themselves and other large firms with experience in relevant optical, chemical, mechanical, or construction technologies - firms such as Nikon, Canon, or Shimizu. And where the equipment producers themselves are small, they are closely linked to larger electronics firms which consume much of their output.\textsuperscript{14} The American capital equipment and services industry, in contrast, resembles its semiconductor producing counterpart in its fragmentation, instability, and entrepreneurialism.\textsuperscript{15} A few stable, relatively large, established equipment firms (e.g. Teradyne and Perkin-Elmer) coexist and compete with innumerable "startups" - newly founded ventures such as Trillium, Master Images, Zycad, Micro Mask, and hundreds of others. As of 1986, 55\% of U.S. equipment and services vendors had annual sales of less than $5 million.\textsuperscript{16} Nearly half are less than ten years old.\textsuperscript{17}
In fact, the Japanese and U.S. industries differ in other respects as well - in their personnel policies, R&D priorities, competitive strategies, patterns of capital investment, technical practices, and so on. It would be difficult to find two more dissimilar national industries. This structural and strategic divergence provides both a test case for alternative models of industrial dynamics and, I will argue, an explanation for the declining competitiveness of the U.S. industry. For both reasons, it will be useful to examine the evolution of the U.S. and Japanese national systems, their respective patterns of behavior, and the nature of their interactions, both cooperative and competitive.

2. The Origins of the Industry

By the beginning of World War II, AT&T and other firms with substantial involvement in electronics - for example RCA and General Electric - already had a long and complicated history of strategic maneuvering based on R&D efforts, control and/or exchange of patents and licenses, and market segmentation arrangements. This strategic use and control of electronics technology began with the development of a commercial radio technology at the turn of the century and continued through the radio patents cross-licensing agreements of 1920 and the contract revisions of 1926.18 At one time, AT&T came remarkably close to controlling both the radio broadcasting and sound motion picture industries. Its efforts were thwarted by alliances of other firms and by antitrust actions. The result of this contest was a stable distribution of markets and technical property rights which endured
for twenty years. In this arrangement, AT&T dominated telephony, albeit with some regulatory constraint following the passage of the Federal Communications Act of 1934, while firms such as RCA and the major film studios dominated other communications media.¹⁹

World War II, however, led to the development of technologies, government policies, and markets which fundamentally destabilized these arrangements and reopened the possibility of AT&T's expansion into, and domination of, new industries such as computers and novel electronic systems. During the war, the Federal government subsidized both basic and applied research towards the development of radar, new forms of telecommunications, electronic control systems, and computers. A number of research organizations developed substantial expertise in novel electronics technologies and products; among them were laboratories run by AT&T, Harvard, IBM, MIT, General Electric, and the Navy.²⁰ While nearly all of the earliest computers and other new devices depended upon vacuum tubes, AT&T recognized two critical facts very early. The first was that there existed important similarities between switching and other technologies used in telephone networks, on the one hand, and computers and other new devices on the other. Second, semiconductors were correctly thought by several groups, of which AT&T was by far the largest, to have potentially important and powerful applications in these new products and markets. AT&T consequently embarked on a research project whose goal was the acquisition of technological leadership and a strong patent position. It would then be able to bargain with or exclude potential competitors in a variety of areas. Perhaps the way would open to enter new businesses, supplementing the
constrained monopoly of telecommunications it had enjoyed since creation of the Federal Communications Commission.

AT&T's early effort was successful and culminated in the invention of the transistor by Shockley, Bardeen, and Brattain in late 1947. Following seven further months of secret effort, the acquisition of a strong patent on transistors in 1948, and the continuation of a large research effort, AT&T opened the transistor technology to licensees. The license terms included five percent royalties on sales and an option to withdraw the licenses after five years. AT&T clearly wished to have the waters tested: to discover what markets and purposes transistors might have and what improvements in the technology might be made. If the invention proved sufficiently important, AT&T could tighten licensing, increase its investment levels, and enter the market with the intention and capability to dominate it — or, if necessary, to trade important licenses for secure markets, access to new technologies developed by others, or protection from competition.

For several reasons this policy probably seemed, at the time, to be the wisest course of action. First, in 1949 the Justice Department Antitrust Division filed suit against AT&T for conspiracy in restraint of trade. The focus of the lawsuit was the relationship between AT&T, Western Electric, and the Bell operating companies. The government sought divestiture of Western Electric and open bidding for equipment. AT&T, rather like IBM twenty years later, may have decided to liberalize several policies in order to render itself less vulnerable to the government's attack. Furthermore, during the period that the antitrust action was pending, 1949-1956,
transistor and semiconductor technology developed only moderately, and it appeared that many eventual applications would be either military or within the telephone system itself. Transistors remained no more than discrete power devices. They were made from germanium, a rare and expensive element, and were used only for specialized defense applications, hearing aids, and other such limited purposes.

The first silicon transistor was made by Texas Instruments only in 1954, and it was not until 1956 that Bell Laboratories and General Electric separately developed a diffusion process for transistor production based on the common SiO2; this was one of several process innovations vital to the transformation of semiconductors from exotic and expensive to pervasive and almost free. However, these technical developments alone would not have ensured the structural transformation of production that in fact followed. The necessary further developments were legal, structural, and strategic.

The transformation of the American industry

First, competition was increasing. In part this was a consequence of AT&T's liberal licensing policy; in part it also derived from American personnel mobility, which permitted Bell Laboratories technical staff to either join other companies or establish their own. In addition, following AT&T's announcement of its technical developments and licensing policy, a number of other large electronics firms - some of which had already been working on semiconductor technology - undertook substantial transistor R&D efforts. Several of the established electronics firms - GE, Raytheon,
Motorola, RCA - rapidly reached the R&D frontier, made technical contributions, and obtained noticeable shares of the (still very small) transistor market.

At least throughout the 1940s and 1950s, most semiconductor innovations were made by a relatively small number of these large firms. AT&T remained the largest single actor, but major advances were made by others such as General Electric and RCA. Of 13 major semiconductor innovations between 1951 and 1963 analyzed by Tilton, seven were made by AT&T, General Electric, RCA, or IBM; one (relevant only to consumer electronics) was made by Sony. Patenting activity was consistent with this picture. By Tilton's accounting, in 1952 Bell Laboratories accounted for 56% of all new semiconductor patents; other established electronics firms held 37%; new firms held only 7%. By 1956 Bell Labs had declined to 26% of all patent awards, while other established electronics firms accounted for 54%. It is noteworthy that "new" firms still accounted for only 20% of semiconductor patents awarded in 1956. Moreover, by far the largest R&D contributor among these new firms was Texas Instruments, a geophysical services and instrumentation firm with previous experience in electronics, and which diversified into semiconductors in the early 1950s by hiring a senior Bell Labs semiconductor research scientist as its semiconductor R&D manager.

Secondly, however, AT&T was forced to settle the antitrust suit several years before the enormous importance of semiconductor production was finally assured. AT&T was faced in 1956 with the possibility that its largest sources of regulated monopoly profits might be eliminated by the long-
simmering antitrust case, and that it would be forced to divest itself of Western Electric, which manufactured virtually all of AT&T's equipment. In that year, on the other hand, its transistor manufacturing and license royalties brought in about two million dollars. The total transistor market between 1954 and 1956 inclusive was only $55 million, whereas the market for the still-dominant technology, vacuum tubes, was over $1 billion.\textsuperscript{22} All electronics together came to $6.5 billion. So transistors were and would long remain a small business compared to either electronics generally or to AT&T's antitrust problems. For AT&T, therefore, semiconductors were financially far less important than preserving the firm's monopoly on telephone equipment and services, and its control of Western Electric.

Therefore AT&T offered to relinquish its external semiconductor business as one of several concessions to the government in exchange for retaining its telephone monopoly and captive supply arrangement. AT&T also offered to refrain from entering the computer industry. The government accepted. In the 1956 Consent Decree, AT&T agreed to refrain "from engaging, either directly or indirectly..., in any business other than the furnishing of common carrier communications services." This meant staying out of open market computer and semiconductor manufacture and remaining only in regulated or government markets. The company also agreed, quite importantly for the future course of events, to license on demand all semiconductor patents it then controlled. On the other hand, AT&T retained the right to produce virtually anything it wanted, including semiconductors and computers, for its own internal use.\textsuperscript{23} The company also continued to perform R&D, and to manufacture, for the military.
Had the need to come to terms with the government been postponed for another five years, this settlement would probably have seemed less appealing. The first transistor radio had been produced in 1955, but this was an analog application in a consumer market, and its importance may have been unclear. Far more important, ultimately, was the increasing use of digital technology. Second generation computers marketed by IBM and others in the late 1950s were the first commercial products in which transistors were used to replace vacuum tubes used as digital switches rather than amplifiers. AT&T had significant expertise in both semiconductors and computers, but the pressure from the Justice Department was immediate and the potential size of the computer market - not to mention its later intersection with the telecommunications business - was far from clear. So AT&T gave away the semiconductor and computer businesses.

Third and finally, the 1950s saw a growing exodus of R&D personnel from the established industry to newer, small firms. In part this seemed to derive from the constraints placed upon AT&T by the antitrust case, both while it was pending and following its settlement. In part, it derived from fluid markets for capital, personnel, and technology licenses, which facilitated the creation of new, small firms by defectors from the major R&D performers. In part, however, it seems also to have derived from the inability of some of the established electronics firms to appreciate and exploit the innovations they had themselves generated.

The late 1950s also saw technical developments which greatly increased
demand for semiconductor products. In a short transitional period lasting from 1956 to 1962, the technological foundations of the industry were endurably transformed by three related innovations: the diffusion process, the planar technique, and integrated circuits. These innovations permitted inexpensive, relatively high volume batch production and initiated the trajectory of miniaturization and increasing functional power that has characterized semiconductor technology ever since. Furthermore, innovation and production increasingly inclined toward logic and memory functions (hence digital circuits) and away from power functions and analog circuits. Consequently new and previously unimagined markets began opening after AT&T abandoned the semiconductor business and opened its patent portfolio to all interested parties.

During the same period that these developments eliminated AT&T from competition, transformed the technology of production, and opened new markets, the structure of the industry changed profoundly. The most remarkable features of the new structure were the increasing market share held by newly created firms, high rates of personnel mobility, the continuous formation of new firms with each technology generation, and the evanescence of market success. Collectively, the largest electronics firms (GE, RCA, AT&T) gave way to relative novices, often newly founded "startups." Startups repeatedly rose to prominence in state of the art markets within a few years of their being founded, only to be displaced in their turn by even newer firms and novel products. This pattern, when combined with low barriers to entry, personnel mobility, and extraordinary rates of growth and technical progress, had profound consequences for the
development of the industry.

Whereas prior to 1956 most semiconductor patents and production were divided between AT&T, GE, and the vacuum tube firms, innovation and production shifted thereafter towards such firms as Shockley, Fairchild, and Texas Instruments, and later to yet newer firms such as Intel. By 1965, the four largest open-market producers were Texas Instruments, Motorola, Fairchild, and General Instrument; Transistor, second in 1960, had already fallen to ninth. GE and RCA were fifth and sixth.

Usually, new firms were founded by, and/or obtained their technical personnel from, established firms such as AT&T - or, later, from prior generations of startups. William Shockley himself founded Shockley Transistor in 1954, and he attracted a number of other scientists and engineers from AT&T and other established firms. Transistor, which held 12% of the transistor market in 1957, was founded by two brothers, one of them previously a solid state physicist at Bell Labs, and recruited its early personnel from Sylvania and GE. Like many startups, Transistor performed essentially no long term R&D itself, and the company eventually failed. Texas Instruments recruited Gordon Teal, an important figure in Bell Labs' semiconductor research, to manage its semiconductor R&D. Texas Instruments earlier (since the 1930s) had focussed on oil exploration surveys; but it began work on semiconductors in 1949, and switched to the scientific instruments and semiconductor businesses in the 1950s. Hence TI was not entirely a "startup." Fairchild Semiconductor was founded in a manner to be seen many times subsequently: through the defection in 1959 of eight R&D
personnel from Shockley.

The aggregate behavior of the U.S. industry stabilized only in the limited sense that a regular pattern of technological progress and market structure emerged. Among the principal regularities, in fact, were perpetually high employee turnover rates and repeated, catastrophic generational upheavals. Nonetheless a measure of industry-level stability appeared to have been established by the early 1970s. Firms continued to come and go, but certain basic patterns of technology, structure, and markets seemed to remain constant. These merit a brief exposition.

Aggregate regularities of the merchant industry era

One form of apparent stability was the merchant industry's nearly total reliance on relatively (for the era) large-batch production of general purpose commodity devices, in contrast to the relative emphasis placed on custom circuits by most internal, or captive, semiconductor manufacturers such as AT&T or Hewlett Packard. This form of stability was associated with the development in the 1960s and early 1970s of commodity "medium scale integration" (MSI) logic devices (adders, shifters, etc.) and then large scale (LSI) semiconductor memories and microprocessors by the merchant industry, on the one hand, and the expensive but significant customization capabilities inherent in LSI, on the other. These technologies gave rise to large civilian markets and products of general purpose functionality, which broadened the industry's markets while reinforcing the dominance of commodity products.
In addition, the industry passed from its initial dependence upon the military to a permanent condition of dependence upon industrial markets. While during the early 1960s semiconductor markets were dominated by the military, civilian markets increased rapidly and by 1975 accounted for the majority of semiconductor production. As I indicate below, early military purchasing policy subsidized learning which was transferred to subsequent commercial production; but by the mid-1970s, commercial markets outpaced military demand, which became financially less important and lagged behind (rather than led) commercial technology. Semiconductor demand by end use evolved as follows:

<table>
<thead>
<tr>
<th>Market</th>
<th>1960</th>
<th>1968</th>
<th>1974</th>
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</thead>
<tbody>
<tr>
<td>Military</td>
<td>50</td>
<td>35</td>
<td>14</td>
</tr>
<tr>
<td>Computer</td>
<td>30</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>Consumer</td>
<td>5</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>Industrial</td>
<td>15</td>
<td>20</td>
<td>33</td>
</tr>
</tbody>
</table>


This period of the industry's development also saw the rise of "captive" (i.e., wholly internal) semiconductor production by large-scale consumers such as IBM and Hewlett-Packard; total semiconductor production came to be rather stably divided between "merchant" (i.e. open market) and captive producers. Merchants produced commodity SSI/MSI (i.e. Small / Medium Scale Integration) circuits and later, with the advent of LSI, began production of powerful general purpose commodity circuits such as memories, microprocessors, and controllers. Some merchant firms entered the custom LSI business, but with a notable lack of success. Computer systems firms, AT&T, and equipment manufacturers such as Hewlett-Packard developed
semiconductor operations (research, design, and production) oriented to their special needs, usually emphasizing custom LSI circuits specific to their products and required in rather small quantities. These captive producers generally did not sell on the open market, although with the exception of AT&T there was no direct legal barrier to doing so.

Significant captive operations were also, paradoxically, largely the result of LSI technology. With large scale integration, fairly complex, powerful circuits of highly specific functionality became practical for the first time. Systems firms found that optimal system designs required large numbers of such special purpose circuits, each produced in small quantities. These circuits were often vital to the market success of systems; therefore any systems firm with a technical advantage was tempted to use captive production as a means of preventing the diffusion of its technology. Such circuits also tended to require technologies distinct from those used in commodity circuits produced by merchant firms, or to require extensive coordination between the technology of the circuit and that of the final system of which it would be a part.

Frequently the merchant producers were therefore unwilling to manufacture them; their design talent was a scarce resource and the technology rendered production and testing of many short runs of complex components much less remunerative than commodity mass production. At the time, no technical means existed to design application-specific circuits rapidly or inexpensively. Thus by default as well as by strategic choice the systems firms (and later other major consumers of special purpose
circuits such as aerospace firms) developed technology and expertise appropriate to custom functionality circuits and their systems integration requirements. Yet since the merchants adequately supplied general-purpose circuits, captive producers tended to confine themselves to their parent firm's special needs and, consequently, refrained from entering the open market in competition with merchants. (Only the very largest consumers, IBM and AT&T, were large enough to manufacture general-purpose devices economically. Both refrained from entering the open market, for antitrust and/or strategic reasons.) Captive production stabilized at a third of total semiconductor production and continued to emphasize special-purpose circuits. The phenomenal growth of the commodity market and its continued domination by merchants remained unaffected.

Another regularity existed in the rate and pattern of aggregate industry growth and technical change. After the merchant industry had passed through several generations of integrated circuit products, it became obvious that technical generations, and the transitions between them, possessed several common features. Technical progress (as measured by changes in integration levels and cost/performance) averaged thirty to forty-five percent per year; the useful life of capital equipment was four or five years; product life cycles were three to five years long. During such a life cycle, costs and prices predictably declined along an exponential decay path as a consequence of continuously improving lithography, the accumulation of device-specific production experience, and through erosion of the innovator's initial monopoly as imitators entered the market. In addition, while sales of individual products rose and fell quite
suddenly, the U.S. industry's trended aggregate growth remained about 15% per year for all semiconductors, and 25% per year for digital integrated circuits. With each generation, the industry gradually became more capital intensive.

During its formative period, therefore, parts of the semiconductor industry looked much as a conventional sectoral life cycle analysis would have predicted. Operational scale gradually increased and became dominated by mass production of general purpose devices - first SSI/MSI logic, then LSI memories and microprocessors as well. Downstream firms with exceptional and specialized requirements were the principal producers and consumers of custom-functionality circuits. Custom LSI was bound by the same technological and economic constraints as commodity LSI, so the technology inherently favored mass production applications. Process technology favored mass production of a limited variety of devices, and the relative backwardness of design techniques rendered LSI device design expensive and time-consuming. Hence custom design was justified only when the match between a circuit and the system using it was critical, as with mainframe computers. Merchant firms were successful only when they were designers and producers of commodity devices.

Hence with respect to many external, aggregate indicators, the semiconductor industry appeared to be maturing in the manner of many others before it, including its largest single consumer, the computer industry. But despite these aggregate regularities, the semiconductor industry established unusual patterns of industrial conduct which have since spread
to other sectors, and particularly high technology sectors, of the American economy. In its internal dynamics, and in the strategic behavior of its member firms, the merchant industry was developing and enforcing upon itself a system of perpetual adolescence.

The peculiar dynamics of American semiconductor production seem to have had their origins in the 1950s, but were not fully developed and explicitly understood within the industry until the mid-1960s. The resulting industrial system endured up to the mid-1980s, but now shows clear signs of strain; fundamental transformation is inevitable, and its signs already visible. But for the moment it is the "classical" structure and dynamics which I will consider.

3. Structure and Strategy in the Classical Merchant Industry

The structure was one of fragmentation, entrepreneurialism, and relatively evanescent market success; it was associated with the apparent absence of scale economies or entry barriers, abundant venture capital, the absence of foreign competition, the apparently inevitable and rapid diffusion of technology to competitors, extremely high rates of personnel turnover, and the frequent use of personnel mobility to create and populate new startups.

This industry pattern also included corporate strategies which frequently emphasized short time horizons and high profitability requirements, high levels of consumption relative to investment, relative
neglect of manufacturing, an absence of either horizontal or vertical cooperation and communication between firms, and an inattention to external strategic assessment, particularly with respect to fundamental trends in technology and foreign competition. By the mid-1960s, individual and firm-level behavior reinforced these structural and strategic conditions through incremental decisions based upon the assumption that these conditions were beyond the control of any single firm. The resulting practices, and the structures associated with them, gave rise to an industrial system which reproduced itself for several generations of technology, products, and companies.

Between the early 1960s and the early 1980s, the U.S. semiconductor industry thus developed, and then institutionalized, several structural and behavioral patterns which resulted in a specific industrial system, one long held responsible for the industry's dynamism and success. As we shall see, however, this is far from clear; indeed I will argue that quite the reverse is the case. Hence this industrial pattern, or "regime," deserves a more detailed examination.

3.1 The Structure of the Merchant Industry and the U.S. Environment

Vertical and Horizontal Structure: Extreme Fragmentation

Relative to other high technology sectors (e.g., computers, telecommunications, aircraft, pharmaceuticals, chemicals) and, as we shall see later, to its Japanese counterpart, the U.S. semiconductor industry has
always been remarkably fragmented and unstable, both vertically and horizontally. (The semiconductor industry's international competitiveness has also deteriorated far more rapidly than that of these other technology intensive sectors. Below, I will argue that this correlation is not coincidental.) But the nature of the industry's fragmentation is not captured fully by traditional economic indices.

Though the four-firm concentration ratio of the merchant semiconductor industry has consistently remained about fifty percent for three decades, the industry has been less stable and more fragmented than this statistic alone would suggest. The rank order and market shares of merchant firms, even the largest ones, has displayed extreme instability relative to other U.S. sectors as well as to the Japanese industry. Texas Instruments and Motorola are the only merchant firms which have consistently remained among the largest four U.S. producers for even a single decade. TI, which ranked 5th in 1955, was the largest U.S. producer by 1960, and remained the U.S. leader until 1985, when it fell to second. Motorola, the second stablest U.S. firm, was 9th in 1955, 6th in 1960, 2nd in 1965, still 2nd in 1979, and is now first, having displaced TI in 1985. TI and Motorola, the two most consistently successful among the major merchants, have also been the two largest merchant firms (in total revenues), the two most diversified, the only two major merchants headquartered outside of Silicon Valley, and the two oldest.

Hence even within the merchant industry, there is evidence that chronic, unstable entrepreneurialism is less productive than stability in
the long run. (If captive producers were to be included, these correlations would probably be even stronger, since the two largest are IBM and AT&T.)

For example in 1979, U.S. merchant market rank correlated with diversification as follows:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>Semiconductor Sales as % of Total</th>
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<tbody>
<tr>
<td>1</td>
<td>Texas Instruments</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>Motorola</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>National Semiconductor</td>
<td>85</td>
</tr>
<tr>
<td>4</td>
<td>Fairchild</td>
<td>69</td>
</tr>
<tr>
<td>5</td>
<td>Intel</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>AMD</td>
<td>89</td>
</tr>
</tbody>
</table>

The younger, less diversified merchants have tended to be more volatile and to fare worse over the long run. (Since several large, diversified firms, particularly GE and RCA, also fared poorly, size and diversification would appear to be necessary but not sufficient conditions for enduring success.) This dynamic instability was not just a matter of shifting competitive success within a stable set of major firms; firms ranking among the largest merchant producers in any given year often had not even existed a decade previously, or had not been among the top ten. In recent years, market leadership among American merchants appears to have stabilized somewhat with TI, Motorola, Intel, National, and AMD emerging as the five largest American semiconductor producers, although National and AMD are losing ground. (Below this level, the industry has remained severely unstable. For example Mostek, founded in 1968, became the seventh largest U.S. merchant by the early 1980s. Mostek closed in 1985 and was then acquired by Thomson/CSF after suffering a precipitous 70% revenue decline and large losses.)
This recent quasi-stability among large U.S. producers is the combined result of newer, more capital intensive cost structures and of the massive shift of competitive advantage to Japan. The data on the following page illustrate the instability of market leadership during the classical period.

The U.S. semiconductor industry's structural fragmentation and instability were vertical as well as horizontal. By the 1970s, both merchant and captive producers were served by a complex upstream network of independent capital equipment and materials producers, services firms, and subcontractors. Both the U.S. semiconductor industry system as a whole and the merchant firms within it consequently remained vertically disaggregated in the extreme. Merchants and captives relied almost entirely on separate industries for such functions as silicon ingot production; mask making; manufacture of capital goods such as diffusion ovens, lithography equipment, and testers; and even frequently factory maintenance, assembly, product testing, and quality assurance. Among merchant producers, only Texas Instruments and Fairchild manufactured test equipment. No merchant producer manufactured lithography or automated assembly equipment; among captives, IBM manufactures electron beam equipment, but no optical equipment, and supplies itself alone. No merchant or captive firm has held a substantial equity position in, or ever entered into a joint venture with, any significant capital equipment, materials, or services vendor. Of course, close informal cooperation could perhaps have substituted for explicit vertical integration; but, as we shall see below, such vertical cooperation was as rare as vertical integration.
Leading U.S. merchant manufacturers ranked by share of world market

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<tr>
<td>RCA</td>
<td>1</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Sylvania</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>General Electric</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td></td>
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<tr>
<td>Raytheon</td>
<td>4</td>
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<td>10</td>
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<tr>
<td>Westinghouse</td>
<td>5</td>
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<td></td>
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<tr>
<td>Amperex</td>
<td>6</td>
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<td></td>
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<tr>
<td>National Video</td>
<td>7</td>
<td></td>
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<tr>
<td>Ranland</td>
<td>8</td>
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<tr>
<td>Eimac</td>
<td>9</td>
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<tr>
<td>Landsdale Tube</td>
<td>10</td>
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<tr>
<td>Hughes</td>
<td></td>
<td>1</td>
<td>9</td>
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<tr>
<td>Transitron</td>
<td>2</td>
<td>2</td>
<td>9</td>
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<tr>
<td>Philco</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td></td>
<td></td>
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<tr>
<td>Texas Instruments</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Motorola</td>
<td>9</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Clevite</td>
<td>10</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fairchild</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>5</td>
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<tr>
<td>General Instrument</td>
<td>4</td>
<td>7</td>
<td>10</td>
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<td>Sprague</td>
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</tr>
<tr>
<td>National Semiconductor</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
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<td>Intel</td>
<td></td>
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<td>4</td>
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<td>Rockwell</td>
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<td>American Micro Devices</td>
<td></td>
<td></td>
<td></td>
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<td>8</td>
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</table>

Though the total size of the industry's infrastructural sector (which I will sometimes call the support industry for simplicity) was probably only a quarter the size of the merchant industry, the horizontal structure and strategic pattern of the U.S. supply sector were nearly identical to those of the merchant industry itself. The capital equipment sector, in fact, was probably the first industry to emulate the structural and strategic pattern established by the merchants. The equipment industry was composed of small, independent, venture capital funded startups which were often founded by defecting executives from merchants or other equipment firms. Rates of growth, employee turnover, and new venture formation were comparable to the merchant industry.

Since the generational crises in the merchant industry were often associated with progress in technology and capital equipment, it was not surprising that the equipment industry, too, showed generational instability: the useful life of most capital equipment was five years or less because technical progress in microelectronics was so rapid. Hence there were regular opportunities for new ventures to enter so long as venture capital funding covered development costs. As with the merchants, several larger firms emerged as relatively stable market leaders (Varian, Teradyne, Perkin-Elmer). But, also in common with the merchant industry, over half of U.S. equipment and services production occurred in small, young, unstable firms dedicated to a single market. The data on the following page illustrate both the fragmentation and generational instability of the U.S. capital equipment sector.

**NUMBER OF EMPLOYEES**

<table>
<thead>
<tr>
<th>Range</th>
<th># of Co's</th>
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<tr>
<td>100 - 499</td>
<td>122</td>
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<td>500 - 999</td>
<td>46</td>
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<tr>
<td>More than 999</td>
<td>56</td>
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<tr>
<td>Not available</td>
<td>79</td>
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**ANNUAL SALES**

<table>
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<tr>
<td>Less than 1m</td>
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<tr>
<td>1 - 5m</td>
<td>313</td>
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<td>5.1 - 10m</td>
<td>121</td>
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<td>10.1 - 25m</td>
<td>112</td>
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<tr>
<td>25.1 - 50m</td>
<td>49</td>
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<tr>
<td>50.1 - 75m</td>
<td>22</td>
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<td>75.1 - 100m</td>
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<tr>
<td>More than 100m</td>
<td>17</td>
</tr>
<tr>
<td>Not available</td>
<td>79</td>
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</table>

**ESTABLISHED YEAR**

Prior to 1960 - 246 Companies
S.E.M.I. Corporate Members
The Phenomenon of Entrepreneurialism in the Merchant Industry

By the late 1960s, the semiconductor and related industries exhibited and then progressively institutionalized an extraordinary rate, and a quite particular pattern, of entrepreneurial new venture creation. The merchant industry, particularly in Silicon Valley, lived in intensive symbiosis with the ingredients of new venture formation, such as supply infrastructure, leasing organizations, headhunters, and venture capital markets. The typical pattern which evolved was for experienced employees, often highly valued technical personnel or executives, to defect from relatively established firms in order to found new, independent, venture-capital backed ventures. Usually, these ventures were established to exploit a single technology or market at the state of the art, in a region not yet dominated by any single firm. In some cases, new ventures were established to exploit knowledge gained by founders and early recruits in order to compete with the prior employer. In these cases, established firms found themselves effectively in the position of financing the creation of competitors through their own R&D efforts. There is some anecdotal evidence that this problem has become so severe that it represents a significant disincentive to R&D investments by established firms.26

As a result executives and firms planned their behavior with the knowledge that starting new firms, and defecting to them, was extraordinarily easy. They also knew that defections by others from their own firms to such startups would inevitably occur, and could inflict serious damage under certain conditions; often the founders of startups were the...
most valued employees of the firm from which they departed. Zilog, for
example, was founded by seven defecting Intel executives for the purpose of
producing Intel-compatible microprocessors. Intel was cofounded by Robert
Noyce, who had coinvented the integrated circuit while at Fairchild, and two
other valuable Fairchild defectors, Andrew Grove and Gordon Moore. Seeq was
founded by two defecting senior Intel employees from Intel's EPROM
operations (the business Seeq entered); Intel sued and the case was settled
out of court. When Seeq began losing money, one of its founders (Gorden
Campbell, formerly general manager of Intel's EPROM division) departed from
Seeq to found Chips & Technologies, which now reverse engineers Intel-based
IBM personal computers for PC clone producers, primarily Asian firms. LSI
Logic was founded in 1981 by departing Fairchild executives, including
Fairchild's ex-president, Wilfred Corrigan; LSI's vice president for
computer aided design had previously held a senior technical management
position within IBM's semiconductor design organization; and in 1985 LSI
Logic recruited the president of GE/Intersil, George Wells, to be its chief
operating officer. MOS Technology was founded by defecting Motorola
employees to enter the business of producing Motorola-compatible
microprocessors; Mips Computers, founded in the early 1980s to design and
market advanced microprocessors, hired a number of Intel microprocessor
engineers; Sequent Computers was founded by 28 Intel employees who departed
en masse.

To be sure, motivations for defection were not limited to creation of
new ventures; sometimes, relatively established firms courted defectors from
their competitors. Earlier in the industry's history, for example, Lester
Hogan left Motorola for Fairchild, taking most of top management with him, repeating a previous episode in which he had defected from General Electric, taking 18 engineers with him to Motorola. Hogan received millions of dollars to make these defections, both to established firms. Nonetheless, new venture formation appears to be the largest source of senior personnel defection, and has traditionally constituted the largest drain on the managerial and technical resources of larger merchant firms. Hence in this pattern of entrepreneurialism, the creation of new, venture-capital backed independent firms came to be linked to, and indeed primarily driven by, defections of valuable personnel from existing producers—often themselves the entrepreneurial ventures of a previous technical generation. The data on the following pages indicate the levels of venture formation exhibited by the merchant and equipment industries over time, and provide a partial lineage of senior-level merchant industry personnel defection. In the industry's early years, the largest sources of defectors and founders were Bell Laboratories and General Electric; later, the established merchants themselves were the largest source of defection.

This pattern has continued through recent years, even as increasing capital intensity, vertical integration requirements, and Japanese competition have turned the fundamental, long run economics of semiconductor production against small, independent firms. In 1985, the U.S. industry's worst year in its history, 38 young semiconductor firms raised $270 million in venture capital, up from $250 million the previous year. Over one-third of these transactions were for early stage funds, i.e. for newly founded firms. Also in 1985, young semiconductor capital equipment firms
**New semiconductor firms in Silicon Valley, 1955–76**

<table>
<thead>
<tr>
<th>Year</th>
<th>Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>Shockley Transistor, b Clevite, b ITT b</td>
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<tr>
<td>1956</td>
<td>Fairchild Semiconductor b</td>
</tr>
<tr>
<td>1957</td>
<td>National Semiconductor, Rheem Semiconductor b,c</td>
</tr>
<tr>
<td>1958</td>
<td></td>
</tr>
<tr>
<td>1959</td>
<td>Signetics, c Amelco, c Raytheon Semiconductor, H.P. Associates</td>
</tr>
<tr>
<td>1960</td>
<td>Siliconix, c Molecrob,c</td>
</tr>
<tr>
<td>1961</td>
<td>Stewart Warner Microcircuits, b General Microelectronics b,c</td>
</tr>
<tr>
<td>1962</td>
<td>Union Carbide Electronics b</td>
</tr>
<tr>
<td>1963</td>
<td>Philco-Ford Microelectronics, b American Micro-Systems, Cal-Dak b</td>
</tr>
<tr>
<td>1964</td>
<td>National Semiconductor, c,d Electronic Arrays, b Intersil b</td>
</tr>
<tr>
<td>1965</td>
<td>Cermetek, c Monsanto Electronics, Avantek, Lab-Go, Integrated Systems Technology, Nortec, Kinetic Technology, b Intel, c Computer Micro-Technology, b,c Qualidyne, b,c Electro Nuclear Labs, Advanced Memory Systems, b,c Precision Monolithics, c</td>
</tr>
<tr>
<td>1966</td>
<td>Lithic Systems, b Communications Transistor Corp., Monolithic Memories, Cartesian, c Advanced LSI Systems, b Signetics Memory Systems, Advanced Micro Devices, c Four Phase c</td>
</tr>
<tr>
<td>1967</td>
<td>Litronix, b Integrated Electronics, c Varadyne, b International Computer Modules b</td>
</tr>
<tr>
<td>1968</td>
<td>Cal-Tex, b Exan, Micro Power, Intersil Memory, Standard Microsystems, b Antex b</td>
</tr>
<tr>
<td>1969</td>
<td>LSI Systems, b Nitron, b Frontier Electronics, b Interdesign, b Light Emitting Devices, b IC Transducers, b,c Opto Ray, b,c Optical Diodes, b</td>
</tr>
<tr>
<td>1970</td>
<td>Data General, c Synertek b,c</td>
</tr>
<tr>
<td>1971</td>
<td>Monosil, Zilog</td>
</tr>
<tr>
<td>1972</td>
<td>Mnemonics, b Maruman Integrated Circuits, Exonix, Semi Processes b</td>
</tr>
<tr>
<td>1973</td>
<td>Supertex, c Cognition, c Integrated Technology Corp. c</td>
</tr>
</tbody>
</table>

---

*a Some firms have been renamed since their foundation.  
b Since closed, dissolved, sold or merged.  
c At least one founder from Fairchild Semiconductor.  
dReformed.

**Source:** Don C. Hoefler, Semiconductor Equipment and Materials Inc., Mountain View, California, 1979.
## ASIC START-UP HISTORY

<table>
<thead>
<tr>
<th>YEAR</th>
<th>COMPANY</th>
<th>PRODUCT LINE</th>
<th>LOCATION</th>
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<tbody>
<tr>
<td>1980</td>
<td>APPLIED MICRO CIRCUITS</td>
<td>CUSTOM, SEMICUSTOM</td>
<td>CUPERTINO, CA</td>
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<tr>
<td></td>
<td>LSI LOGIC</td>
<td>SEMICUSTOM</td>
<td>MILPITAS, CA</td>
</tr>
<tr>
<td></td>
<td>VLSI TECHNOLOGY</td>
<td>FOUNDRY, CUSTOM</td>
<td>SAN JOSE, CA</td>
</tr>
<tr>
<td></td>
<td>SILICON SYSTEMS</td>
<td>CUSTOM</td>
<td>TUSTIN, CA</td>
</tr>
<tr>
<td>1981</td>
<td>INTERNATIONAL MICROCIRCUITS</td>
<td>SEMICUSTOM</td>
<td>SANTA CLARA, CA</td>
</tr>
<tr>
<td></td>
<td>INTERNATIONAL MICROELECTRONICS PRODUCTS</td>
<td>CUSTOM, FOUNDRY</td>
<td>SAN JOSE, CA</td>
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<td></td>
<td>Telmos</td>
<td>CMOS GATE ARRAYS, ANALOG</td>
<td>SUNNYVALE, CA</td>
</tr>
<tr>
<td></td>
<td>ZYCREX</td>
<td>PLAS (HALS)</td>
<td>SUNNYVALE, CA</td>
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<td>1982</td>
<td>ARRAY DEVICES</td>
<td>H-CMOS GATE ARRAYS</td>
<td>SAN DIEGO, CA</td>
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<td>ARRAY TECHNOLOGY</td>
<td>CUSTOM, SEMICUSTOM CMOS</td>
<td>SAN JOSE, CA</td>
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<tr>
<td></td>
<td>CUSTOM MOS ARRAYS</td>
<td>CMOS GATE ARRAYS, FULL CUSTOM, STANDARD CELL</td>
<td>MILPITAS, CA</td>
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<td></td>
<td>CYPRESS SEMICONDUCTOR</td>
<td>CMOS PLAS</td>
<td>SAN JOSE, CA</td>
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<td></td>
<td>LATTICE LOGIC</td>
<td>GATE ARRAYS, CAD SOFTWARE</td>
<td>EDINBURGH, SCOTLAND</td>
</tr>
<tr>
<td>1983</td>
<td>ALTERA SEMICONDUCTOR</td>
<td>ELECTRICALLY PROGRAMMABLE LOGIC</td>
<td>SANTA CLARA, CA</td>
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<td></td>
<td>EXEL MICROELECTRONICS</td>
<td>ULTRA-HIGH-SPEED E2 PROMS</td>
<td>SAN JOSE, CA</td>
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<td></td>
<td>INTERNATIONAL CMOS TECHNOLOGY</td>
<td>PLAS</td>
<td>SANTA CLARA, CA</td>
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<td>LATTICE SEMICONDUCTOR</td>
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<td>S MOS SYSTEMS</td>
<td>GATE ARRAYS</td>
<td>SAN JOSE, CA</td>
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<td>WAFER SCALE INTEGRATION</td>
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*SOURCE: DATAQUEST AUGUST 1984*
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<th>Company Name/Date Founded</th>
<th>City</th>
<th>Previous Employment/ Number of Founders</th>
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<td>American Microsystems (1966)</td>
<td>Cupertino</td>
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<td>Fairchild (3)</td>
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<td>Electronic Arrays (1967)</td>
<td>Mountain View</td>
<td>Philco-Ford (4), Bunker-Ramo (2)</td>
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<td>Intersil (1968)</td>
<td>Sunnyvale</td>
<td>Union Carbide (3)</td>
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<td>Avantek (1968)</td>
<td>Santa Clara</td>
<td>Applied Technology (4)</td>
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<td>Integrated Systems Technology (1968)</td>
<td>Santa Clara</td>
<td>Fairchild (3)</td>
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<td>Nortec Electronics Corp. (1968)</td>
<td>Santa Clara</td>
<td>Fairchild (3)</td>
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<td>Intel (1968)</td>
<td>Santa Clara</td>
<td>Fairchild (3)</td>
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<td>Precision Monolithic (1969)</td>
<td>Santa Clara</td>
<td>Fairchild (3)</td>
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<td>Computer Microtechnology (1968)</td>
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<td>Monolithic Memories (1969)</td>
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<td>Advanced LSI Systems (1969)</td>
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<td>TI</td>
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<td>Mostek (1969)</td>
<td>Sunnyvale</td>
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<td>Sunnyvale</td>
<td>Fairchild (8)</td>
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<td>Advanced Micro Devices (1969)</td>
<td>Sunnyvale</td>
<td>TI</td>
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<td>Richardson, TX</td>
<td>Fairchild (6), General Instruments (2), Mellonics (1), other (1)</td>
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<td>Monsanto (1)</td>
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<td>Integrated Electronics (1970)</td>
<td>Mountain View</td>
<td>TI (2), Nortec (4)</td>
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<td>Varadyne (1970)</td>
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<td>Caltex (1971)</td>
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<td>Exar (1971)</td>
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<td>Standard Microsystems (1971)</td>
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<td>Antex (1971)</td>
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<td>Zilog (1974)</td>
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<td>Maruman (1975)</td>
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<td>Supertex (1976)</td>
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Spin-offs from Shockley Transistor, Hughes Aircraft and Sperry Semiconductor

Bell Telephone Laboratories

- Tyco Semiconductor 1980
- Sylvania 1963
- IBM 1962
- Texas Instruments 1963
- Shockley Transistor 1966

- Varz 1980
- Hunt Electronics 1980
- Mostek 1989

- Semiconductor 1966
- PHIlips 1964
- Radiant 1983
- Westinghouse Electric

- American Power Devices 1967
- Landale Transistor 1962
- Siliconix 1982
- Norden, United Aircraft 1980
- Stewart Warner Microcircuits 1984
- Industro Transistor 1966

Spin-offs from Bell Telephone Laboratories and Westinghouse Electric

- General Electric
- RCA
- Radio Receptor

- Motorola Semiconductor 1967
- KMC 1963
- Silicon Transistor 1957
- General Transistor 1954

- Dickson Electronics 1960
- US Semcor 1967
- Integrated Circuit Engineering 1984
- Microstar (bankrupt)

- General Semiconductor 1965
- American Micro Devices 1961 (bankrupt)

Spin-offs from General Electric, RCA and Radio Receptor. Source: Golding (1972)
raised $70 million in venture capital, of which over 40% went for early stage financing.  

Defection, Turnover, and Compensation Structures

Annual employee turnover in the U.S. semiconductor industry has been twenty percent since the late 1960s. By contrast, turnover rates in IBM, AT&T, DEC, and in Japanese firms are typically less than five percent. Turnover is highest in young, small firms, as the following data indicate:

Exempt Employee Turnover Rates, U.S. Electronics Industry, 1979

By Number of Employees Per Firm and Industrywide

<table>
<thead>
<tr>
<th>Number of Employees Per Firm</th>
<th>Industry</th>
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<tbody>
<tr>
<td>1-100</td>
<td>101-250</td>
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<tr>
<td>251-500</td>
<td>501-1,000</td>
</tr>
<tr>
<td>1,000+</td>
<td></td>
</tr>
</tbody>
</table>

28% 27% 24% 25% 15% 19%


Even in the larger and more stable merchant firms, turnover is high enough to be a major source of difficulty. National Semiconductor's turnover rate has averaged 15% or more throughout its history. Intel, considered the most progressive and stable employer in the merchant industry, still has a turnover rate of 8%. These high turnover rates appear to have three major sources. First, firms have often assumed high turnover
to be inevitable, and consequently employed policies which perpetuate it, for example using mass layoffs during recessions, and declining to invest in the long term training of their employees. Second, the continuous creation of new ventures increases defection from established firms. And third, the instability of merchant firms' market success caused frequent and rapid shifts in employment and hiring patterns.

As a result, experienced semiconductor executives have often worked for, or even been founders of, half a dozen firms during their careers. The same is true of engineers, programmers, and other professional employees. Furthermore, executives and high level professionals in the merchant industry have an extraordinary reputation for aggressiveness, individualism, and independence often bordering on ruthlessness. Throughout the industry's history, they have perceived themselves, often correctly, as scarce commodities readily marketable elsewhere; many are exceptionally and self-consciously blunt in personal conversation. Management practices reflected this style, and have tended to be idiosyncratic. As one would expect in an industry constantly repopulated by new firms, managers have tended to be permanently inexperienced with major investments and large organizations. Furthermore, managers absorbed the aggressive, individualistic ethic which dominated the industry generally; the instability of the industry and its high rate of new venture creation implied that the cost of leaving a firm was small. It has been common for professionals and managers to resign or be fired as the result of internal disputes. Some departing executives have responded by founding competitors of their prior employer, sometimes taking other employees with them when they depart.
The hiring and compensation practices of the industry have reflected and perpetuated these characteristics. Professional salaries are high and based less on seniority than perceived merit. Favored employees receive large raises and tax favored stock options. By the early 1970s stealing employees was an art form, and innumerable professional and executive search firms had sprouted in the Valley. Some firms began offering their employees thousand dollar rewards for referring new hires. And defection to startups was further encouraged by the lower effective cost of compensation enjoyed by new ventures relative to established firms.

Founders of startups typically hold large blocks of stock which, often as a precondition of obtaining venture capital investment, they cannot liquidate for several years except under controlled conditions. As startups grew, early white collar employees - the first several dozen, sometimes the first several hundred or even thousand - received substantial and heavily tax advantaged stock options (Incentive Stock Options, or ISOs) which uniformly vested over a four-year period, twenty-five percent annually. Early employees of successful startups were therefore often able to sell their stock shortly after the firm's initial public offering (IPO). Under pre-1987 law, ISOs were taxed neither when granted nor when exercised, but only when stock was sold, and capital gains rates applied. Hence they offered both income deferral and favorable treatment when eventually taxed. Often subsequent options (usually taxable Non Qualified Options, or NQOs) were added for valued employees.
But at the same time, everyone recognized the transitory nature of allegiances. Semiconductor firms raided other companies, and recognized that they would inevitably be raided in turn, particularly by new startups. ISOs could only be granted once per employee; hence as startups grew larger and older, their effective costs of compensation rose, and approached those of established firms.

Corporate Life Cycles and Self-Limiting Success

Throughout the merchant industry's history, new and/or second-tier merchant semiconductor firms displayed a characteristic life cycle in matters such as technical leadership, financial success, growth rates, and turnover. The cycle began with creation of a new company focussed on a single emerging technology or market opportunity - 1K memories for Intel, microprocessors for Zilog and MOS Technology, electrically erasable memories for Seeq, gate arrays for LSI Logic. Executives defected from an established firm and created a new one. One to three rounds of venture capital, in some cases totalling up to $50 million, were obtained while the new firm raided larger and more established firms, including the founders' previous employer(s), to obtain high-quality technical talent. After one to three years, the firm's initial products were successful enough that the firm had operating profits. At this time or shortly thereafter, the firm would announce its initial public offering (IPO), which usually generated $25 million to $75 million in cash. (LSI Logic's IPO, the most successful in the industry's history, generated $160 million.)
After several further years of rapid growth, however, firms began to encounter difficulties. Typically, they experienced a generational crisis as early products became obsolete, they became dependent upon current revenue to finance themselves, and fully vested employees began to defect to other, newer firms. Because startups rarely could (or even tried to) invest in the creation of a strong, long term, diversified technology base, and because they were typically focused on a single market, they were extremely sensitive to technological change which demanded R&D, technology, or customer relationships with which they were inexperienced.

Often the qualitatively different organizational requirements of a larger, more structured firm strained the abilities of managerially inexperienced founders. The firm's growth rate slowed as these problems, and the problem of sustaining growth in the face of them, reduced its competitive advantage. Some firms such as Texas Instruments and Motorola were able to maintain high growth and innovation levels - at or above the industry average - through several product generations. But continued success was only one of three possible paths. The second was failure, and the third was acquisition. A number of firms were acquired upon meeting with difficulty, sometimes by larger companies with no previous experience in electronics. Most of these acquisitions fared badly, as the best employees abandoned the acquired firm for newer ventures and the firm's technology obsolesced. Examples of ailing merchants being acquired include Zilog (acquired by Exxon), Mostek (acquired by United Technologies), Synertek (acquired by Honeywell, but later defunct anyway), Intersil (acquired by GE), and Fairchild (acquired by Schlumberger).
Hence as their problems mounted, aging startups succumbed either to competition by the few enduring, stable merchant firms (TI, Motorola, perhaps now Intel), subsequent generations of startups, or (more recently) Japanese competition. As they decayed, their executives and most valuable technical personnel departed for newer firms. Transitron, 2nd among merchants in 1960, sank to 9th by 1965 and then disappeared altogether. Mostek’s revenues rose from $220 million in 1982 to $467 million in 1984, only to decline to $110 million in 1985. During this period, Mostek’s CEO was a defector from IBM. One of Mostek’s original founders, Bob Palmer, departed in 1985 is now a vice president at DEC. Fairchild ranked 3rd among U.S. merchants in 1977, but had fallen to 6th by 1985. Fairchild was falling further when it was sold to National in 1987 for $122 million, after an earlier attempt to sell the company to Fujitsu met political resistance.

Fairchild’s former president, Wilf Corrigan, departed in 1981 to found LSI Logic. He took with him some of Fairchild’s best talent, and also borrowed from other firms (IBM, Intersil, Synertek) as well. LSI Logic rose to 15th among U.S. vendors by 1986 with revenues of $190 million. Seeq’s revenues rose from $9 million in 1983 to $53 million in 1984, only to decline to $31 million by 1986. Unofficially, Seeq has apparently been for sale. One of Seeq’s two founders, Gordon Campbell, had previously been general manager of Intel’s EPROM division; Seeq specialized in related products, and was sued by Intel. Campbell then departed to found Chips & Technologies, whose revenue was running approximately $60 million per year as of mid-1987. Chips & Technologies specializes in reverse engineering
circuits produced by established firms, particularly those used in IBM compatible personal computers. An even more extreme case was Micron Technology, whose naivete and nearly complete dependence upon the memory market led to a rapid ascent followed by an equally rapid decline. Micron Technology's revenues rose from $5 million in 1982 to $117 million in 1984 (the year of the firm's IPO), collapsing to $36 million the next year.

This remarkable instability, though perhaps diminishing somewhat with the continuing growth of scale economies and Japanese competitive pressure, appears nonetheless to be continuing to a degree vastly greater than seen in Japan. With the industry's cyclical upturn in mid-1987, Intel reported such rapid growth (55% over the prior year, with earnings of $81 million on quarterly revenues of $501 million) that it may soon overtake National as the third largest merchant firm. Conversely, for the same quarter AMD reported far slower revenue growth (14% over the year-ago period) and a huge loss ($54 million on revenues of $261 million). Therefore the structural forces of the U.S. system appear to be such that even the largest merchant firms continue to face instability greater than that of the U.S. industry as a whole, and far greater than that faced by Japanese producers.

Technology Diffusion, Turnover, and Licensing

Innovation and technical leadership in the merchant industry have been associated with large but evanescent advantage. The technology, coupled with twenty percent annual employee turnover, made reverse engineering and imitation relatively easy, while simultaneously the existing legal regime of
intellectual property rights was largely useless to the industry. Indeed by the late-1970s there existed firms (such as Mosaid, or more recently Chips & Technologies and Phoenix Technology) which specialized in "documenting" products for clients considering imitation or reverse engineering. Furthermore, many large consumers (IBM, the Defense Department) routinely required second sources for important products made by small firms of dubious stability. The practice of requiring second sources, of course, also perpetuated instability by denying firms any guarantee of a stable cash flow, and conversely providing a means by which newer cash-poor entrants could obtain designs and business.

Beyond these specific considerations, there was also the awareness that success, particularly for the smaller firms, was probably transitory. Consequently merchants realized by the 1970s that proprietary technical advantage was difficult to maintain for long periods of time, and planned accordingly. Typically, innovators would enjoy a brief period of monopoly profit-taking and would then enter a period of extreme competition, wide technology licensing, or both. In this subsequent period, innovators hoped to retain some competitive advantage by being further down an experience curve permitting them to be first to market with "shrinks," redesigns, or successor products. But given the transitory nature of market success, the high levels of turnover within the merchant industry, and the relative absence of effective legal protection, firms rarely expected to maintain a profitable, definitively superior position in any single product or technology for a long period. There was rarely any doubt that imitative and/or competitive products would rapidly appear whether or not licensing
occurred; it was simply a question of time. For devices of simple design, imitators often entered within six months; for very complex devices, imitative entry might be delayed by perhaps two years.

Licensing to Japanese Competitors

As the VLSI era arrived, however, the cost of both design and process development escalated enormously, and technology ownership became more valuable and important. Wide licensing continued, particularly to Japanese firms, for three reasons. First, large customers continued to require second sources, in part precisely because the industry's instability made large users nervous about dependence upon a single, small merchant firm. Second, the merchants became cash constrained, and any individual cross-licensing agreement reduced their initial cost burden by permitting them to obtain immediate cash and/or another firm's designs or technology. And third, the Japanese market remained substantially closed to direct U.S. penetration, rendering licensing attractive over the short term as a method for an individual firm to obtain revenue from the Japanese market and/or process technology from large Japanese firms.

In this environment, licensing and second sourcing often seemed preferable to unlicensed imitation because innovators could at least auction off licensing rights and technical knowledge, and could sometimes thereby negotiate for development and cross-licensing of complementary products with licensee firms. As costs escalated, licensing could provide either quick cash or some useful technology or both. These licensing agreements,
therefore, rarely constituted long term cooperation or joint activity. To the contrary, they were simply the method by which acknowledged enemies dealt with each other and their surrounding environment.

Indeed, miscalculations involving license agreements have been a major source of market share loss. By 1985, for example, Intel held less than half the world market for its own microprocessors; authorized Japanese second sources held nearly half, with authorized U.S. and unauthorized Asian producers holding the remainder. Motorola held slightly over half of its own microprocessor market; about one third was held by Hitachi. Similarly, Toshiba now competes directly with its contractual technology supplier, LSI Logic, in the ASIC market. Earlier, in the late 1960s, Texas Instruments licensed its patents to the Japanese industry in return for the right to build a factory in Japan. Other major license agreements with Japanese producers include Zilog (microprocessors and microcontrollers), Motorola with Toshiba (32-bit microprocessors), and MIPS Computers (reduced instruction set microprocessors). These license arrangements were concluded despite the fact that Japanese firms have a strong reputation for reverse engineering, manipulation of licensing agreements, and rapid entry of markets previously dominated by U.S. licensors. In part, this represented naivete on the part of inexperienced merchant firms; in part, however, it represented a perception that U.S. firms had no alternative. Japanese firms sometimes stole what they could not license, and usually could find at least one U.S. firm willing to provide the desired technology.
Indeed it appears that between the late 1970s and early 1980s, the direction of technology transfer was almost entirely from the U.S. to Japan. Recently technology importing has also been widely practiced by South Korea. Micron Technology, for example, was founded in the early 1980s, went public in 1984, and collapsed in 1985 when DRAM prices fell rapidly. In 1985 Micron licensed its technology to a Korean competitor, Samsung, for less than $3 million. A partial list of recent licensing, sourcing, and/or equity agreements between American and Korean firms is as follows. Goldstar has arrangements with AT&T, LSI Logic, Zilog, Texas Instruments, AMD, and Fairchild; Hyundai, with International CMOS Technology, the Western Design Center, and Texas Instruments; and Samsung, with Exel, Micron Technology, Intel, National, and Zytex. In all cases technology transfer is one-way from the U.S. to Korea; and AT&T is the only American firm have a major equity position in the licensee firm.34

Japanese licensing has most recently focused upon microprocessors, digital communications, and ASICs. Agreements concluded over the last five years include Toshiba with Motorola, LSI Logic, and possibly Sun Microsystems; Ricoh, with VLSI Technology and Custom MOS Arrays; Fujitsu, with Fairchild, Texas Instruments, and Ungermann-Bass; and Kawasaki Steel, with LSI Logic.35 In most cases Japanese firms are trading cash and/or process technology, in which they have and will maintain superiority, for CAD, product designs, and design technology36 - which, to anticipate somewhat, are the sole areas in which the United States still leads Japan.

Related to these considerations, and in part derivative of them, was a
specific pattern of decisionmaking with respect to production strategy, one which strongly affected firms' entry into, and exit from, product markets. Merchants, particularly firms such as TI and Intel who were innovative leaders, frequently abandoned markets as soon as their current ROI fell below some target rate. Until the early 1980s, for example, Intel explicitly maintained a 20% pretax profit target and exited any market failing to meet it. As a result, Intel abandoned production of several generations of its own microprocessor devices before demand for them even peaked. As Japanese competition intensified, Intel found that with each generation its period of high profit near-monopoly became shorter - eventually so short that rising development investments could not be recouped unless the firm could either restrict imitation or greatly reduce costs. For similar reasons, the entire merchant industry (with the sole major exception of TI) abandoned the DRAM business within five years of the onset of Japanese competition, despite the fact that the memory market is expected to grow 25% per year for another decade or more. The general tendency of the merchant industry has been to seek differentiated, safe, high ROI niches rather than to remain in seriously contested markets.

Interfirm Structures: Relationships Within the U.S. Industry

The frequency of arms' length licensing agreements, as opposed to enduring joint development efforts, and of short term ROI calculations in corporate strategy, both exemplified a wider pattern. Just as the U.S. industry was fragmented and unstable in its formal structure, and just as it emphasized short term optimization in production decisions, it was also
nearly devoid of long term, close interfirm relationships. Rather, relationships between firms, their customers, and their suppliers were arms length and contractual, often hostile, and often unstable and/or of short duration. Merchants played capital equipment suppliers off against each other, bargaining for lower prices; customers did the same with merchants; firms in each category withheld much information from the others.

This general absence of vertical and horizontal cooperation has been visible in several forms. Joint ventures, enduring cooperative R&D activities, and systematic exchanges of personnel or information within the U.S. industry have been extremely rare. Multiple firm horizontal cooperative R&D relationships were literally nonexistent prior to the formation of the Microelectronics and Computer Technology Corporation, the Semiconductor Research Corporation, and Sematech in the 1980s. One to one vertical relationships - e.g., cooperative development of capital equipment involving a semiconductor producer and a capital equipment firm - have been slightly more common. IBM has a substantial history of collaboration with Perkin-Elmer in lithography, and with Teradyne in testers; not by chance, these firms are also by far the largest and most stable U.S. producers of semiconductors and capital equipment respectively. More recently IBM has also entered into substantial development and technology exchange agreements with Intel, once again the largest and most stable producer in its major markets (microprocessors and EPROMs).

These relationships, however, have been both exceptional in the American industry and less intimate than the interfirm relationships.
characteristic of Japan. Aside from IBM's investment in Intel, no major U.S. semiconductor consumers hold, or have ever held, equity positions in major semiconductor producers; and the same is true of both semiconductor consumers and producers in relation to major capital equipment or infrastructure firms. Nor is there, or has there ever been, a single major joint venture among such firms. Even individual instances of technical cooperation, such as codevelopment of a specific new product, have been the exception rather than the rule. Far more common has been decisionmaking based upon immediate, one-time considerations of price, availability, and/or current product characteristics.

This vertical disaggregation extended to relationships with the producers of skilled labor and fundamental research, namely universities and national laboratories. While larger systems firms such as IBM, DEC, and Hewlett Packard, merchants and equipment firms had enduring, sometimes close relationships with universities (via internships, equipment donations, educational leave programs, and sometimes cooperative research), merchants rarely developed such relationships. Even Intel, a relatively stable firm dependent upon advanced technology, does not permit employees to take educational leave.40

Most cooperative agreements, therefore, have been bilateral, horizontal, and limited to cross licensing. And even when horizontal agreements have been negotiated, they have sometimes collapsed when one firm fails or competitive conditions change. For example, Intel and AMD negotiated a 10-year cross licensing agreement in the early 1980s, only to
have the agreement disintegrate in 1986. Intel alleged that AMD had failed to fulfill its obligations to develop peripheral circuits; in return, AMD alleged that Intel had simply decided that retaining a monopoly over its 32-bit microprocessors would be more profitable than sharing the market with AMD. As of 1987, the matter is in arbitration. In other cases, firms have found themselves orphaned when their partners went bankrupt, switched technologies, cancelled major development projects, or found themselves unable to meet demand.

3.2 The American Industry in the International System

During the period of its global dominance, the international conduct of the American industry (like that of many other U.S. industries in the first several decades of the postwar period) was largely determined by its internal dynamics and by domestic cost conditions. There were three significant exceptions to this rule, one of which - the industry’s relationship with Japan - was to have major long run consequences. These three exceptions were low wage offshore assembly operations; European manufacturing to secure access to the EEC market; and the sale of capital equipment and technology, rather than products, to Japan in the face of Japanese protectionism and strategic coordination.

Within the U.S. industry (equipment and captive producers included), most high value-added, capital intensive, technologically advanced activities such as headquarters services, R&D, capital equipment development, wafer fabrication, and advanced education occurred largely in
the United States. International flows consisted principally of small but noticeable imports of skilled labor, particularly European and Asian engineers; low-wage offshore assembly operations, principally in Asia; manufacturing and marketing operations in Europe; exports of semiconductor products and some technology to Europe; and, quite importantly for the subsequent course of events, exports of capital equipment, licenses, and technology (not products) to Japan. International operations consisted of offshore assembly and operations within the EEC, but a nearly total exclusion from Japan.

Manufacturing: Labor Intensity and Offshore Assembly

The American merchant industry grew during a period in which domestic wages were high by world norms, particularly the norms of Asia and/or less developed nations. Hence while the U.S. remained the preferred location for activities where advanced technology and human capital were required, it became noncompetitive, at least in short run simple cost terms, as a location for semiskilled, labor intensive activities such as semiconductor device assembly. (As we shall see below, Japan, with a highly educated general workforce but until recently far lower wage costs, was attractive for both kinds of activity but was unavailable to U.S. firms.)

In the merchant industry, furthermore, short term costs were a major consideration. Therefore production was separated from other functions (R&D, design, marketing, headquarters services), and assembly was sent offshore to low-wage regions. The preferred workforce consisted of young,
unmarried, illiterate women paid twenty-five cents to a dollar an hour, often at piece rates; the resemblance to garment production was striking.

Texas Instruments established plants in El Salvador and several Asian nations; by the 1970s, nearly half of National Semiconductor's worldwide labor force - over twenty thousand employees - was located in Southeast Asia; Intel's assembly was concentrated in Malaysia, the Philippines, and (until recently) Barbados. Many firms established plants in Indonesia and the Philippines. Dependence upon low-wage offshore labor increased until, by the late 1970s, 80 percent of merchant assembly was conducted outside the U.S. Sometimes it was even performed by short-term subcontractors rather than in merchant-owned plants; LSI Logic, for example, still used a Philippine subcontractor in 1985.

**Europe: Merchant Dominance by Direct Foreign Investment**

For very different reasons, Europe and Japan were both important to the evolution of the merchant industry. The European market was, nearly from the first, dominated by the larger American merchant firms. The extent of this dominance, in combination with national divisions within the EEC and the strong European presence of large U.S. semiconductor consumers, was such that the European industry never became a major force in world markets. Indeed, Europe's share of world semiconductor markets declined from over 15% in the early 1970s to approximately 10% by the early 1980s; even now, the merchant industry still holds about 50% of the European market. The Japanese response to the growth of the U.S. industry, however, was far more coherent, and stronger, than that of Europe. While European nations
sometimes protected against imports, they permitted and even encouraged direct foreign investment. Japan severely limited both imports and foreign investment, and used market access strategically in order to extract technology and intellectual property rights from the U.S. industry. By 1974, for example, the merchant industry operated 45 factories in Western Europe but only 6 in Japan, despite the fact that the Japanese semiconductor market was already larger than that of Europe.42

A major contribution to the disparity between Japan's maintenance of autonomy and Europe's penetration by American producers was and remains the contrast between Japan's coherent government technocracies, closely linked to financial and industrial management, and the very different relationships between political and economic integration in Western Europe. Western Europe is nationally divided in policy, industrial structure, and production but economically integrated in that the EEC is a unified market at least theoretically devoid of internal trade barriers. EEC nations had divergent interests which were partially subordinated to the presumed economic returns to intraEuropean free trade. Integration of EEC markets was coupled with substantial external barriers on most finished goods and relatively permissive attitudes regarding U.S. direct foreign investment.

This situation suited the larger American semiconductor firms perfectly. In the 1960s and early 1970s they performed all R&D, facilities engineering, and prototyping in the United States, where they also standardized processing through experience acquired in the military market. Subsequently commodity production was transferred to Europe, often in low-
wage areas, in order to circumvent the tariff barrier. This procedure sometimes also allowed the American firms to play off various European governments against each other when choosing production locations. American firms held strong bargaining positions because of their technical lead, because direct foreign investment was widely permitted, and because international operations were more stable and concentrated than were American domestic industry and its markets. The concentrated, oligopolistic character of American firms' international operations - which were dominated by TI, Motorola, and later National and Intel - facilitated at least weak forms of coordination. Conversely the national interests of European governments made effective cooperation among them difficult; for example, support for "national champions" resulted in redundant operations effectively limited to national markets.

In contrast, three factors made it possible for the American merchants to display less savage competitive postures towards each other in European markets than in the United States. First, the merchants's European operations were largely restricted to manufacturing and marketing mature products. Hence the intense supply side competition found in the U.S. - for R&D talent, government contracts, new technology - did not exist in Europe. Second, defection from European operations to start new ventures was next to impossible. Europe simply did not possess the venture capital markets, technical infrastructure, and defection incentives found in Silicon Valley. Third, major international operations were one of the few areas in which relatively major economies of scale and stability were to be found. Entering the European market required dealings with several foreign
governments, transfers of technology to foreign factories, and mass production for relatively large, mature markets. Almost by definition, young startups were excluded. This further reduced defection pressures and also resulted in a far more concentrated structure than the one prevailing domestically.

In part because venture capital and startups were rare in Europe, labor mobility also failed to provide effective technology transfer to European producers. This barrier was increased by the fact that most merchant R&D occurred in the United States, and European production was generally kept one to three years behind the state of the art. Moreover, many of the best European engineers were recruited by American firms, and frequently emigrated to the United States to advance their careers. One of the project leaders for TI's Schottky TTL development was a French emigre taken from TI's French operations, now a second line manager at DEC; Wilfred Corrigan, once the CEO of Fairchild and now the CEO of LSI Logic, is English; George Wells, formerly President of Intersil and now COO of LSI Logic, is Scottish.

For such reasons, the American industry maintained a dominant technological and market position in worldwide semiconductor activities, with the exception of Japan. From this position came further scale and learning benefits, and the emergence of relatively stable structures of European production and marketing, within the largest merchant firms. This international strategic equilibrium had self-sustaining characteristics as strong as those driving the domestic equilibrium of disaggregated innovation. The larger American merchants, such as Texas Instruments,
National Semiconductor, and Motorola (jointed later by Intel and perhaps yet more recently AMD), typically developed products based on a new technology, acquired experience through early domestic sales, and then commercialized the mature product in Europe once the technology was well understood and devices could be produced there on a commodity basis. Hence research, development, prototyping, advanced fabrication, and the most significant forms of learning occurred in the United States.

So long as the American firms retained a technological lead on the order of years over European and Japanese firms, this strategy was viable. The world could be viewed as a commodity market to be exploited through a particular strategy: local production using standardized technologies and products a generation behind those used commercially in America. Once established and successful, such a strategy generated a stable equilibrium and was self-sustaining; it would fail only if indigenous foreign producers could somehow break the grip of the American firms, construct internal capabilities secure from merchant competition, and eventually eliminate the merchants' technological lead and market power. This is what Japan was able to do in the 1960s and 1970s, and what South Korea may be doing now.

The U.S. Industry and Japan: Technology Transfer to a Closed System

In Japan, the American industry's principal exports to Japan were capital equipment and technology, some fraction of which were "exported" involuntarily. Throughout the 1960s and 1970s, the Japanese industry's imports of capital equipment and licensed technology roughly equalled
imports of U.S. semiconductor products in absolute terms, an extraordinary condition by world standards. In addition, many of the semiconductor and capital equipment architectures, technologies, and products developed by Japanese firms were unlicensed imitations, sometimes legal and sometimes not, of U.S. counterparts. Licensing was facilitated not only by the size and structure differentials between U.S. and Japanese producers, but also by the long time horizons required to enter the Japanese market, the general closure of the Japanese economic system, the protectionism of the Japanese government, and the propensity of Japanese firms to imitate or steal that which they could not buy. Unlicensed imitation was facilitated by many of the same forces, and additionally by the delays associated with litigation and the disarray of intellectual property law.

Consequently until the early 1980s the United States provided nearly all of the capital equipment used by Japanese semiconductor producers, and much of their technology as well. U.S. firms—including such major patent holders as TI, IBM, and AT&T—granted licenses to Japanese producers for process patents, product designs and patents, the major U.S. microprocessor families (including those of Intel, Motorola, and Zilog), a variety of other major product designs (e.g. gate array masterslices), and software systems such as university-developed circuit simulators and LSI Logic's CAD systems. In addition to their licensed activities, Japanese firms also directly copied, reverse engineered, or otherwise imitated a wide variety of U.S. architectures, processes, and products. These included the architecture of Sentry memory testers (copied by Takeda Riken, now Advantest), Motorola's 68000 microprocessors (reverse engineered in CMOS by Hitachi, which also
licensed the original device), Intel's 16 bit microprocessors (copied, allegedly illegally, by Fujitsu), Intel's microprocessor microcode (allegedly copied illegally by NEC), the microcode of an important National Semiconductor Corp. communications circuit (allegedly copied illegally by Toshiba), TI's memory technology (allegedly copied illegally by all 6 of the major Japanese memory producers), and a variety of other objects pertinent to semiconductor operations. Taken together, these actions represented an enormous transfer of knowledge, technology, and property rights from the United States to Japan.

Conversely, American penetration in Japanese operations and product markets was very small, in part because it was carefully regulated. Imports were controlled both by government action and by the strategic decisions of the principal consumers (who were also, in large measure, the principal producers). Until 1975, direct foreign investment in the Japanese semiconductor industry was formally restricted as well, and in fact was essentially prohibited both by government policy and by the structure of industry and asset markets. Hence not only was the U.S. industry precluded from operating within Japan and from securing a strong market position, it was also unable to gain access to Japanese capital or personnel. In contrast to the European situation, virtually no Japanese personnel emigrated to the United States to work in the merchant industry.

The sole exception was Texas Instruments, but even the exception largely proved the rule. In 1968, TI - then by far the largest open market semiconductor producer in the world, and possessing both a significant
technology lead and a strong patent position - was permitted by MITI to establish Japanese operations, first through a joint venture with Sony and later as exclusive owner. In return, however, TI was required by the government (and agreed) to restrict itself to a small fraction of the Japanese market and to license its then-current patent portfolio to the entire Japanese industry.

During the period that the American merchant and equipment industries were institutionalizing themselves, therefore, the Japanese semiconductor and equipment industries were developing in parallel but not in open market competition with them. While the U.S. industry was prohibited from major participation in the Japanese market (aside from technology transfer), the Japanese industry also refrained from export drives directed at the United States until the late 1970s. As late as 1977, annual U.S. imports of Japanese semiconductors totaled less than $50 million. Five years later, they exceeded $1 billion.43

Rather, the Japanese industry concentrated upon process development and efficient manufacturing of products required by Japanese electronics exporters. Hence by the late 1960s Japan already accounted for a third of total world production of linear integrated circuits, most of which were incorporated into Japanese consumer electronics products, a high proportion of them manufactured by the same firms which produced the semiconductors. (By the late 1960s, Japan had obtained large shares of world markets for "transistor" radios, televisions, and high-fidelity equipment.) And by the mid-1970s, Japan had essentially reached parity with American technical
practice, at least in process technology. Therefore as a consequence of the combination of Japanese protectionism, specialization for domestic semiconductor markets, and increasing technical prowess, American firms never held more than a quarter of the Japanese semiconductor market, even at the height of American technical superiority and world market penetration.

In short, the Japanese system behaved quite differently than either the fragmented but collectively dominant U.S. industry, or the nationally organized but penetrable European system. These differences deserve some further elaboration.

4. Structural and Strategic Development of the Japanese Industry

The development of the Japanese semiconductor and equipment industries in large measure followed the general patterns of the Japanese economy. Semiconductor production was undertaken through the diversification and backward integration of larger electrical and electronics equipment firms, most of which were in turn members of even larger industrial groups affiliated with Tokyo banks and global trading companies. Semiconductor producers thus adhered to, and derived much of their character from, the structural and strategic norms prevailing throughout Japanese business. As in other sectors of the pre-1980s Japanese economy, capital was supplied (and rationed) by these large firms and the Tokyo city banks. Independent venture formation, personnel defection, and hostile acquisitions were so strongly discouraged that they were nonexistent, and no organized venture capital market existed. Until the 1980s, even entry via diversification by
other large industrial firms was rare after the semiconductor industry's principal firms began operations in the 1950s and early 1960s. The Japanese industry's international activities, too, conformed to the norms of the Japanese manufacturing sector in use of domestic closure, technology acquisition, investment, market selection, and choice of competitive strategy.

The Structure of the Japanese Industry

Relative to the American industry, the Japanese industry has displayed very high levels of diversification, vertical integration, structural stability, and indeed homogeneity. All of Japan's four largest semiconductor producers had begun semiconductor operations by 1954; all of the largest eight, who account for 90% of all Japanese production, had begun semiconductor operations by 1962. With the exception of the relative decline of Sony and the rise of Fujitsu, their identities and even rank order have stayed virtually unchanged for the last fifteen years. Remarkably, this is true not only of these firms' semiconductor production but also of their participation in other, related, markets. The largest semiconductor producers are NEC, Hitachi, Toshiba, and Fujitsu in that order; the same four firms in a different order (Fujitsu, NEC, Hitachi, Toshiba) are Japan's four largest computer manufacturers. In yet a different order (NEC first), they are Japan's largest telecommunications equipment producers. Together with the fifth and sixth largest semiconductor producers (Matsushita and Mitsubishi, whose semiconductor revenues are roughly $1 billion each), the same leaders in semiconductor

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production also account for a majority of Japan's consumer electronics industry. (Sony, whose semiconductor production is less than $300 million, is the only major exception.) Not surprisingly, therefore, the largest Japanese semiconductor producers are also, collectively, the largest semiconductor consumers.

All the principal semiconductor manufacturers, furthermore, display the same structural pattern. All are very large, highly diversified firms. For example in 1986, 35% of NEC's revenues of approximately $16 billion derived from communications equipment, 39% derived from computers, 7% from home or consumer electronics, and 19% derived from electronic devices (mostly integrated circuits). In that year, NEC exported 32% of its total production. Fujitsu, probably the least diversified of the major semiconductor producers, derived 72% of its 1986 revenues of over $12 billion from computers, 16% from communications equipment, and 12% from semiconductors; Fujitsu's export ratio was 22%.

In earlier years, of course, these firms were smaller; but they have been highly diversified throughout the postwar period, and by the late 1970s Japan's six largest semiconductor producers all had total corporate revenues of $5 billion or more, not counting affiliated subcontractors, unconsolidated partly owned subsidiaries, or other members of larger industrial groups. By the mid-1980s, the smallest of the six, Fujitsu, had annual revenues of over $12 billion; NEC's revenues were over $15 billion; Hitachi and Matsushita's revenues were roughly $30 billion each. Together, the same six producers have consistently accounted for over 80% of Japanese
Furthermore, all sell semiconductors both internally to themselves and to the market. Within Japan, all of the major producers buy from and sell to each other; these cross-purchases are comparable in size to their internal consumption. (Intra-Japanese purchases are and have always been larger than imports.) All of the major producers now also export semiconductors, though none of them exported at significant levels until the late 1970s. All produce a wide variety of devices including commodities such as DRAMs, SRAMs, and EPROMs. All of the largest four have long produced microprocessors second-sourced, licensed, or copied from U.S. architectures: Toshiba has used Zilog's designs and more recently has licensed Motorola's, NEC and Fujitsu have used Intel's, Hitachi used Motorola's. Fujitsu and NEC depended upon allegedly illegal copying for their microprocessors.

Indeed, all have pursued essentially similar production and market strategies. The Japanese industry developed through licensing and imitation of U.S. architectures and products, followed by low-cost, low-price, high quality mass production in their mature markets. As the Japanese industry accumulated experience with complex devices and its process technology reached parity with the merchant industry, the interval between U.S. design innovation and imitative Japanese market entry shrank. By the early 1980s, the Japanese industry had acquired market dominance and even innovation leadership in commodities requiring advanced processing but simple design, such as memories.
As the Japanese industry gained in sophistication and size, it continued its backward integration into capital equipment, materials, and infrastructural activities such as clean room construction. Once again, entry occurred either through direct backward integration by the producers themselves, through their creation of closely linked firms, or through cooperative arrangements with other large, diversified firms in relevant technologies. For example, Fujitsu owns 22% of Advantest (test equipment), NEC owns 50% of Ando (testers), and Hitachi owns Hitachi Electronic Engineering (various products). NEC and Fujitsu manufacture their own robots for semiconductor and computer production; Hitachi and Matsushita manufacture their own automated assembly equipment; Toshiba and Hitachi produce electron beam machines used both for semiconductor production and for making masks, the blueprints for integrated circuits. Dai Nippon and Toppan lead in maskmaking, Hoya and Shin-Etsu lead in production of mask blanks, Canon and Nikon produce advanced optical lithography equipment, Shimizu and Ohbayashi lead in high technology plant construction. As in other sectors of Japanese industry, relationships between capital equipment suppliers, manufacturers, and the government are extremely close. It is commonplace for NTT R&D personnel to work in the facilities of firms developing new products, for personnel from equipment suppliers to work semi-permanently in users' factories, and for contractual relationships between closely linked firms to be informal, fluid, and of long duration.

As with semiconductors themselves, these efforts in supporting industries were heavily concentrated in a small number of firms, and
independent startups were nonexistent. Once again, many of these efforts originated through imports, imitation, and/or reverse engineering of U.S. technology, followed by import substitution. And, again as with semiconductor and systems production, the Japanese semiconductor equipment industry was far more stable and concentrated than its U.S. counterpart.

For example, two firms (Nikon and Canon) account for over 90% of Japanese optical lithography equipment production; two other firms (Advantest and Ando) account for over 90% of Japanese production of automatic test equipment.46

Concomitantly, Japanese production of semiconductors themselves progressed from mature to state of the art technologies and devices. By the early 1970s, the Japanese industry held over 20% of the world semiconductor market, primarily through domestic sales of mature commodities (such as linear circuits for consumer applications). By the mid-1970s, however, Japanese production was already rapidly shifting from linear to digital products, towards higher integration levels, and even in some cases towards proprietary versus purely imitative designs. By the late 1970s, Japan had reached parity with the merchant industry in manufacturing, exports began, and Japan's share of the world market began to rise sharply.

By the mid-1980s, the Japanese industry dominated many commodity markets, possessed superior process technology, clearly superior manufacturing and quality control skills, and had reached near parity with the merchants even in advanced design. By 1987, most of the major Japanese firms were testing 6 MIPS, 20 MHz, proprietary 32 bit microprocessors based
upon 1 micron CMOS technology, i.e. devices near or even at the technological frontier.\textsuperscript{47} And, to anticipate somewhat, a similar trajectory (from imitative manufacturing of mature products to proprietary technology) is being employed in the Japanese industry's (i.e. these same firms') recent entry into world markets for semiconductor intensive digital systems products such as computers and telecommunications equipment.

This strategic development path possessed several noteworthy features. One was that its success depended strongly upon favorable environmental conditions not only in the Japanese semiconductor industry, but in the Japanese and U.S. political and economic systems. In particular, the growth and strategic conduct of the Japanese industry depended heavily upon massive imports of American technology, upon the closure of the Japanese domestic arena, and upon the absence of any American strategic response to Japanese closure.

Japanese Closure: Structure, Strategic Behavior, and Government Policy

The closure of the Japanese high technology system included but was not limited to closure, or strategic regulation, of the domestic market. During the embryonic period of the Japanese industry, MITI exercised considerable control over both foreign penetration and the activities of domestic firms, for example via its power to grant or deny import licenses. Not only did such licensing requirements restrict U.S. market penetration, they also provided a means to influence the Japanese industry - by selectively permitting imports of needed inputs such as capital equipment, while
simultaneously providing a coercive tool via the threat to open a market to foreign competition.

However, Japanese closure also included and depended upon a variety of other government policies and structural characteristics of the Japanese economic system which made Japanese operations difficult for U.S. firms, and particularly unpleasant for relatively small, undiversified, and/or unstable firms with short time horizons. For example, asset markets widely open in the United States (such as markets for experienced professional labor, corporate control, capital, or university graduates) were either nonexistent in Japan, or closed, or accessible only through persistent, long term efforts. The market for corporate control was essentially nonexistent; mergers and acquisitions were rare and never hostile, in part because a large fraction of most important firms' equity was held by other firms in their industrial group and their affiliated bank. These holdings rarely changed hands. For example, the largest shareholders of NEC, a member of the Sumitomo group, ranked as follows in 1986:48

<table>
<thead>
<tr>
<th>Shareholder</th>
<th>% ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sumitomo Life Insurance</td>
<td>7.1</td>
</tr>
<tr>
<td>Sumitomo Bank</td>
<td>5.0</td>
</tr>
<tr>
<td>Sumitomo Trust</td>
<td>4.1</td>
</tr>
<tr>
<td>Nippon Life Insurance</td>
<td>3.1</td>
</tr>
<tr>
<td>Dai-Ichi Mutual Life Insurance</td>
<td>2.9</td>
</tr>
<tr>
<td>Sumitomo Marine &amp; Fire Insurance</td>
<td>2.8</td>
</tr>
<tr>
<td>Sumitomo Electric</td>
<td>2.4</td>
</tr>
<tr>
<td>Sumitomo Corp.</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Moreover, patterns of ownership unthinkable in the United States supplement the cross-selling patterns discussed above in facilitating communication and industrywide cohesion. A number of the largest Japanese banks and insurance companies (a majority of them affiliated with one of the
six major keiretsu) hold substantial equity positions not just in one, but in several, of the largest electronics producers. In 1986, for example, Nippon Life not only held 3.1% of NEC but also 1.6% of Fujitsu, 3.9% of Hitachi, 4.1% of Matsushita, 4.0% of Mitsubishi, 3.9% of Toshiba, and 5.9% of Sharp. Sumitomo Life Insurance held not only 7.1% of NEC (the major electronics producer in the Sumitomo group), but also 3.7% of Sharp and 4.6% of Matsushita. Sumitomo Bank, in addition to holding 5.0% of NEC, also held 4.6% of Matsushita. Dai-Ichi Mutual Life, a member of the DKB industrial group which includes Fujitsu, held not only 2.9% of NEC (see the table above) but also 2.8% of Hitachi, 4.7% of Toshiba, 2.0% of Mitsubishi, and 6.0% of Oki. The Industrial Bank of Japan (IBJ) held 2.5% of Hitachi and 2.6% of Fujitsu. And in addition to direct equity positions, financial institutions generally hold large loans outstanding to the major producers, as Japanese industrial firms are highly leveraged, far more so than U.S. firms.49

Moreover, these same financial institutions, together with the major producers themselves, also hold large equity positions in the principal firms in the support industry. This is true not only of the major producers of semiconductor capital equipment mentioned above but for a wide array of semiconductor related capital goods, materials, and services providers. For example Fujitsu owns one quarter of Fanuc, a $2 billion firm which is Japan's largest producer of industrial robots, and whose operations are concentrated in the Mt. Fuji foothills near many of Fujitsu's. Or consider Toshiba Ceramics, which in 1986 was Japan's fifth largest silicon wafer producer, and which also produces other semiconductor materials such as
quartz and ceramics. In 1986, Toshiba Ceramics' principal shareholders were as follows:

<table>
<thead>
<tr>
<th>Shareholder</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toshiba Corp.</td>
<td>50.2%</td>
</tr>
<tr>
<td>Sumitomo Trust Business Dept.</td>
<td>2.6%</td>
</tr>
<tr>
<td>Mitsui Trust</td>
<td>2.6%</td>
</tr>
<tr>
<td>Yamagata Bank</td>
<td>2.5%</td>
</tr>
<tr>
<td>Toyo Trust</td>
<td>1.6%</td>
</tr>
<tr>
<td>Nippon Life</td>
<td>1.1%</td>
</tr>
<tr>
<td>Daiwa Bank Annuity</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

Or consider Hitachi Chemical, a $2 billion chemicals firm, over 40% of whose revenue derives from electronic parts and materials. In 1986 Hitachi Chemical's largest shareholders were Hitachi Ltd. (55.6%), Nippon Life (2.9%), Sanwa Bank (2.6%), Fuji Bank (2.6%), Toyo Trust (2.3%), Industrial Bank of Japan (2.2%), Dai-ichi Kangyo Bank (2.1%), Dai-ichi Mutual Life (1.6%), and Yasuda Trust (1.5%). Hitachi Cable, to consider one final example, is a $1.5 billion producer of wires, cables, semiconductor leadframe materials, optical fibers, and gallium arsenide, 11% of whose revenue derives from sales to Hitachi. In 1986 Hitachi Cable's largest shareholders were Hitachi Ltd. (52.3%), Nippon Life (2.2%), Meiji Mutual Life Insurance (2.0%), Sanwa Bank (1.9%), Dai-ichi Mutual Life (1.7%), Toyo Trust (1.3%), and Daiwa Bank Annuity (1.2%). (Notice the common minority ownership between the Hitachi and Toshiba affiliates. In addition, Dai-ichi Kangyo Bank and Dai-ichi Mutual Life, which both hold minority positions in both Hitachi Chemical and Hitachi Cable, are members of the DKB group which includes Fujitsu.) Nor are these examples exceptional. Each of the major producers has several dozen consolidated and unconsolidated affiliates in whom it owns at least a substantial interest, and often the firm's competitors or members of competitors's larger groups hold a minority interest in the same firm. And, as I indicated earlier, these firms often
forward personnel to each others' plants, engage in cooperative R&D, and have close R&D and/or procurement relationships with NTT.

A different, but related and equally powerful, set of norms and structures inhibited independent personnel mobility and thereby both prevented U.S. firms from effective recruiting and prevented the formation of independent startups. Japanese lifetime employment policies, as nearly uniformly practiced by the major electronics firms (though not their subcontractors), implied that choice of an employer by new graduates was essentially a one-time, lifelong decision. Consequently the established strength and long run prospects of prospective employers were far more important than in the United States. Given my earlier description of the dynamics of the U.S. semiconductor industry, it is hardly surprising that Japanese graduates did not find merchant firms desirable employers, even when the merchants were sufficiently knowledgeable to understand the system. Moreover, university recruiting often depended upon long term relationships between firms and senior faculty members who exercised considerable influence over the decisions of students. U.S. merchants, of course, had no such relationships upon first entering the Japanese arena.

Finally, the internal norms and strategic density of the Japanese arena effectively prevented U.S. entrants from hiring experienced personnel from Japanese firms. Japanese firms reacted strongly when any such attempts were made, and the degree of concentration and vertical integration of the Japanese industry implied that U.S. firms were highly vulnerable to such intervention. Given the structure of Japanese civil society, so were
employees themselves; and even in the late 1980s, defections from major Japanese firms remain quite rare (although they are increasing). This immobility is not simply because Japanese firms are kind, benevolent employers; it also derives from the fact that independent new venture funding is difficult to obtain, and that in Japan, attempted defection can be a very painful experience.

In 1987, for example, I interviewed a Japanese defector, D., whose motives for leaving his company included an unusual personal and familial history of linkages with the United States. In his youth D. had travelled widely, obtained an advanced degree from an elite American university, and worked in the United States before returning to Japan upon accepting an offer from the research division of a large Japanese electronics firm, J. After several quite successful years at J., D. decided in the early 1980s that he wanted to leave, in part so that he could have further contact with the United States. Knowing that no other Japanese firm would hire him, particularly if he expressed an interest in working in the United States, he solicited offers from U.S. firms. Several firms expressed interest and sympathy but declined to make offers; finally, IBM offered D. an attractive position in the United States, and he notified J. of his intention to leave. Upon receiving notice from D., J. at first made exceptionally generous counteroffers. When these were declined, however, D.'s managers at J. spoke to his parents, his wife, his wife's family, his friends, his coworkers, and his former university professors, asking that they persuade D. to reconsider. J. also approached IBM directly, at high levels. After six months of discussions, IBM withdrew its offer. Only after a considerable
period did D. secure a position with his current employer, another large U.S. firm.

In recent years, Japanese employment norms have come under increasing stress, and they may someday weaken substantially. For example, overcapacity in mature export sectors such as the steel industry has recently created substantial pressure on the lifetime employment system, and upon the ability of Japanese firms to credibly guarantee employment security. The increasing value of the yen is also forcing Japanese firms to shift capacity, contracting, and personnel to other nations. But during the formative period of the Japanese industry, these norms clearly operated quite strongly, and in growing sectors they continue to do so. The barrier to Japanese operations, and/or market penetration, presented to unstable U.S. firms with short time horizons was therefore formidable. This shifted the incentives of U.S. merchants and equipment firms away from direct market penetration or political pressure and towards the sale of technology, knowledge, and intellectual property rights.

Closure, Technology Extraction, and Learning

Until the early 1980s, Japanese producers depended very heavily upon American capital equipment, most of which they simply purchased and imported, some of which they also reverse engineered. They also depended heavily upon American product designs, which they licensed, reverse engineered, or directly copied. Their ability to extract technology and collectively protect their domestic market both depended heavily upon
Japan's high degree of strategic coordination and closure relative to the U.S. industry. Otherwise, technology embargoes by the U.S. industry, political pressure, direct U.S. investment, and/or cheating by Japanese firms might have been employed to increase American penetration into the Japanese arena, causing strategic disruption which might have proved fatal to the later growth of the Japanese industry.

However, I will argue below that the combination of oligopoly, partial strategic coordination, and national protectionism did not lessen competitive discipline or performance incentives to improve within the developing Japanese industry. To the contrary, in combination with the long time horizons, pressure for long term coexistence with competitors and the requirement to provide partly captive, domestic production yielded extreme incentives for improvement. One reason for this was that semiconductors were inputs to other products which faced international competition and which were the semiconductor producers' principal source of revenue. If anything, the strategic concentration and vertical integration of the Japanese arena thereby increased effective competitive discipline. Each major firm possessed internal capabilities with which the vendors linked to competitors were forced to compete, and these internal capabilities deterred suppliers from exercising market power. Collectively, furthermore, Japanese semiconductor suppliers and users depended upon competitive semiconductor technology to compete in export markets for final goods.

Indeed, there was mounting evidence of rapid Japanese progress even before Japan entered world semiconductor markets. As early as 1971, a
publicly available study (Tilton's "The International Diffusion of Technology: The Case of Semiconductors") indicated clearly that the Japanese industry was reducing its lag relative to world standards.

Tilton's study demonstrated that the Japanese industry exhibited strong barriers to entry, that it depended upon technology imports, and that its technical practice had surpassed Europe's. Tilton concluded that the U.S. industry's lead relative to Japan, as measured by lags between U.S. innovation and Japanese adoption of critical technologies, had declined over the prior decade to about one year (versus a three year U.S. lead relative to Europe).

Hence the growth and success of Japanese semiconductor production was substantial, despite the fact that the Japanese industry differed from the American in virtually every conceivable respect, and despite the fact that it depended heavily upon strategic arrangements generally considered, at least in neoclassical economics, to reduce efficiency. Moreover, the rapidity and strength of the Japanese industry's export drive beginning in the late 1970s, and the equally rapid decline of the U.S. industry, were striking even by the standards of troubled U.S. sectors such as the automobile industry. Whereas prior to the late 1970s Japan's share of world semiconductor markets had remained at 20 - 25 percent for a decade, between 1978 and 1986 Japan's share of the world market nearly doubled.

In large part, these developments arose from strategic and institutional forces analyzed below. However, a major reason for the timing and suddenness of Japan's entry into international competition in
semiconductors was technological. Very Large Scale Integration, a family of technologies ironically developed almost entirely within the United States, doomed the classical merchant industry by vastly increasing the scale, scope, vertical coordination requirements, and initial costs of semiconductor production. The nature of VLSI technology was such that its arrival presented Japanese electronics firms simultaneously with large opportunities and deep threats. The implicit bargain by which the Japanese and American industries had coexisted previously, i.e. American technology exports and acquiescence to Japanese closure in return for Japan's absence from international markets, was destined to end.
NOTES TO CHAPTER TWO

1. As recently as 1980, Japan imported two-thirds of its capital equipment requirements, at a time when imports of semiconductors themselves had already declined to less than a quarter of Japanese consumption.

2. Semiconductor imports were subject to severe formal restrictions until 1975, and are still restricted in practice through a combination of government and industrial practices. Direct foreign investment, once explicitly prohibited, is now increasingly common, though a joint venture with a local producer is usually a practical necessity. Texas Instruments was granted exceptional permission to establish a wholly owned Japanese subsidiary, at a time when TI had leverage through its possession of critical patents. As a condition for entry, TI was required by MITI to license its patents to the entire Japanese industry, which it did, and to restrict itself to a small fraction of the Japanese market. This latter condition proved very easy for TI to meet.

3. U.S. integrated circuit imports from Japan were less than $50 million in 1977. In 1984, they were over $1.1 billion. Source: U.S. Industrial Outlook, U.S. Department of Commerce, various years.


5. The identities and rank order of the principal Japanese semiconductor producers have remained extremely stable. In contrast, market leadership changed hands repeatedly in the U.S. industry. For market share data, see Dataquest and BA Asia Ltd.


7. Company annual reports; Dodwell, "Industrial Groupings in Japan" and "Key Players in the Japanese Electronics Industry," various years; Japan Company Handbook, various years.
8. Semiconductor industry statistics are notoriously uncertain, and captive production is difficult to estimate precisely because captives rarely disclose production information, and because their production is not sold competitively. However, fairly reliable estimates of captive production have been constructed. IBM is the largest captive by far with worldwide production of $4 billion. Other major captives are AT&T, GM/Delco, Hewlett-Packard, and DEC. Estimates for captive production are those of Dataquest, ICE Corp., and the author. Estimates for merchant production are those of Dataquest.


11. For information regarding turnover in the U.S. industry, see: Braun & Macdonald, op. cit., particularly pp. 132 ff.; for industrywide statistics, see the surveys of the American Electronics Association. The author has also gathered proprietary information from industry sources.


13. IBM was among the first, if not the first, to produce semiconductor memories and use memories (of its own manufacture) in computers in the early 1970s, and also developed elaborate testing and packaging technologies in the same decade - for example Level Sensitive Scan Design (LSSD) and Thermal Conduction Modules. AT&T has been a technology leader throughout the industry's history. And as early as 1971, there existed a public study (J. Tilton, "The International Diffusion of Technology: The Case of Semiconductors," Brookings, 1971) which suggested that the Japanese industry was rapidly closing on the U.S. industry. By the mid-1970s, Japanese practice was less than a year behind the U.S. industry in most technologies.
14. Statistical data are taken from company reports; Dodwell, op. cit.; VLSI Research Inc., a U.S. market research firm covering the semiconductor equipment industry; the U.S. Dept. of Commerce, "A Competitive Assessment of the U.S. Semiconductor Manufacturing Equipment Industry," 1985. Assessments of supplier - customer relationships and comparative technological strength are derived from confidential industry and government sources. Considerable effort has been devoted to these questions.

15. VLSI Research; S.E.M.I.; Dataquest; and company reports.

16. SEMI membership data.

17. SEMI membership data.


19. Ibid.


21. See Braun & Macdonald, chs. 3 - 5.

22. Ibid.


26. Personal interviews. Several executives have reported to me that they consciously consider the likelihood that R&D investments will be appropriable, and that dealing with potential defections both raises the cost, and lowers the real quantity, of corporate R&D activities. However, this is a difficult matter to quantify.


29. Fairchild and National Semiconductor were particularly well known for having extremely ungenerous attitudes towards employees. They also had very high turnover rates. Fairchild spawned more startups than any other firm of its size.


31. This term refers to the re-implementation of an existing product using smaller design rules, permitted by advancing lithography. This makes the device smaller, hence less expensive, and also faster, hence more attractive.

32. Dataquest, 1986.

33. Company annual reports and product literature describe the products and technologies made available to Toshiba by LSI Logic, particularly the LDS computer aided design system. Toshiba supplies process technology in return, but not processing hardware or training. Confidential industry interviews have indicated that the competition between the two companies is quite fierce.


35. Dataquest, 1985. For Kawasaki Steel, personal communication. For Motorola's agreement with Toshiba, confidential interviews.

36. Dataquest; confidential interviews.

37. Confidential interviews, senior Intel employees.

38. Confidential interviews, Intel personnel.

40. Personal interviews, current and former Intel employees.


44. See Tilton, p. 138 ff., for exact dates.


49. See Flaherty & Itami's contribution to "Competitive Edge" for a discussion of the sources of funds for Japanese versus U.S. firms.


52. Dodwell's provides the most comprehensive survey of these relationships available in English.

53. Minor details have been concealed or changed. The major elements of this episode, however, have not been altered.
CHAPTER THREE
DESTABILIZATION: VLSI AND GLOBAL COMPETITION

1. Technological Pressure: The Advent of VLSI

Very Large Scale Integration (VLSI) is a technology family defined by high integration levels (100,000 to 10 million transistors per circuit) and demanding process technology. Advanced VLSI permits the single circuit implementation, mass production, and low cost sale of digital systems which would have been implemented as room-size, million dollar machines three decades ago. VLSI's novel requirements and capabilities favored Japanese industrial strategies relative to the American merchant regime, and also forced Japan to intensify its semiconductor development efforts. VLSI in fact placed extreme pressures upon both the classical merchant industry equilibrium and upon the delicate bargain which had previously kept the peace in international markets. Future developments associated with Ultra Large Scale Integration (ULSI), synchrotron based X-ray lithography, and possibly wafer scale technologies in the 1990s will probably intensify these pressures yet further.

We have seen that during the period of American dominance which persisted until roughly 1980, the merchant industry grew rapidly both technologically and economically, but without fundamental change in its pattern of disaggregated, innovative, but inefficient entrepreneurialism. Individual firms and product families came and went with generational transitions, but the general characteristics of the merchant sector and its
markets remained constant. The importance of the comp electronics, and telecommunications markets gradually inc the defense market as low-cost commodity circuits of sig functionality (memories, controllers, microprocessors) app consumer market grew in worldwide terms, but shifted t consumer electronics industry deteriorated. Circuit densi integration levels continued to increase. The number and producers increased with the growing microelectronics re downstream firms; but the ratio of merchant to captive ; at roughly two to one. Most open-market semiconductor commodity components devoid of strong connections to s

But by the mid-1970s, it became apparent that this without fundamental change was in jeopardy; the inventi microprocessor was perhaps the first signal to this effect. American merchant industry seemed stronger than ever, technology implied that structural transformation would t contrapositive of this proposition, of course, is that in the such structural change, American competitiveness would be 1980, changes in markets and technology had created visib relationships between merchants and captives, upon Ame markets, and upon the capacity of merchant firms to ex; technology generation, i.e. VLSI.

This pressure came in several forms. First, the gro military world semiconductor market increased its size at
world economy sufficiently to render it an attractive strategic target. By 1980 world semiconductor sales neared $15 billion, and it appeared that by 1990 they would reach $50 billion. The direction of technology also implied that much of this growth would occur through the substitution of VLSI for more traditional technologies, both electronic and mechanical, and that advanced VLSI would become increasingly critical to success in mass production industries such as consumer electronics. At the same time as this reduced the significance of the American military in financing technological change and production experience, it induced Japan’s large and vertically integrated electronics firms, in conjunction with the Japanese government, to initiate ambitious programs for the development of VLSI technology and products.

Furthermore, the particulars of the technology became relatively more favorable to Japanese as opposed to American strategies, production systems, and markets. In fact, technological progress was the fundamental source of the industry’s sudden strategic destabilization, globalization, and emerging structural transformation. Its direction strongly favors large industrial complexes over unstable entrepreneurs. Though large infusions of venture capital in the early 1980s temporarily masked this trend in the United States industry (and thereby worsened the subsequent shock), it is now generally acknowledged to be a critical determinant of the industry’s future. New microelectronics technologies (VLSI and beyond) are deeply, inherently incompatible with the merchant strategic regime whose decay we are now witnessing. This incompatibility has two closely related sources, namely VLSI product capabilities and process technologies respectively.
Consider product technology first. VLSI initiated the forced merger of device design and system design, which had formerly been distinct activities carried out by different industrial sectors (and therefore, in the United States, by different firms). This was a straightforward consequence of achievable integration levels, and of the fact that communication within a chip is (and has always been) faster and much less expensive than communication between chips. Crudely speaking a VLSI device is any circuit with at least 100,000 transistors on it. Current VLSI circuits, many of which have over 500,000 transistors, have capabilities several hundred times greater than the most advanced circuits of 1970. Furthermore, such integration levels increasingly invite the implementation of major subsystems or even entire systems on a single integrated circuit. Motorola's and Intel's 32 bit microprocessor families, for example, include not only single-circuit 32 bit CPUs rated at several million instructions per second but also single-chip coprocessors and peripherals such as floating point processors, graphics controllers, memory management units, and input/output controllers. The MC68020 microprocessor circuit, priced at less than a hundred dollars, has the complexity and power of a 1970 mainframe CPU costing perhaps a million dollars. The same underlying forces transformed custom and semicustom logic, greatly increasing their importance. It is now possible to design and implement major custom functions using single circuits containing 100,000 logic gates, sometimes in as little as two weeks.

When circuits become systems to this degree, circuit design and
performance become closely coupled to a multitude of complementary systems products and to strategic decisions formerly of concern only to downstream firms. The design of microprocessors, for example, now requires consideration of interactions with coprocessors, peripherals, and systems software products which reach the machine level (e.g. development systems, operating systems, and compilers), as well as compatibility with earlier product generations. This in turn implies rising integration requirements between semiconductor and systems design, and far closer coupling between VLSI device design and final market requirements.

For example, microprocessor design and production decisions now have extremely strong implications for the market possibilities of systems based upon them. These implications range from the strictly technical determinants of performance - efficiency in data management versus scientific applications, virtual memory support, etc. - to those involving the more general development of business strategy over the life cycle of a product family. Systems firms ranging from Apple to Sun to IBM are now critically dependent upon the migration paths and improvement rates of microprocessor families, and upon the continued strength of their vendor / designers.

Uncertainty, delay, or inappropriate design on the part of the microprocessor supplier passes through directly to the systems business; users of Intel 432, Zilog Z8000, and MOS Technology 6502 processors have discovered this the hard way. The Intel 432 failed to develop a large installed base, as a consequence of its unorthodox architecture; Zilog has
failed to develop successor products for the Z8000, now nearly obsolete; and MOS Technology went bankrupt, resulting in a decade of delay before the Western Design Center produced a successor for the 8-bit processor used in the Apple 2. Furthermore, the power of circuits to act as systems produces strategic interactions previously seen only in the computer market, for example the rise of PCM competition. NEC has developed processors compatible with Intel's; Hitachi and Signetics have developed Motorola-compatible processors; and even Zilog's early Z80 was compatible with Intel's 8080 device.

Nor are these interactions limited to microprocessor families. They also operate strongly in other VLSI logic markets - in areas such as LAN controllers or signal processing circuits, ASICs such as standard-cell or compiled logic, and in emerging markets for Semi-Standard Logic (SSL). It has been reported, for example, that IBM's token-ring LAN efforts were delayed by Texas Instruments' problems in design and production of the five VLSI circuits which control the network. Indeed it was the power presented by VLSI devices which led to the rapid growth of these new product markets and of application-specific circuit design by end-users. Largely as a consequence of VLSI's functional power, application specific markets are expected to increase from one sixth of total IC markets in 1980 to one quarter by 1990.

The availability of VLSI devices also, therefore, intensified the destabilization of downstream industries by permitting digitization of previously analog systems, which frequently led to novel functionalities
and/or redefinition of industry boundaries. To mention one major example, the rate of digitization of telecommunications, and therefore its convergence with computing, is a function of progress in microelectronics, and secondarily photonics, technologies. Other affected sectors include various office automation markets (publishing, facsimile), consumer electronics, industrial automation, military electronics, and – quite importantly – microelectronics itself.

For several years it has been evident that VLSI-based electronics are increasingly critical to the cost and performance of a wide variety of systems. At the same time, VLSI devices eliminated the formerly clear distinction between general-purpose commodities produced by merchants, on the one hand, and special purpose logic produced by captives, on the other. This distinction was replaced by a continuum ranging from specialized, high performance devices (say, a custom signal processor) to specialized "standard" logic (say, a one-chip Fast Fourier Transform) to general purpose devices such as microprocessors whose flexibility resulted in reduced performance for any specific application. A correspondingly broad spectrum of design strategies, process technologies, and cost tradeoffs came into existence as a result. Consequently merchant and captive production became increasingly similar – and therefore competitive. Concomitantly, logic markets became increasingly dominated by system-level performance and strategic considerations, rather than the narrow calculus of switching speeds and unit costs of otherwise identical commodity components which dominated the formative period of the American merchant regime.
VLSI memory devices, conversely, remain primarily general purpose commodities. Current markets for circuits such as DRAMs, EPROMs, or static RAMs, superficially resemble traditional markets because competitive advantage is based upon the same general product characteristics: being first to market, price competitiveness, product reliability, and sometimes device speed or power consumption. Nonetheless these advanced commodities and their potentially huge markets (MOS memory markets, $5 billion in 1984, may reach $20 billion by 1990) have been as profoundly affected by VLSI as systems-level logic markets. This is a consequence of the fact that competitive advantage in memory markets requires extremely high quality, efficient manufacturing. Required capabilities include not only mass production but also flexibility in rapidly switching production to match demand, automated testing of a complex product mix, and device specific error analysis and correction (e.g. through laser trimming of defective memory cells).

In short, VLSI fabrication is becoming one of the world's most expensive, complex, and capital-intensive technologies; it is no longer a garment industry analogue in which competitive advantage can be obtained by paying Salvadoran or Indonesian women thirty cents an hour. This is one of several transformations in VLSI process technology whose effects (on both memory and logic production) are arguably as important as those deriving from the power of VLSI products themselves.

VLSI process technologies
The entire VLSI technology cycle and value chain (R&D, design, fabrication, assembly, testing, and marketing) increasingly displays several characteristics never seen in American microelectronics before 1980. First, advanced VLSI is an extremely capital intensive, high fixed cost business. Minimum efficient scale and initial cost requirements have escalated at an astonishing rate; a world-class plant now costs over $250 million, a tenfold increase since 1975. As a consequence, capital expenditures by American merchants increased from six percent of revenues in 1974 to twenty percent in 1984.1 (Japanese capital expenditures, however, rose from six percent to twenty-eight percent of revenues during the same period.2) Product design costs have escalated correspondingly. As lithography continues to improve, device densities rise, and the economically optimal power and complexity of circuits continually increases, the cost and complexity of system and circuit design are becoming ever larger considerations. The currently reported cost of designing a 32 bit microprocessor chip set is now over $50 million. The cost of developing a new generation of process technology has escalated similarly. Intel reportedly spent over $75 million between 1986 and 1988 to develop its 1-micron CMOS process.3 DEC reportedly maintains two permanent CMOS development teams, operating in parallel on staggered 4-year development schedules, with each team cycle costing about $40 million.

Moreover, similar transformations overtook many capital equipment and services markets, albeit at lesser absolute scale in most cases. The capital investment required to establish an efficient-scale maskmaking operation, for example, increased from roughly $2 million in 1975 to $15 million presently. This was largely the result of the crossover from
$250,000 optical systems, which fail below 2 micron geometries, to computerd
-driven electron beam systems and laser based defect removal systems which
can resolve submicron geometries but which cost $3.5 million each.
Development and manufacturing in areas such as electron beam direct write
systems, precision lasers, direct steppers, integrated computer control
systems, and automatic testers are now capital intensive systems processes
unto themselves. Product development costs for capital goods frequently
exceed $20 million and continue to increase.

Furthermore, as geometries continue to shrink, extreme precision and
cleanliness become critical not only in semiconductor fabrication but
throughout the capital equipment and services sectors. As these
requirements increase, so do capital and fixed costs; and high precision,
high purity manufacturing environments are inherently expensive. So are
products suited to such environments. Consequently, the average unit costs
of semiconductor capital equipment have increased sharply since the arrival
of VLSI. Consider the following data:

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<th></th>
<th>1977</th>
<th>1983</th>
<th>CAGR</th>
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<td>563</td>
<td>49</td>
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<tr>
<td>Automatic Test Equip.</td>
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<td>405</td>
<td>22</td>
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<tr>
<td>Assembly Equip.</td>
<td>10</td>
<td>47</td>
<td>31</td>
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</tbody>
</table>

Source: VLSI Research, Inc. (1986), Table 2.1.2-4

At the same time, the qualitative characteristics and integration
requirements of semiconductor processing have radically changed. VLSI
technologies are now systems-intensive, highly automated, and heavily
dependent upon other high technology, electronics-intensive sectors which,
as indicated above, are themselves increasingly automated, systems-
intensive, and capital-intensive. This has two principal results. The first is that firms must increasingly view semiconductor processing as an integrated, computer-controlled process rather than a succession of disjoint steps. The entire sequence of design, tooling, fabrication, and testing processes are increasingly automated, computer-controlled, and linked by information systems and robotic cassette-to-cassette materials handling systems. Computer control and the rise of Application Specific Integrated Circuits (ASICs) have produced intense pressure to employ low-inventory, rapid-turnaround techniques with which Japanese producers are far more experienced than merchant firms. (Some ASIC vendors now provide fabricated, tested products within two weeks of their design by customers.) These fabrication conditions place great pressure on yields, inventory reduction, and capacity utilization. These pressures make Just-In-Time and low-defect, low-testing production strategies highly attractive. These techniques, however, require a skilled and stable workforce, close supplier relationships, and integration of the entire production process.

Relatedly, VLSI processing requirements - like VLSI products - have increased the interdependence of the semiconductor, equipment, and computer systems sectors. Computer systems and software for CAD, process control and testing are now a substantial portion of semiconductor capital spending. These products, of course, are in turn heavily dependent on electronics and computer systems themselves, and therefore on VLSI circuits. Hence just as VLSI technology destabilized downstream sectors, it also destabilized itself. VLSI products became so complex that expensive systems were required for design and testing; the scale, complexity, and fragility of
VLSI processing invited VLSI-based automation, which increased scale and integration economies even further.

Those who can most readily transfer and coordinate employees, technologies, knowledge, and resources between semiconductor and systems operations are thus heavily favored. It is therefore unsurprising, for example, that the manager of Hitachi's 32-bit microprocessor development efforts was formerly a technical manager in Hitachi's computer division; or that IBM and Intel cross-licensed their CAD, packaging, and microprocessor technologies. To the contrary, the great puzzle posed by the advent of VLSI, and one to which I return below, lies in the failure of most of the U.S. industry (including many consumers) to act in the manner obviously favored by technological requirements.

Implications

Even in the absence of large-scale Japanese entry, the economics of VLSI would have gradually forced structural change in American semiconductor production. VLSI technology was incompatible with the merchant strategic regime in several respects. First, the extreme vertical and functional disaggregation of production was incompatible with growing system integration requirements. Second, the strong centrifugal forces contributing to horizontal disaggregation and domination of innovation by small firms was incompatible with an industry characterized by extreme scale economies and by high initial and fixed costs of design, training, and facility construction. And third, the emergence of novel VLSI logic
technologies eroded the previously clean distinction between commodity merchant producers and custom captive producers.

VLSI therefore posed both large problems and opportunities for Japanese producers. It represented a potentially threatening generational change in a technology critical to export markets. As we noted earlier, VLSI makes possible the digitization of previously analog systems and offers radically novel functionalities. By the mid-1980s, for example, nearly all newly introduced consumer electronics products - VCRs, compact disk players, digital audio tape systems, high definition televisions - already depended heavily upon VLSI microelectronics. Continued American dominance of this technology would therefore put Japan's export position in downstream sectors at risk. Conversely, Japan already led the United States in technology transfer, manufacturing automation, high quality mass production, and robotics. This strength, together with the potentially large size of VLSI markets, led naturally to a strategy of developing VLSI capabilities in order simultaneously to displace American merchants in commodity semiconductor markets and preserve competitive advantage in electronics-intensive downstream markets.

In what follows, I therefore describe and analyze the relative performance of the U.S. and Japanese industries in the new era of international competition. First I will discuss the evidence for, and the detailed structure of, Japanese ascendancy in semiconductor technology and markets. Then I will consider alternative explanations for the comparative structure, conduct, and performance of the Japanese and American
semiconductor industries, and of the industry's international competitive system taken as a whole. My argument will be that although the Japanese industry certainly benefited from favorable economic conditions of the traditional sort (lower labor and capital costs), structural and strategic forces were the primary locomotive of international competitive performance; and indeed strategic variables affected even the traditional economic variables.

2. Competitive Decline

Introduction

Upon the advent of VLSI and the Japanese industry's attainment of world-class manufacturing capability, Japanese firms directly attacked the U.S. industry in world markets, forcing the globalization of the industry and bringing the formerly independent paths of the two national sectors into direct conflict. The subsequent decade has seen the decay of the traditional U.S. industry and the beginning of a new strategic system, one which retains specifically national components but which is both more globally integrated and increasingly dominated by Japan. The remainder of this chapter considers the nature and extent of U.S. decline since the onset of global competition.

Aggregate Measures and Market Shares

Whereas the world market shares held by the Japanese and U.S.
semiconductor industries remained roughly constant for fifteen years prior to the late 1970s, they have shifted dramatically since the advent of VLSI. Using one Dataquest time series 4 (the usual warnings regarding semiconductor market statistics apply), the world market shares of the leading semiconductor producing regions evolved as follows between 1970 and 1979:

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<th>Year</th>
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The statistical uncertainties notwithstanding, it seems clear that no dramatic shifts in market performance were evident prior to the late 1970s or early 1980s. But when the Japanese industry entered international competition, its rise (and the concomitant U.S. decline) was far more rapid than the competitive reversals suffered by other declining U.S. industries (steel, automobiles, textiles, etc.). In 1979, the Japanese semiconductor industry held roughly 26 percent of the world semiconductor market. By 1982, it had slightly more than a third; by 1985, about 40 percent; and by 1987, about 50 percent (in dollar terms). American producers’ share of the world market, conversely, dropped from over 60 percent to about 40 percent between 1978 and presently. (Europeans’ market share fared even worse, declining from over 15 percent to less than 10 percent of the world market.)

During the same period, Japan’s share of world semiconductor capital equipment markets rose from approximately 10 to 35 percent. 5 Furthermore, Japanese growth and American deterioration are probably more severe than these aggregate statistics indicate. American deterioration is occurring most rapidly in some of the most advanced and important markets and technologies, and includes R&D for future technology generations as well as
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Source: DATAQUEST, Inc.
| SIS Companies | © 1986 Dataquest Incorporated Jan. 20 ed. | 7 | 138B |
|----------------|------|------|------|------|------|------|------|------|
| TRW            | 47   | 63   | 97   | 114  | 118  | 118  | 142  | 128  |
| Unitrode       | 40   | 60   | 70   | 70   | 73   | 81   | 106  | 184  |
| Universal      | 40   | 60   | 70   | 70   | 73   | 81   | 106  | 184  |
| VLSI           |      |      |      |      |      |      |      |      |
| VLSI Technology|      |      |      |      |      |      |      |      |
| Hitachi        | 21   | 36   | 69   | 118  | 118  | 118  | 142  | 128  |
| Hitachi        | 19   | 50   | 50   | 50   | 50   | 50   | 50   | 50   |
| Mitsubishi     | 6    | 12   | 23   | 27   | 30   | 30   | 30   | 30   |
| Mitsubishi     | 6    | 12   | 23   | 27   | 30   | 30   | 30   | 30   |
| NED 3          | 34   | 36   | 38   | 38   | 38   | 38   | 38   | 38   |
| Sharp          | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| Sharp          | 115  | 115  | 115  | 115  | 115  | 115  | 115  | 115  |
| Sony           | 129  | 154  | 192  | 226  | 241  | 241  | 241  | 241  |
| Sony           | 129  | 154  | 192  | 226  | 241  | 241  | 241  | 241  |
| Toshiba        | 481  | 442  | 629  | 774  | 715  | 983  | 1,561| 1,450|
| Others         | 523  | 374  | 516  | 690  | 815  | 787  | 484  | 436  |
| European Companies | 1,442 | 1,789 | 1,245 | 1,193 | 1,129 | 2,215 | 3,183 | 2,858 |
| Asea-Hobo      | 5    | 6    | 8    | 10   | 13   | 14   | 14   | 14   |
| Brown-Boveri    | 21   | 25   | 27   | 24   | 24   | 24   | 24   | 24   |
| Euromat        | 9    | 13   | 18   | 15   | 15   | 15   | 15   | 15   |
| Ferranti       | 26   | 39   | 39   | 40   | 40   | 40   | 40   | 40   |
| Hitachi        | 4    | 26   | 50   | 41   | 41   | 41   | 41   | 41   |
| Matsushita     | 28   | 16   | 17   | 19   | 21   | 25   | 31   | 35   |
| Marconi Electronic | 28   | 16   | 17   | 19   | 21   | 25   | 31   | 35   |
| Philips-Signetics 10 | 819  | 761  | 935  | 828  | 797  | 917  | 1,325| 1,088|
| Pifer          | 7    | 9    | 10   | 10   | 10   | 10   | 10   | 10   |
| Plessey        | 26   | 30   | 48   | 49   | 53   | 61   | 82   | 99   |
| Philips         | 26   | 30   | 48   | 49   | 53   | 61   | 82   | 99   |
| SIGS           | 926  | 989  | 1,058| 1,061| 1,073| 1,073| 1,073| 1,073|
| Siemens        | 263  | 306  | 413  | 337  | 337  | 337  | 337  | 337  |
| StC 6          | 24   | 24   | 24   | 24   | 24   | 24   | 24   | 24   |
| Teg            | 21   | 23   | 24   | 24   | 24   | 24   | 24   | 24   |
| Telefunken Electronic 12 | 110  | 150  | 173  | 130  | 143  | 134  | 161  | 178  |
| Thomson        | 148  | 171  | 221  | 180  | 148  | 195  | 280  | 324  |
| Others         | 17   | 20   | 22   | 22   | 22   | 22   | 22   | 22   |
| Rest of World Companies | 18   | 25   | 35   | 45   | 98   | 174  | 238  | 311  |
| Ersa           | 23   | 23   | 50   | 50   | 50   | 50   | 50   | 50   |
| Gold Star      | 15   | 21   | 24   | 24   | 24   | 24   | 24   | 24   |
| IEC            | 15   | 21   | 24   | 24   | 24   | 24   | 24   | 24   |
| Sanyo          | 15   | 15   | 15   | 15   | 15   | 15   | 15   | 15   |
| United Microelectronics | 10   | 25   | 35   | 45   | 51   | 51   | 51   | 51   |

Note: For footnotes, see the last page of this document.

Source: Dataquest
current performance. Let us begin by considering recent world and regional semiconductor market share estimates for Japanese producers over the last eight years:

<table>
<thead>
<tr>
<th>Year</th>
<th>N.America</th>
<th>W. Europe</th>
<th>Japan</th>
<th>ROW</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>2</td>
<td>2</td>
<td>80</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>1982</td>
<td>12</td>
<td>7</td>
<td>87</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>1985</td>
<td>15</td>
<td>12</td>
<td>89</td>
<td>46</td>
<td>41</td>
</tr>
</tbody>
</table>

Note: numbers approximate. Sources: author's estimates; Dataquest; Semiconductor Industry Association; New York Times, various issues.

Since 1985, furthermore, the U.S. industry has continued to lose market share rapidly, at least in dollar terms. Given that Japan now (in 1987) supplies over 90 percent of its own market while holding about 25 percent of America's, trade deficits are to be expected. The bilateral U.S.-Japan trade balance in integrated circuits broke even early in the decade; in 1983 the deficit reached $355 million, and in 1984 it rose to $917 million; in 1985 it declined to about $500 million, primarily as a consequence of weak U.S. semiconductor demand. (In 1982 the U.S.-Japanese trade balance in computers and peripherals also turned negative.) Relative to Japan, the U.S. is now a major net importer not only of dynamic and static RAMs, the products most commonly mentioned, but also EPROMs and ROMs (-$105 million in 1984) and microprocessors (-$52 million in 1984).

Now, consider compound annual growth rates (hereafter, CAGRs) for Japanese versus U.S. production in various technology categories. The newest, most important, highest growth technology families are precisely those in which Japanese advantage and market share growth are greatest:

<table>
<thead>
<tr>
<th>Comparative CAGR, Shipments by Region, 1974-1984, in Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>All semiconductors</td>
</tr>
<tr>
<td>Integrated circuits</td>
</tr>
</tbody>
</table>
Since CMOS-based products, which already account for roughly 40 percent of MOS integrated circuit production, are expected to account for over 60 percent of all MOS production by the early 1990s, these growth rate differences are of nontrivial importance. Even the aggregate statistics, then, indicate a major and still-continuing transformation of competitive advantage in Japan's favor.

Furthermore, the observed pattern of development indicates a high standard of sophistication and foresight in strategic planning within the Japanese industry. The successive phases of Japanese VLSI technology development and market penetration systematically coincide with the probable future course of structural change in the technology base requirements, capabilities, and uses of advanced microelectronics. The Japanese technological effort is riding two wavefronts simultaneously. The first, whose technical description is beyond the scope of this essay, is the careful use of the processing / product cycle both within and across technology generations. This cycle involves commencing with memory and/or other mass produced products of simple or standardized design, using these as process technology drivers to optimize design rules and fabrication technologies, and proceeding to more design-intensive circuits. By the early 1980s, massive Japanese investments in this strategy had already denied important scale economies and learning to the American industry, even on the assumption that the U.S. industry would otherwise have obtained or used such benefits.
The second trend exploited by Japanese producers concerns large scale, long run trends in microelectronics technology. Japanese penetration of successive markets has followed the Japanese industry's increasing sophistication, and the growth of Japanese expertise has rationally followed the expected direction of technological change, particularly as regards the role of microelectronics in large downstream industries. Japanese market penetration began with DRAMs, then with more complex memories such as static RAMs and EPROMs, then licensed microprocessors, and is finally progressing to ASICs, proprietary architectures, and custom devices. Not coincidentally, the world is between an era dominated by conventional integrated circuits (which from the point of view of downstream industries are essentially commodities) and one in which advanced microprocessors and application-specific VLSI logic will play an increasingly important role.

The evolution of Japanese research, investment, and production reflects this progression. The Japanese industry has already, in large measure, obtained control of world markets for dynamic RAMs; it will soon control static RAM, EPROM, and EEPROM markets; it dominates 4 bit and 8 bit microprocessor / microcontroller markets and is entering 16 bit and 32 bit markets; it has now entered ASIC markets, particularly for gate arrays and standard cell products; and it is now (in 1987) entering markets for proprietary 32-bit microprocessors. Hence while Japanese producers entered commodity memory markets first, they did not stop there. Having mastered memory technology, they used memories, and successive logic generations, as process and design drivers in order to enter advanced VLSI logic markets.
They also used their stability and market success to extract further technology transfers from the weakened U.S. industry. Consequently I will describe Japanese advance and American decline across a variety of product markets and technology categories, beginning with memories.

Memory Markets

The total 1984 world market for semiconductors was approximately $25 billion, of which approximately $20 billion was accounted for by integrated circuits. Of this amount almost a quarter, or nearly $5 billion, came from MOS memory shipments. The largest single category within the MOS memory market consists of dynamic Random Access Memory, or DRAMs. Other major markets include static RAMs (SRAMs) and various erasable, electrically erasable, and/or programmable Read-Only Memories, or ROMs. The DRAM market is the oldest and best understood; it was started by Intel's 1K product in 1971, though IBM was actually the first producer (for captive use within its 370 series mainframe computers). Because DRAMs are geometrically regular, relatively easy to design, and produced in extremely large volumes, they usually employ the highest process technology available when introduced. Consequently they have been used as a proving ground for technology and a source of scale economies in addition to representing a large market per se. (Although current and future developments in semiconductor technology appear to be reducing the importance of this so-called "technology driver" role, it is agreed to have played a substantial role in the 1970s and early 1980s.) The long run CAGR of the MOS memory market is approximately 25 percent; that of DRAMs is slightly less, but still higher than that of
integrated circuit markets as a whole. The American merchants have now been eliminated, for all significant purposes, from world DRAM markets, as the statistics below indicate. First the Japanese industry defeated in merchants in direct competition; later (by 1986) most of the merchants, and all of the major firms except for TI, simply abandoned the market. While the protectionism afforded by the semiconductor trade agreement and its "Fair Market Value" (i.e., price floor) provisions may slightly increase U.S. market share, the effect is likely to be minor and the long term trend is unambiguous. In the statistics below, the year indicated is the year in which the newest technology generation entered commercial mass production by several firms; at any given time, two to three product generations will be in production at varying volumes. The market share indicated is for the new product generation only; total Japanese market shares in any given year are slightly less, since penetration has increased with each new generation. Market share statistics are as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Integration Level</th>
<th>J. Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>1K</td>
<td>Zero</td>
</tr>
<tr>
<td>1974</td>
<td>4K</td>
<td>5</td>
</tr>
<tr>
<td>1978</td>
<td>16K</td>
<td>40</td>
</tr>
<tr>
<td>1982</td>
<td>64K</td>
<td>70</td>
</tr>
<tr>
<td>1985</td>
<td>256K</td>
<td>85</td>
</tr>
<tr>
<td>Est. 1988</td>
<td>1M</td>
<td>Est. 90+</td>
</tr>
</tbody>
</table>

Sources: Dataquest; Hambrecht & Quist; SIA.

As CMOS technology has improved, it has displaced NMOS in DRAM markets and, simultaneously, stimulated SRAM markets for reasons associated with the low power consumption of CMOS devices. Japanese producers, who clearly possess the world's best CMOS process technology, increased their share of
total world SRAM markets from approximately 25 percent in 1980 to over 50 percent currently, and appear to hold nearly 90 percent of world CMOS SRAM markets. Since CMOS devices will soon dominate SRAM markets, Japan's market share will increase yet further.

Recently EPROMs, EEPROMs, and other varieties of erasable and programmable ROMs, a smaller but rapidly growing market, have similarly become the focus of Japanese effort. Major Japanese entry into EPROM markets resulted in an unprecedented 80 percent decline in prices in 1985, and the U.S. became a substantial net importer. As Japanese market share increased and a Hitachi memorandum instructing salespeople to undercut Intel's prices was made public, three American firms filed trade petitions in order to obtain domestic market protection. These firms - Intel, National, and AMD - were simultaneously experiencing severe financial problems, as we shall see below. These trade cases, together with the Commerce Department's DRAM antidumping case, were suspended as part of the semiconductor trade agreement reached in 1986, and which specified price floors in both DRAM and EPROM markets.

Microprocessors and microcontrollers

The world microprocessor market grew from $890 million in 1980 to $1.9 billion in 1983, and is expected to grow 30 to 35 percent annually through the early 1990s. The market will be divided between the U.S. and Japan; European firms are no longer involved, with the possible exception of Inmos. If recent trends continue, Japanese producers will control the world market
by about 1990. The likelihood of this result, however, remains insufficiently appreciated. As recently as last year, several university and even private sector analyses predicted that Japanese producers would find microprocessor and related markets difficult to penetrate due to their advanced design requirements. Unfortunately, the penetration has already occurred, and is rapidly spreading to even the most advanced product categories. While early Japanese entry was based upon second-sourced designs for mature products, it is increasingly derived from proprietary products, even for relatively current product technologies. As the following statistics indicate, the Japanese effort began two to four years after memory market penetration and resulted in extremely rapid market share growth. Consider first Japanese and U.S. world market shares for all microprocessors (measured in units, not revenue):

<table>
<thead>
<tr>
<th>Year</th>
<th>Japan</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>10</td>
<td>88</td>
</tr>
<tr>
<td>1981</td>
<td>16</td>
<td>81</td>
</tr>
<tr>
<td>1982</td>
<td>22</td>
<td>75</td>
</tr>
<tr>
<td>1983</td>
<td>27</td>
<td>68</td>
</tr>
<tr>
<td>1984</td>
<td>30</td>
<td>63</td>
</tr>
<tr>
<td>1985</td>
<td>41</td>
<td>52</td>
</tr>
</tbody>
</table>

Source: Dataquest, 1986.

Microcontrollers (MCUs) are essentially one-chip systems containing a microprocessor plus associated interfacing and control logic on a single circuit. They tend to employ microprocessor designs one generation behind current markets because a less complex MPU design leaves space for other logic to fit on the chip. Microcontroller market shares, also measured in units, have evolved as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Japan</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>31</td>
<td>69</td>
</tr>
<tr>
<td>1981</td>
<td>51</td>
<td>48</td>
</tr>
<tr>
<td>1982</td>
<td>60</td>
<td>38</td>
</tr>
<tr>
<td>1983</td>
<td>63</td>
<td>34</td>
</tr>
<tr>
<td>1984</td>
<td>60</td>
<td>34</td>
</tr>
<tr>
<td>1985</td>
<td>62</td>
<td>30</td>
</tr>
</tbody>
</table>

Source: Dataquest, 1986.

These statistics are, of course, susceptible to the criticism that they
might overstate Japanese market share because mature, low technology, inexpensive products are a high fraction of unit production but a low fraction of revenue. There is some truth in this argument, but not much. First, Japan has already penetrated several advanced markets, as I will indicate shortly; and second, the detailed structure of Japanese market penetration, together with recent product announcements, imply that this penetration will intensify. Japanese entry and market share growth are strongly correlated to market size. Japanese producers’ past strategy has consistently been to maintain a general process technology advantage, and then to enter and rapidly dominate product markets when they reach a size which justifies mass production. Consider first the following data:

<table>
<thead>
<tr>
<th>Japanese Share of World MPU Markets by Generation &amp; Size, 1980-1985</th>
<th>Shares in percent, Total Available Market (TAM) in Millions of Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 bit share</td>
<td>11</td>
</tr>
<tr>
<td>TAM</td>
<td>22</td>
</tr>
<tr>
<td>16 bit Zero</td>
<td>7</td>
</tr>
<tr>
<td>TAM</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Dataquest, 1986.

The evolution of MCU markets shows a similar pattern:

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4 bit share</td>
<td>35</td>
</tr>
<tr>
<td>TAM</td>
<td>96</td>
</tr>
<tr>
<td>8 bit</td>
<td>16</td>
</tr>
<tr>
<td>TAM</td>
<td>22</td>
</tr>
</tbody>
</table>

Source: Dataquest, 1986.

Furthermore, Japan's generational lag appears to be declining while its design efforts are steadily maturing. Five to ten years ago, most Japanese microprocessor production was based upon second-sourced American designs for quasi-obsolete products. But Japanese efforts have smoothly progressed through successive phases of more advanced product licensing, unauthorized
copying, pure reverse engineering, reverse engineering with additional proprietary effort, and now – reportedly – proprietary designs. By the early 1980s, several Japanese firms had licenses for advanced American MPUs such as the Intel 8088, 8086, and the Motorola MC68000. In the last two years, however, a potentially critical shift has occurred. Japanese producers have successfully progressed from licensing and pure imitation to reverse engineering, plug-compatible redesign, and significant proprietary design of advanced 16 bit, 16/32 bit, and 32 bit microprocessors.

Several years ago Toshiba designed and began producing, thusfar only for its internal use, a wholly proprietary 16 bit microprocessor. Conversely several other Japanese firms have entered the arena through other routes. NEC and Hitachi have used their reverse engineering skills and process technology advantage to directly challenge Intel and Motorola respectively. NEC designed and is now shipping production quantities of two CMOS microprocessors, the V20 and V30, whose instruction sets are upward compatible with Intel's 8088 and 8086, and which offer superior performance. In addition, NEC announced that these MPUs are the first of a family of compatible CMOS processors which will include advanced 16 bit and 32 bit products. By early 1987, NEC had already developed and distributed prototypes of a 16/32 bit device which is compatible with Intel processors at the 8086 level, but of proprietary architecture at the 32 bit level; NEC has also developed, and in mid-1987 began sampling, a pure 32-bit microprocessor rated at 6.5 MIPS, once again compatible with both Intel and NEC devices at the 16 bit level, but compatible only with NEC devices at the 32 bit level. NEC has begun designing this device into its
telecommunications equipment, though still using Intel devices in NEC personal computers.\textsuperscript{12}

Intel sued NEC, claiming that copyrighted microcode was illegally employed in the 16 bit products; NEC retaliated by offering to indemnify other firms and signed a second source agreement with Zilog, a small American producer owned by Exxon. The litigation, however, is probably of secondary importance in the long run. It is unlikely that Intel will prevent distribution by NEC of these (or if need be, re-engineered) products; indeed the NEC devices are already, reportedly, selling well throughout Asia. After several court rulings favorable to Intel, NEC was able to suspend the litigation in 1987 by alleging that the sitting judge should be disqualified for conflict of interest because he was a member of an investment club which owned two (2) shares of Intel stock valued at less than one hundred dollars.

What is primary is the fact that NEC has entered strategic warfare with Intel in advanced markets, and that it has the technical ability to do so. NEC's initial strategy was strongly imitative and based more on process technology and device performance than on architectural superiority. But NEC did not directly copy Intel's design (microcode aside); rather it redesigned a compatible product, behaving as a classical PCM competitor. Moreover its 32 bit product is nearly completely of its own design. If NEC acquires a large market share and sufficient design experience to come to market roughly as fast as Intel in future generations, NEC will switch from PCM (i.e. compatibility based) competition to standard stealing, possibly
using its own microprocessors in its systems businesses. (NEC is the leading vendor of both personal computers and telecommunications equipment in Japan.) In this case NEC's subsequent products will retain internal compatibility but grow progressively less compatible with Intel's designs.

Thusfar NEC's actions have provoked purely hostile responses from Intel, which has categorically refused to license its 32-bit 80386 circuits to Japanese firms. Motorola initially behaved somewhat differently towards Hitachi, though its more recent behavior, and the long term result, will likely be similar. Some years ago, Hitachi became a second source for the MC68000. In addition to manufacturing it, however, Hitachi proceeded to compete very aggressively with Motorola through price reductions, and to reverse engineer the device and re-implement it in CMOS. Hitachi rapidly acquired roughly one-third of the Motorola-compatible microprocessor market. In 1985, Motorola agreed to become Hitachi's second source for the Hitachi CMOS product.

Motorola's subsequent response to Hitachi's aggressive competition was to enter into a joint venture agreement with Toshiba in 1986. Under this agreement, Motorola secures rights to Toshiba's CMOS process technology immediately, and provides future licensing rights for its microprocessor family as a function of the joint venture's success in the Japanese market. In addition, Hitachi, Mitsubishi, and Fujitsu announced in early 1987 that they will standardize upon Hitachi's instruction set for advanced conventional 32-bit microprocessors. Hitachi's device was already being sampled in mid-1987, and operates under both UNIX and the TRON operating
system architecture developed at the University of Tokyo.

While many American technical experts consider the TRON architecture to be of poor quality, several Japanese firms have also undertaken aggressive UNIX efforts and are devoting increased attention to advanced microprocessors based upon reduced instruction set (RISC) architectures. Toshiba has concurrently entered into manufacturing agreements with Sun Microsystems, a producer of high performance UNIX workstations whose first generation products are based upon the Motorola architecture. (Sun's successor products, introduced in 1987, are based upon the SPARC RISC microprocessor, designed by Sun but implemented in Fujitsu technology; the circuit is both manufactured by and licensed to Fujitsu. Sun has no semiconductor manufacturing capability of its own.) Also in 1987, Japanese firms (albeit diversifying machinery firms, not existing computer vendors) purchased substantial minority equity positions in Dana Systems and MIPS Computers, two Silicon Valley startups developing advanced RISC workstations and RISC microprocessors. MIPS already used Matsushita for fabrication of its microprocessors and peripheral circuits. Once again, therefore, strategic warfare with leading American microprocessor producers (and soon, in a computer market as well) is on the horizon.

These efforts are too recent to permit assessment of their market impact, though the 16-bit NEC devices are reportedly selling well and many Japanese firms have announced 32-bit engineering workstations. But more generally if history is any guide, the Americans are in trouble. The combination of a demonstrated capacity (by the Japanese industry) to reverse
engineer advanced devices, continuing licensing by both established and newly
created U.S. vendors, the architectural simplicity of emerging RISC designs,
and superior Japanese process technology and financial resources, are likely
to prove formidable problems for merchants such as Intel and Motorola. And,
once again, these developments demonstrate that Japanese producers need not
and will not limit themselves to mature, commodity, or low-margin markets.

Application-Specific Integrated Circuits (ASICS)

With the possible exception of 32 bit microprocessors, ASIC and related
semistandard logic (SSL) markets will grow more rapidly than other IC
markets for the next five to ten years, rising from 18 percent of IC markets
currently to perhaps 25 percent by the early 1990s.\textsuperscript{17} 1983 worldwide ASIC
production was estimated to be $3.9 billion, of which $2.2 billion was
captive and $1.7 billion was open-market. The unusually high proportion of
captive production reflects the traditional division between custom captive
producers and commodity merchants. However, ASIC technologies and markets
will soon become critical to the competitive performance of a wide variety
of electronics-intensive industries, most of whose member firms (at least in
the United States and Europe) cannot afford efficient-scale captive
facilities. Hence ASIC production, formerly the preserve of captive systems
producers, is already shifting towards open market production and will
continue to do so for the foreseeable future.

ASICS and semistandard devices such as custom CPUs, signal processors,
and microprocessor based customized circuits will displace obsolete
small/medium scale standard components and even, possibly, significant portions of the standard microprocessor and microcontroller markets. The resulting transformation, whose first phase is already visible, will represent a generational upheaval likely to cause serious damage to firms dependent upon mature standard logic. The major U.S. firms most likely to be affected are probably Texas Instruments, National Semiconductor, and (if defined as American) Signetics. Conversely the growth of ASIC markets in recent years was associated with a wave of startups, one of which - LSI Logic Corporation, founded in 1980 and with expected 1987 sales of $300 million, was the world's largest ASIC vendor until Fujitsu superceded it in 1987. However, this transformation will increasingly require highly automated, flexible, and capital intensive fabrication lines analogous to mechanical Flexible Manufacturing Systems (FMSs) and capable of high volume but extremely heterogeneous production. Major Japanese firms are far more experienced with these technologies than U.S. entrepreneurs.

As with microprocessors, many analysts have argued that ASIC technology and markets would pose substantial obstacles to Japanese producers. Four reasons are generally given. First, ASIC production nearly by definition involves relatively small batches of distinct circuits, and therefore precludes the high quality mass production strategies typical of Japanese firms. Second, ASIC design requires extremely advanced software, an area in which Japan supposedly lags U.S. firms. Third, many ASICs are user-designed and consequently require an extensive service organization, including customer design centers, training, and consulting services. Fourth, ASICs embody proprietary information often relevant to Japanese producers (because
keiretsu are diversified), and Japanese producers have a reputation, partially deserved in the author's experience, for large-scale illicit imitation.

These difficulties are real, but it is also clear that they are far from insurmountable. Extensive R&D, employee training, and computer control in fabrication can remove many difficulties related to custom production, and (as indicated above) may in fact give Japanese producers an advantage over Americans. NEC's enormous Kyushu factory in Kumamoto, for example, now produces over 2,000 distinct circuits in any given year, and over 1,000 in any given month, using roughly 100 distinct processes. Some ASIC technologies, such as gate arrays, can be structured to permit commodity mass production up to a final customization step. Software can be developed, imitated, or licensed; indeed LSI Logic licensed its design systems to Toshiba in 1981, only to find Toshiba become a competitor whose ASIC revenues now substantially exceed LSI Logic's. Service organizations can be constructed, and have been, as will be seen shortly. Encryption and security schemes can provide users with some degree of confidence in the privacy of their work.

And as with microprocessors, Japanese capacities and success in ASICs until recently remained underappreciated. While highly accurate statistics cannot be obtained, the best available estimates of worldwide ASIC market shares do not support the proposition that Japan cannot succeed. Japanese vendors apparently already hold at least 25 percent, and possibly over 30 percent, of world ASIC markets. In some of the most important and rapidly
growing markets, Japanese penetration is even greater. The world market for
MOS gate arrays, for example, will exceed $500 million market this year, and
will probably grow 50 percent annually through the decade. Consider the
following data:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>12</td>
<td>18</td>
<td>29</td>
<td>53</td>
<td>116</td>
<td>223</td>
<td>384</td>
</tr>
<tr>
<td>Japan</td>
<td>1</td>
<td>4</td>
<td>13</td>
<td>30</td>
<td>92</td>
<td>195</td>
<td>290</td>
</tr>
<tr>
<td>Europe</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>16</td>
<td>28</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>ROW</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>World</td>
<td>13</td>
<td>24</td>
<td>50</td>
<td>100</td>
<td>239</td>
<td>463</td>
<td>740</td>
</tr>
</tbody>
</table>


Even allowing for the fragility of the data, Japanese producers clearly
increased their world market share from nearly zero to nearly 40 percent
within a six year period. The MOS gate array market, furthermore, is
extremely dependent upon advanced CAD software and a large customer design /
service infrastructure. Its fabrication process is split between a
preliminary mass production phase (masterslice production) and a small-batch
personalization (i.e. metallization and packaging) phase. This market
therefore provides a strong test of the entry barriers presented by design,
customization, and service requirements, and suggests that such barriers are
rather weak. By early 1984 Japanese gate array producers operated 25 design
centers inside Japan, had opened approximately 30 foreign design centers,
and planned to open over 30 more foreign centers. Although definitions of
the term "design center" differ, it appears that Japanese vendors now
operate nearly as many centers worldwide as do American vendors.

Over the next five to ten years, gate arrays - currently the leading
semicustom technology - will be superseded by other technologies such as
standard cells, compiled logic, and sophisticated semistandard products
embodying multiple technologies, standard and application specific, on a single circuit. Japanese producers are preparing for this transition, apparently as aggressively as the U.S. industry. Fujitsu already markets standard cell products, albeit in low volume, in both Japan and the United States. Toshiba, NEC, and other Japanese firms have reported prototype semistandard devices based on standard MPUs plus custom control logic.

Corporate Performance

Consider now some indicators of the financial and technical strength of Japanese producers relative to the American industry, beginning with the market performance and financial condition of the major American merchants. Since Japanese strategic entry in the late 1970s, the major merchant firms have grown less rapidly than the total world market, while the large Japanese producers have significantly outpaced it. Japanese firms have already displaced American merchants to the extent that four of the world's six largest semiconductor firms are Japanese. In dollar revenue terms, in 1986 NEC, Hitachi, and Toshiba were first through third worldwide. Texas Instruments, which had been first worldwide in 1983 and for many years before, was sixth.

This transformation is quite robust, and it should be emphasized that it transcends recent currency fluctuations. The graphs at the end of this chapter, prepared by M. Suzanne Peterson of First Boston Corp., show growth by product line for the four largest U.S. and Japanese firms from 1979 through 1983. The results reflect not only the aggregate growth of Japanese
producers, but also the extent of Japanese growth, and American weakness, in areas usually regarded as under American control - microprocessors, for example.

Moreover, this information, striking as it is, understates the problem for two reasons. First, the position of the American merchants has worsened since 1983, as the data above has suggested and as I demonstrate shortly. Second, the aggregate growth statistics leave out another variable: stability. As the strength of the Japanese industry increased, American producers found themselves losing not only market share but also their ability to predict, and hence plan for, the future. Japan rapidly became the core of the industry and the Americans its periphery. Japanese firms acted while the merchants reacted; and risk factors such as cyclical variation in demand became concentrated in the American merchant sector. In the last two years this phenomenon, evident since roughly 1980 in RAM markets, has become so pervasive that it is now a major variable in the merchant industry's condition. In 1984 the merchant industry, unprepared for rapid growth, struggled to meet demand by increasing production and investment. The industry perceived 1984 as an excellent year because its growth was abnormally high (over 40 percent), even though Japanese growth was greater (55 percent) and the U.S.-Japanese bilateral trade deficit in integrated circuits tripled to over $900 million. In 1985, the market collapsed and the American merchants absorbed a disproportionate share of the contraction.

The result was the worst recession in the industry's history. While
world semiconductor sales declined approximately 18 percent in 1985, sales by U.S. firms declined 22 percent. The semiconductor revenues of the leading U.S. merchants declined by 25 to 60 percent while Japanese revenues remained approximately constant. The American decline, furthermore, is not limited to producers of commodity memory devices. Relative to the same period in 1984, Motorola's semiconductor orders declined 55 percent in the first half of 1985. Nor did matters greatly improve in the third quarter of 1985. On October 1, 1985 Motorola reported a third quarter loss of $39 million. Total corporate revenues declined 6 percent, but semiconductor revenues declined 32 percent and new semiconductor orders declined 44 percent relative to the previous year. AMD reported a 50 percent decline in corporate revenues ($127 million versus $257 million) for the quarter ending in September 1985. In that quarter AMD also reported an operating loss of $29.5 million, partially offset by tax credits. At one point, AMD reportedly had less than $10 million in cash.

Intel reported its first loss since 1971, an operating loss of $23 million partially offset by tax credits and interest income, and a 28 percent decline in revenues, $312 million versus $432 million, relative to the same quarter of 1984. Simultaneously with reporting these results Intel announced that it was abandoning the DRAM market, which it had created in 1970. National Semiconductor reported a net loss of $53 million, and a 25 percent revenue decline, for roughly the same period. Texas Instruments has also suffered large losses in its semiconductor operations, and reported a corporate-wide net loss of $82 million for the third quarter of 1985. Mostek closed entirely in October 1985 after sustaining 1985 losses.
totalling $330 million, and then was sold to Thomson-CSF for a fraction of
its book value. A number of smaller firms such as Micron Technologies,
Seeq, Synertek, and Signetics, also reported large losses and revenue
debits. Several entered bankruptcy or were sold.

These financial difficulties, furthermore, have resulted in severe
contractionary measures including plant closings, permanent layoffs,
reductions in spending for R&D and capital investment, product
cancellations, and withdrawal from markets. Temporary layoffs in the
merchant and supporting industries exceeded 60,000. I estimate that
permanent U.S. layoffs exceeded 10,000. Merchant capital spending probably
declined by 50 percent.

Once again, however, the sharp recessionary contraction merely
accelerated the progress of a secular trend. Since the late 1970s, the
Japanese industry’s R&D and capital equipment expenditures have consistently
increased more rapidly than those of the merchant industry, both absolutely
and as a percentage of revenues. The graphs at the end of this chapter show
these trends for the largest five U.S. merchants and Japanese producers.
Even before the extreme instabilities which have characterized the industry
since 1984, Japan was outperforming the United States.

3. Technological Decline

Manufacturing, Process Technology, and Equipment
Concomitantly with their direct penetration of semiconductor markets, Japanese firms have increased their manufacturing efficiency, technical autonomy and scope. Since approximately 1980, Japanese producers have obtained technical equality or even superiority in several categories of fabrication equipment, and large market shares in a variety of equipment and services sectors. They have also obtained superiority in manufacturing efficiency and product quality; indeed this strength probably leads, rather than lags, Japanese penetration of capital equipment markets. Since the early 1980s, Japanese firms have possessed a one to three year lead over American merchants in CMOS technology and manufacturing as measured by new commodity product introductions, design rules, yields, and costs. Since CMOS is expected to increase from approximately 30 percent of MOS IC production currently to over 60 percent by 1990, this is a technical advantage of some significance. In commodity markets such as DRAMs and SRAMs, it translates directly into market dominance. In addition, Japanese semiconductor producers have diversified into semiconductor capital equipment production. They have also formed close relationships with other emerging Japanese equipment, materials, and services firms which have often entered by diversification themselves - firms such as Toppan, Dai Nippon, Canon, Nikon, Hoya, and JEOL.

Excellence in capital equipment translates both into improved semiconductor fabrication and into direct revenue. Between 1975 and 1984, Japan’s share of world semiconductor capital equipment markets grew from less than 15 percent to over 30 percent, and has probably increased further since. Moreover, with the probable exception of CAD systems,
control software, and equipment developed internally by IBM and AT&T, it appears that Japanese equipment is generally equal or superior to U.S. equipment in technical capability and reliability. In some cases, Japanese equipment may now be superior to the best manufactured in the U.S.

Automatic processing, assembly, and memory testing equipment made and/or used by Japanese firms is considerably more advanced than equipment used by American merchants. The most striking differences appear to be in maskmaking, certain categories of optical and X-ray lithography equipment, high performance automatic testing equipment (ATE), and in automatic or robotized assembly equipment. As I indicate below, electron beam direct write equipment markets will probably also soon be dominated by Japan. Some of this Japanese equipment appears to be less than completely accessible to the U.S. industry. This in turn appears to result from a combination of deliberate withholding and from the lesser development of Japanese producers' marketing, distribution, and maintenance infrastructure in the United States. 24

Manufacturing

The hypothesis of substantial Japanese superiority in manufacturing is supported by several forms of evidence. The first is the consensus of the trade. Among semiconductor technologists and executives who have visited Japanese firms and/or who purchase semiconductors, there is now nearly universal agreement that the technology levels, product quality, and manufacturing efficiency of current Japanese production are well beyond the average level of major U.S. producers. Several reports have indicated that
average yields in major Japanese plants are nearly twice as high as those obtained in roughly equivalent merchant facilities. IBM, DEC, and other large U.S. users continue to find that U.S. merchant produced semiconductors require far more testing, and are less reliable, than Japanese-sourced devices. A vice president of one major user told me in 1987 that merchant-produced memories constituted less than 5% of his firm’s semiconductor purchases, but over 20% of its incoming semiconductor quality problems.

Additionally, there is Japan’s generally superior CAD/CAM and robotics technology and practice. It is widely agreed that Japanese robotics is superior to America’s; half of the world’s industrial robots are produced and used in Japan. Japanese commercial operations are already more capital intensive than those of the merchant industry. Whereas as recently as 1980 approximately eighty percent of American-made circuits were assembled in low-wage, labor-intensive Asian factories, the comparable statistic for Japan was ten percent. In part this simply reflected the smaller differential between Japanese and East Asian wages, but in part it reflected investments in organization and automation. Furthermore, Japanese production has been growing steadily more capital intensive since the early 1970s, and has been more capital intensive than U.S. production for some years. And finally, the Japanese industry appears to employ both more effective technical practices - such as advanced contamination control techniques and Just-In-Time production - and more highly trained workers than U.S. firms. The resulting efficiency difference has by now become substantial, though once again precise statistics are unobtainable for the
semiconductor industry. One computer executive estimated that U.S. products required five times as much incoming quality control processing as Japanese products in the 1980s.27

Japan generally excels in the manufacturing techniques appropriate to advanced, flexible manufacturing, not only in semiconductor production but in other sectors. A recent study by Jaikumar, for example, analyzed the usage of Flexible Manufacturing Systems (FMSs) in Japan and the United States.28 Jaikumar surveyed the installed base of such systems in both nations, and then specifically studied 35 U.S. systems and 60 Japanese systems. First, Jaikumar found that 40% of the world installed base of FMS systems resides in Japan. But second, Japanese systems enormously outperformed their technically equivalent U.S. counterparts. System development time averaged 2.5 to 3 years in the U.S., but 1.25 to 1.75 years in Japan. U.S. systems produced an average of 10 different parts concurrently; Japanese systems produced 93. U.S. systems produced 88 units per day on average; Japanese systems produced 120. U.S. systems handled an average of one new part introduction per year; Japanese systems handled 22. The average utilization rate of U.S. systems was 52%; of Japanese systems, 84%. No U.S. systems operated unattended; 18 Japanese systems did.

Moreover, Jaikumar's study found that the workforces showed the same patterns which have been noted, less systematically, in the semiconductor sector. In the Japanese plants, 40% of the workforce was made up of college educated engineers; the the U.S. plants, the comparable statistic was 8%. Training time used for skill improvement was three times longer in Japan.
than in the United States. Jaikumar wrote of one U.S. user, "...management prevented workers from making process improvements....The technology was applied in a way that ignored its huge potential for flexibility and for generating organizational learning."

Capital equipment, materials, and services markets

Through penetration of semiconductor capital equipment and services markets, Japanese producers are causing upheavals in the equipment sector similar to those seen in the merchant industry itself. The pattern of entry is also similar: Japanese firms, often with linkages to major semiconductor producers, invest heavily and enter markets in which high quality, capital intensive, high initial cost activities confer advantage. They have a quasi-assured internal market, while in world markets they typically face a disaggregated American sector composed of smaller, self-financed startups. Whereas in 1984 the Japanese equipment industry (as defined by one market research service) contained 108 firms, the U.S. industry contained over 500 firms. And whereas most of the U.S. firms resembled merchant semiconductor producers in that they were recently established, independent, small firms with narrow product lines, many Japanese producers are subsidiaries of semiconductor producers themselves or of other major industrial enterprises. Examples of the latter include Canon, now a $6 billion diversified optical, industrial, and office equipment vendor, and Shimizu, a $7 billion construction and engineering services firm. Below, I discuss several categories of equipment in more detail.
Consider first automatic test equipment (ATE). Ando, half owned by NEC, and Takeda Riken (now called Advantest), 22% owned by Fujitsu, compete against established American firms such as Fairchild/Sentry, Teradyne, Genrad, and Varian, plus a considerable number of smaller startups such as LTX, Trillium, and the like. By the mid-1970s, Japan's open market participation in ATE was rapidly increasing. Between 1975 and 1980, Japan increased its share of total world ATE production from 4% to 10%, while increasing its share of world ATE consumption from 7% to 16%. Its participation in semiconductor ATE markets progressed even more rapidly. Between 1975 and 1980, Japan's consumption of all semiconductor ATE rose from 13% to 26% of world consumption, while its world market share rose from zero to 16%. Japanese semiconductor ATE production rose by 56% in 1980, while non-Japanese production rose by 25%. By 1985, Japan held over one third of the world ATE market.

Finally, Japanese participation showed large increases in the most advanced sectors: memory and VLSI testing. By 1980 Japan consumed 23% of world VLSI ATE and 32% of world memory ATE. Japanese producers' world market share in all ATE increased from 18% in 1975 to 25% in 1980. By 1985, Japanese producers held approximately half of the world memory ATE market. In the last several years, moreover, Japanese technical advantage and market penetration appears to have increased yet further. The recent technical and financial performance of many U.S. firms, furthermore, has been poor. Varian, Genrad, and others announced losses and major layoffs in 1985. Teradyne, the leading U.S. ATE firm, is generally considered well managed, but it faces severe competitive pressure. U.S. demand for memory testers, a
major product line, has nearly disappeared with the exception of IBM. Teradyne's world market share appears to be roughly constant.

Electron beam (E-beam) equipment is required for advanced mask and reticle manufacture, and is increasingly desirable for high-density lithography (1.5 microns and below). E-beam technology, however, is extremely complex and capital intensive; product development requires $40 million or more, and each machine costs over $3 million. Six competing, independent American firms undertook R&D efforts in order to enter this market. By May of 1985, five of the six (Varian, GCA, Veeco, General Signal, and CDC / Microbit) had cancelled their efforts, writing off total losses in excess of $100 million. Other than IBM, which reportedly spent $50 million developing a system it uses internally and does not sell, only one American firm - Perkin Elmer - remains active in the area. Conversely, three Japanese suppliers - JEOL, Hitachi, and Toshiba - have major development efforts and are expected to dominate future markets. JEOL already markets a system in the United States. Hitachi and Toshiba, of course, are major semiconductor producers.

Also in 1985, several Japanese firms rapidly increased their presence in the U.S. maskmaking market, rapidly taking a large share of the market from about 15 underfunded American startups. Semiconductor markets have become more mask-intensive due to the rapid growth of application specific markets involving large numbers of designs. Mask quality, furthermore, has a significant effect on production yields, and rapid delivery is important to reduce production cycles. As lithography has improved, E-beam etching
equipment and precision laser-based defect removal systems have become nearly obligatory, and the minimum efficient scale of capital investment has risen from roughly $2 million five years ago to $20 million presently. Some further scale economies appear to exist at even higher capitalizations.

Recently three Japanese firms - Dai Nippon, Toppan, and Hoya - entered the maskmaking market after investing heavily. Dai Nippon and Toppan now have annual maskmaking revenues exceeding $50 million, whereas the largest American firm had 1984 revenues of $16 million. Micro Mask, Master Images, and others reported operating losses in 1985. There is now wide agreement that the Japanese suppliers offer faster delivery, higher quality, and lower price. In early 1985 Intel, for example, reportedly switched from using seven U.S. suppliers to using two Japanese and two American suppliers, with the Japanese firms supplying roughly half of Intel's requirements.32

Maskmaking also requires extremely high-quality quartz or glass; the dominant supplier in the 1970s was Corning Glass. Now, however, Hoya and Shin-Etsu together hold 90% of the world market.33 (Hoya now also competes in maskmaking.) This appears to be part of a more general pattern of emerging Japanese superiority in base materials capabilities - GaAs crystals and wafers, high purity silicon, highly purified gases, high quality ceramics, and other exotic materials required for increasingly demanding technologies. Several U.S. studies have now concluded that Japanese producers now hold a significant technical advantage over the U.S. in production of highly purified, defect-free electronic materials.34

Lithography tools, like masks and materials, are critical to
semiconductor manufacturing quality and yield. Nikon and Canon now hold strong positions in world markets for direct steppers and projection aligners. Between 1979 and 1984, Canon advanced from the 18th largest semiconductor equipment supplier worldwide to the 10th. Nikon was not even a producer in 1979; in 1981 it was 51st worldwide; in 1984 it was 7th.\(^\text{35}\) Nikon has also developed an X-ray stepper.\(^\text{36}\)

Hence, with the probable exception of CAD software, it would appear that Japanese technical practice and capital equipment, materials, and services capacities are equal or even superior to those of the United States. This appears to be even more strongly true for the most advanced materials and process technologies, such as GaAs wafers and X-ray lithography tools.

Research and Development

Finally, an increasing fraction of Japanese technology derives from indigenous development rather than imitation, and in many areas Japanese semiconductor R&D now compares favorably with that of the United States. Several recent general assessments, including one each by the Defense Science Board\(^\text{57}\) and the National Research Council,\(^\text{58}\) support this conclusion. So do the available statistical indicators of R&D. Between 1975 and 1982, the U.S. share of world integrated circuit patent activity declined from 43% to 27%, while Japan's share rose from 18% to 48% in the same period.\(^\text{39}\) By the mid-1980s, over 40% of papers accepted for presentation at the IEEE Solid State Circuits Conference were of Japanese
R&D spending by the Japanese industry now exceeds merchant industry spending both absolutely and as a percentage of revenues, and will exceed total U.S. spending (including captive and government R&D) by the early 1990s at the present trend. In one area important for future lithography at 0.4 microns and below (X-ray lithography), Japanese efforts include cooperative construction and use of several synchrotrons by NTT, the Japan Agency for Science and Technology, and major Japanese producers - efforts far larger and more coherent than those of the United States. Japanese firms also have substantial R&D programs in laser-based lithography, including affiliations with U.S. startups, and in 3-D semiconductor technology, which may become commercially important by the early 1990s. Japanese efforts in 3-D technology, which are concentrated in several R&D consortia involving the major producers, appear to be several years ahead of United States research.
SEMICONDUCTOR R&D SPENDING
(Calendar Year)

SEMICONDUCTOR CAPITAL SPENDING
(Calendar Year)

*Includes NEC, Hitachi, Toshiba, Fujitsu, and Matsushita
**Includes TI, Motorola, Intel, National, and AMD

Based on Dataquest Numbers
SEMICONDUCTOR R&D
AS % OF SEMICONDUCTOR SALES
(Calendar Year)

17.5
15.0
12.5
10.0
7.5
5.0


Average: Top 5 Japanese Firms*
Average: Top 5 U.S. Firms*

SEMICONDUCTOR CAPITAL SPENDING
AS % OF SEMICONDUCTOR SALES
(Calendar Year)

35
30
25
20
15
10
5
0


Average: Top 5 Japanese Firms*
Average: Top 5 U.S. Firms*

*Weighted Average of NEC, Hitachi, Toshiba, Fujitsu, and Matsushita
*Weighted Average of TI, Motorola, Intel, National, and AMD

Based on Dataquest Numbers

COURTESY M. SUZANNE PETERSON
1ST BOSTON

COURTESY H. SUZANNE PETERSON
1ST BOSTON
NOTES TO CHAPTER THREE

1. Dataquest Semiconductor Industry Service.


3. Confidential interview.


5. VLSI Research, Inc.

6. Dataquest.

7. I am grateful for confidential conversations with employees of IBM, AT&T, and Intel concerning this subject.

8. Ibid.

9. Ibid.

10. Dataquest.

11. Confidential interview.


13. Confidential interviews.

15. Confidential interview.


17. Ibid.

18. This discussion is based upon confidential interviews and the author's consulting experience.


20. Dataquest.

21. Confidential interview.

22. Confidential interviews, particularly with large consumers.

23. VLSI Research.

24. Confidential interviews.


29. Dataquest.

30. Ibid.

32. Confidential interviews.

33. Dataquest.

34. Confidential interviews indicate that this opinion is held by relevant personnel in Perkin Elmer, IBM, and Texas Instruments, among others.

35. VLSI Research.

36. Confidential interview. Nikon has been reluctant to supply this machine to at least one U.S. firm which has sought to obtain it.


40. Damien Saccocio, "Publish or Perish?," unpublished manuscript, MIT Department of Political Science, 1986.

41. Personal interviews (IBM, SLAC, and merchant firms) and trade press reports.
CHAPTER FOUR
ECONOMICS, STRATEGICS, AND THE LOGIC OF MERCHANT DECLINE

1. Alternative Explanations for Semiconductor Industry Behavior

The semiconductor case raises serious questions as to the adequacy of existing models of industrial dynamics such as those provided by neoclassical economics and relatively similar population ecology descriptions. On the other hand, modeling the industry's behavior as a vector of linked, long term strategic interactions suggests explanations of its otherwise puzzling behavior. Concomitantly, this approach leads to new units of industry and market analysis, such as consistent strategy sets, strategic trajectories, and equilibrium strategic regimes. Applying them to the semiconductor case suggests that while traditional parameters such as factor costs and returns to scale have certainly played major roles in the industry's development, their role has been neither determinative nor of the kind assigned to them in neoclassical models.

In particular, it appears likely that the most important role of factor costs and changing cost structures has been to affect strategic behavior via their impact upon the time horizons of strategic actors such as firms. In both the U.S. and Japan employees, firms, and governments continuously faced multiple, concurrent strategic interactions with each other, confronting them with alternatives such as whether and for what purposes to cooperate with one another. In significant measure as a consequence of time horizon differences (induced by factor costs among other signals), Japanese and U.S.
actors made widely divergent strategic choices. These decisions eventually led to the evolution of stable, self-reinforcing patterns of strategic behavior which had profound effects upon the two industries' structure, conduct, and competitive performance. Traditional economic effects associated with factor costs, high initial costs (e.g. for R&D), and/or increasing returns, such as the pure technical scale advantages enjoyed by the better capitalized industry, appear to have been of secondary importance. Indeed, some strategic effects acted in directions contrary to conventional economic signals, and seem to have overridden them. Hence, for example, the U.S. industry failed to rationalize when cost structures and technological change should have dictated that it do so.

As a result, many of the structural, behavioral, or performance results predicted by neoclassical theory have failed to appear in this industry. Much the same can be said of population ecology models, to the extent that they implicitly or explicitly accept the existence of "selection" mechanisms independent of endogenous strategic interactions. The same is also true of several other proposed explanations of Japanese behavior and/or U.S. decline, such as hypothesized failures of U.S. management, manufacturing, and so forth.

This is an important point. Both for analytic reasons and as a result of the place occupied by economics in modern debates concerning industrial behavior and economic policy, any explanation which does not directly rely upon neoclassical categories must still answer to neoclassical logic. So if the dynamics of an entire industry are to be explained through some singular
variable (e.g., "management failure") rather than by economic categories such as factor endowments, then some very large market "imperfection" must have interfered with competitive equilibrium - or, if you prefer, with natural selection and population adaptation. To put it simply, if something other than macroeconomics - something specific to the industry - was wrong, then one must explain why it was wrong throughout the entire industry, and why the market didn't efficiently select against it. In the semiconductor case, one must for example explain why the U.S. industry often displayed self-destructive behavior despite a history of rapid growth coupled with fierce marketplace competition, conditions which should have provided ample rewards to superior performance and equally severe discipline for failures.

I will therefore discuss some of the anomalies raised by existing models, particularly neoclassical economics, and consider how to account for them. My conclusion is that much of the divergence between neoclassical prediction and actual industry behavior involves different Japanese and American choices in response to a similar set of iterated, i.e. long term, strategic problems. I will describe a set of linked domestic and international strategic processes to which, for fairly straightforward reasons, firms in the two national sectors responded differently. I will further describe how the aggregate effect of individual decisions was to create and cement an entire structural and strategic system which imprisoned its members.

These long run strategic interactions, in combination with the semiconductor industry's high initial costs, increasing returns,
unpredictability, and the presence of potential or actual government policies affecting strategic incentives, account for the evolution of both domestic and international structure, conduct, and performance. Similar considerations suggest how many industries, and most strikingly high technology industries, might frequently depart from textbook competition.

Furthermore, such analyses of strategic forces, and the factors affecting strategic choice, also provide a natural way of explaining divergent national industry trajectories. They also strongly imply that major, sector-specific government policy interventions can be critical to sectoral performance. But, in contrast to neoclassical economic models which restrict potentially beneficial government actions to public goods provision, in strategically dense systems policy interventions can promote success as well as failure. Far from being inherently disadvantageous sources of market distortions, policies with appropriate effects upon time horizons and strategic incentives might, at least in principle, produce benefits which more than compensate for handicaps in traditional assets such as capital. Conversely, inappropriate interventions with counterproductive incentive effects might worsen industrywide performance far more than a strictly neoclassical analysis would predict.

In game-theoretic terms, this amounts very roughly to saying that the long run aggregate difference in payoffs between optimal and suboptimal strategic outcomes is large relative to the effect of factor inputs upon payoff size. Or to put it another way, ensuring productive patterns of cooperation is far more useful than simply throwing resources around, while
conversely distributional conflict can easily nullify large initial advantages in wealth or factor costs. Theoretical models based upon such effects might, therefore, shed light upon such questions as the efficiency benefits of organizations and the reasons that some poor nations with interventionist governments grow rapidly while others do not.

The strategic argument summarized

Now, consider a restatement of the issue posed by the semiconductor industry case and the manner in which the strategic analysis will address it. We want to understand the Japanese and American industries' counter-conventional structural, behavioral, and efficiency differences; the rigidities which apparently prevented the U.S. industry from responding appropriately both to the implications of VLSI and to Japanese competition; and finally, the rapidity of U.S. decline. The explanation will rely upon a set of linked strategic problems faced by both sectors domestically, and another set of strategic choices faced in international competition.

First, I will argue that domestic interactions, which proceeded independently in the two sectors for several decades, led to the formation of characteristic national regimes. Owing to their differing nature and to the protectionist support of the Japanese government, the choice to initiate international interactions was nearly entirely Japan's. Once initiated, these international strategic processes proceeded on favorable terms as a result, again, of nationally specific conditions.
The rigidity of the U.S. regime derived from essentially three sources. The first, ironically, was its having a structure and degree of market fluidity which, on a neoclassical interpretation, would maximize its adaptiveness. This fragmentation and its strategic concomitants implied that many forms of corrective action had public goods characteristics; therefore any firm undertaking them would, at least for some period, be helping its competitors as much as itself. No potentially dominant "arena-maker" existed who could appropriate enough private benefits to have rational incentives for socially optimal investments. Secondly, the various strategic decisions faced by actors were strongly interdependent. This raised the initial cost of changing behavior, forcing strategic action to march in lockstep. And third, there also existed traditional economic increasing returns and switching costs associated with each strategic path. Thus the noncooperative fragmentation path led to elaborate, decentralized networks, headhunters, subcontractors, service providers, and a host of complementary internal firm-level choices. Moving to a different strategic regime became more and more expensive as institutional experience and investments accumulated, and as alternative strategic pathways grew further and further apart.

With this hypothesis in mind, let us begin the detailed sectoral analysis by considering neoclassical explanations and their problems.

2. Economic Explanations of the Semiconductor Case

The difficulties associated with neoclassical interpretations of the
semiconductor case involve not only international competitive performance, i.e. explaining why in the 1980s the U.S. industry collapsed, but also industry structure and strategic behavior. In fact, the neoclassical hypotheses which would most naturally be invoked to explain the industry's structure and behavioral characteristics would be largely inconsistent with those necessary to explain the course of its international and competitive performance. Let me begin, therefore, by considering structural characteristics, both as they are in fact and as neoclassical analysis views them.

Industry Structure

The neoclassical analysis of industrial market structure, whether as summarized in Scherer's standard text or as extended in more recent "strategic" neoclassical treatments, generally considers variables such as levels of entry and exit, cost structures such as scale and learning effects, industry concentration, oligopolistic interactions in output levels and pricing, product market segmentation, and occasionally the impact of R&D, innovation, or technological progress. The majority of neoclassical analysis is devoted to the relationship between costs, industry concentration, and product market behavior (largely output and price levels). Occasionally diversification, multinational operations, network externalities, and vertical integration are now considered as well. Not all structural issues, however, have received substantial treatment. The presence or absence of markets, the boundaries of firms, and the prevalence of external purchases and open market sales (versus purely captive
production of intermediates) by vertically integrated firms, are rarely considered; similarly for the degree of (horizontal and/or vertical) technical cooperation among firms; and possible interactions between multiple, concurrent technological and structural forces receive less attention still.

So a number of important issues in industrial structure have simply been neglected by neoclassical analysis. For present purposes, the most important of these is probably the extent of "procompetitive" technical cooperation among firms, either between suppliers and users or among competitors. A second, related issue is whether vertically integrated competitors will trade in intermediates, versus producing only for their internal use. Both issues are of major importance to the semiconductor industry, and in both Japanese practice differs from American.

But in addition, the semiconductor industry contradicts neoclassical models even in well explored areas such as horizontal industry structure and levels of entry and exit. There are large-scale, persistent differences between the structure of the U.S. and Japanese national industries which cannot be readily accounted for in neoclassical terms. Very broadly speaking, neoclassical models imply that national industries producing similar products with similar technologies, and competing in similar or globally integrated markets, should display roughly similar structural characteristics.

These models also generally imply that structure follows technology:
that industry structure will, for example, become more or less concentrated as scale economies and entry costs increase or decrease. National divergences could arise if, for example, one nation has very different factor endowments, or possesses more cumulative experience, or holds technical leadership while the other is a follower. However, these various caveats do not apply in the semiconductor case, as I will shortly indicate. In fact, the most natural neoclassical explanations of these national structural differences present the additional difficulty that they have additional implications for strategic behaviors and/or performance opposite to those we actually observe.

We can begin by considering the following broad summary of the structural characteristics of the Japanese and U.S. industries in the 1970s and early 1980s, as described in the previous chapter:

<table>
<thead>
<tr>
<th>Variable</th>
<th>U.S.</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal concentration</td>
<td>Medium, declining</td>
<td>High, increasing</td>
</tr>
<tr>
<td>Stability of firm market share</td>
<td>Medium to low</td>
<td>Very high</td>
</tr>
<tr>
<td>Major new entrants</td>
<td>Several annually</td>
<td>Zero</td>
</tr>
<tr>
<td>Entry by new ventures</td>
<td>5 - 30 annually</td>
<td>Zero</td>
</tr>
<tr>
<td>Exit by major firms</td>
<td>Frequent</td>
<td>Zero</td>
</tr>
<tr>
<td>Diversification of firms</td>
<td>Medium to low</td>
<td>Very high</td>
</tr>
<tr>
<td>Size of principal open market producers</td>
<td>$0.1B - $5B</td>
<td>$5B - $30B</td>
</tr>
<tr>
<td>Semiconductor % of firm revenue</td>
<td>35% - 100%</td>
<td>10% - 25%</td>
</tr>
<tr>
<td>Large captive producers</td>
<td>2 - 5</td>
<td>Zero</td>
</tr>
<tr>
<td>Major domestic vertical equity linkages</td>
<td>1 (Intel/IBM)</td>
<td>All firms</td>
</tr>
<tr>
<td>Major foreign owned producers</td>
<td>3 - 8</td>
<td>Possibly 1 (TI)</td>
</tr>
<tr>
<td>Mergers and acquisitions</td>
<td>Common</td>
<td>Extremely rare</td>
</tr>
<tr>
<td>Vertical integration of firms</td>
<td>Low</td>
<td>Very high</td>
</tr>
<tr>
<td>Open market producers' share of domestic consumption</td>
<td>5 - 10%</td>
<td>50 - 80%</td>
</tr>
<tr>
<td>Open market producers' share of domestic downstream markets</td>
<td>5 - 10%</td>
<td>50 - 80%</td>
</tr>
<tr>
<td>Offshore assembly (% of total)</td>
<td>80%</td>
<td>10%</td>
</tr>
<tr>
<td>Personnel mobility</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>individual discretion</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>corporate discretion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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As also indicated in the previous chapter, a similar set of structural observations can be made with respect to the two national capital equipment industries. Thus the broad picture is of two very different national industry structures. One, the Japanese, is a fixed, closed, and purely domestic structure with little entry or exit, and dominated by a handful of very large, diversified, vertically integrated, stable industrial complexes, all of which produce semiconductors internally for themselves, for sale to each other, and for the general market. The other, the American industry, is a vastly more fluid, permeable, fragmented and pluralistic structure dominated, particularly in open market production, by relatively small, narrowly focused, independent, and unstable firms with arms' length marketplace relationships to their sources of capital, suppliers, competitors, customers, and even employees.

This picture suggests at least three questions. The first is why the Japanese and U.S. industries had such dissimilar structures for at least a decade before the advent of VLSI and the onset of global competition. The second is why the U.S. industry's structure remained the same in the face of dramatic technological changes which, as the prior chapter indicated, greatly increased the importance of structural rationalization, scale, capital intensity, mass manufacturing skill, organizational stability, and vertical technical coordination. The third question is how this structural picture correlates with the U.S. and Japanese industries' other attributes, in particular their strategic behavior and relative competitive performance.
It is exceedingly difficult to account for the two industries' structural differences in neoclassical terms, except as economically optimal responses to noneconomic market distortions, such as might (on neoclassical views) be induced by government policy. The properly neoclassical mechanisms, such as differences in national asset endowments or traditional forms of strategic behavior, simply do not fit well. For example, one neoclassical argument holds that U.S. possession of an extremely advanced R&D labor force versus Japanese emphasis upon mass engineering education might affect the optimal choice of technique or market niche by the two industries; or, the Japanese industry's status as a latecomer and imitator might affect its structure. Such differences might, for example, lead to Japan's emphasizing imitative manufacturing over product R&D, by inference generating a more concentrated horizontal structure. But that hardly accounts for the absence from the Japanese scene of new entrants, mergers, acquisitions, foreign owned firms, imports, or personnel mobility; nor for the vertical integration and diversification of Japanese producers. Furthermore, for most of the industry's history, the merchant industry's manufacturing labor costs were actually lower than Japan's, because nearly half of the U.S. merchant industry's worldwide labor force consisted of low-wage offshore assembly personnel (Indonesian, Filipino, Malaysian), whereas the Japanese industry used domestic labor.

Another possibility which would explain a somewhat higher fraction of the Japanese industry's structural profile would be that the Japanese sector had somehow evolved a cartel with impressive stability characteristics. And indeed the cartel hypothesis is paradoxically closest, among traditional
economic explanations, to the alternative model I will propose - the
evolution of a stable strategic regime with both cooperative and competitive
elements. But the paradox is that the traditional version of the cartel
hypothesis fails completely. First, it still cannot account for certain
aspects of the Japanese structure, e.g. the similar structure of all the
major producers or the absence of personnel mobility or offshore production.
But more importantly, in neoclassical models the structural cartel
hypothesis has strong implications for conduct and performance; and the
Japanese industry did not behave like a neoclassical cartel.

Successful neoclassical cartels ration output, maximize joint profits,
and tend to stagnate. The Japanese semiconductor industry certainly
displayed strategic coordination, but its coordination did not prevent (and
probably even contributed to) intense intramural competition in product
markets, rapid technical progress, rapid response to change, and a strong
preference for investment and growth over profits. And, to anticipate
slightly, the competitive performance of the Japanese industry is precisely
the inverse of that expected of a cartel.

Neoclassical models also hold that cartels tend to be unstable,
particuarily where technical barriers to entry are modest, where the
rapidity and unpredictability of technological change continuously
destabilizes existing arrangements, and where there exist formidable
external challengers, so that in the long run the market wins and the cartel
disintegrates. In this case, however, there existed a noncartellized U.S.
industry which controlled 60% of the world market and which for decades held
world technical leadership. Until the appearance of VLSI, both technology and U.S. behavior indicated that purely technical barriers to entry were minimal. Yet the Japanese industry's structure remained essentially unchanged for decades. Even if the original source of this structure was the formation of a traditional cartel, how could this cartel establish and perpetuate itself? Government protectionism and intervention (in both the financial sector and the real economy) is the best candidate answer.

Within the neoclassical context, then, we are left with explanations of Japanese / U.S. structural divergence which rely upon the economic consequences of political interventions in the industry. And while government interventions certainly played a major role in the genesis of the two national structures, we shall see that here, too, straightforward neoclassical interpretations cannot be sustained. The interventions were certainly massive, but they frequently did not have the structural, behavioral, or performance consequences neoclassical theory would expect of them. Moreover as government interventions became less important over time, even in Japan but particularly in the United States, the divergence between the two national industries if anything increased.

To be sure, U.S. government actions favored structural fragmentation, while those of Japan did not. In the U.S., antitrust pressure directly created one captive producer (AT&T), possibly influenced the behavior of another (IBM), and indirectly subsidized the formation of new producers by eliminating AT&T's competition and patent advantages in 1956. Department of Defense purchasing subsidized the early merchant industry, while DOD second
sourcing requirements also tended to increase the industry's fragmentation. Tax expenditures such as loss carryforwards, the R&D tax credit, and favorable treatment of both stock options and capital gains also subsidized startup firms dependent upon venture capital finance. Conversely in Japan, the government protected the domestic industry from foreign competition, restricted imports, strictly regulated the financial markets, and differentially assisted a relatively small number of favored firms, for example through NTT R&D efforts, government procurement, and MITI subsidies of cooperative R&D.

In general, therefore, government activity did act to produce a more fragmented U.S. industry and a more concentrated Japanese one. Yet once again, these interventions do not seem to account for several of the most persistent, massive, and basic divergences of national structure, for example the extreme instability of merchant firms' market shares and the absence of vertical integration within the U.S. Furthermore, neoclassical analysis would predict that political interventions such as massive Japanese protectionism and entry restrictions would lessen competitive discipline, cause allocative distortions, generate rent harvesting, reduce incentives to expand internationally, and reduce the Japanese industry's efficiency. Thus the political explanation for structural divergence, while probably correct, would predict competitive outcomes different than those we have observed.

Perhaps most striking, however, is the failure of the U.S. industry to rationalize itself in response to the advent of VLSI. By the late 1970s the U.S. industry's persistent fragmentation required more explanation, from the
vantage point of economic rationality, than the Japanese industry's concentration and vertical integration. Supposing that the earlier discussion of the technology and economics of VLSI microelectronics was roughly accurate, the U.S. industry's continuation of its prior structural pattern for the subsequent decade is exceedingly puzzling from the point of view of either a neoclassical or population ecology analysis. It would appear to imply not only that the managements of U.S. firms failed to appreciate the industry's trends, but also that market processes failed to reward and punish appropriately.

Rather than ask what mechanisms prevented entry, exit, and so forth, we must therefore ask what in the United States prevented the concentration and vertical linkages implied by optimal technical practice. This is all the more anomalous given that American firms were disciplined by entry, by markets for personnel, and by foreign competition as well as by competition from existing domestic producers, whereas Japanese firms were disciplined only by each other. Hence U.S. firms should have faced strong incentives to invest appropriately, and they should also have understood the nature of the new technology. Since until the 1980s American universities and R&D organizations dominated advanced research. U.S. firms held 90% of the world capital equipment market, 60% of the world semiconductor market, and over half of world markets for the relevant semiconductor-intensive systems products, U.S. firms should collectively have possessed the information and resources to make any necessary structural changes prospectively and well in advance of the Japanese industry.
In addition American merchants were subject to a market for corporate control, and were available for acquisition by foreign as well as domestic firms, whereas Japanese firms were exposed to neither possibility. And conversely, for precisely the same reasons American firms therefore possessed far more flexibility in allocating their assets, at least in the senses considered by neoclassical theory. They could hire and fire personnel, both experienced and inexperienced, with relative ease; they could merge with, purchase, and/or divest other companies and business units; they could invest abroad and employ offshore labor, even short term subcontractors, where it was appropriate to do so. They could always purchase materials, components, consulting services, and capital equipment from whoever had the best at the time, rather than using suppliers because they were internal or associated with a parent industrial group; they could also create or purchase a supplier if that were the optimal course. Yet, for the most part, the American industry failed to evolve a more mature structure. It remained unstable and both vertically and horizontally fragmented.

These observations, in turn, bring us to the question of how structural conditions relate to the strategic behavior of the U.S. and Japanese industries.

The Two Universes of Japanese and American Strategic Conduct

Japanese semiconductor producers displayed extensive strategic reciprocity and coordination in dealing with inputs, assets, and sectoral
public goods (long term R&D, personnel, capital equipment, government policies, premarket product standardization, generic technology), while competing fiercely in most product markets. U.S. firms, in general, exhibited no substantial reciprocity or coordination in any of these areas. Japanese producers also appear to have adhered with near uniformity to national and/or sectoral strategic norms, such as preference for Japanese rather than American suppliers once domestic products were available. In contrast, U.S. firms frequently relied upon or sold technology to Japanese firms without apparent regard to nationalistic criteria. Similarly, the Japanese industry possessed a closer, more cooperative, and more unified relationship with the national government than did the U.S. industry.

Japanese firms exhibited a strong preference for growth relative to profitability. Japanese firms spent a higher fraction of revenue on R&D and capital investment than U.S. firms; they accepted lower profits to gain market share; they rarely abandoned a growth market even if they temporarily lost money in it. U.S. firms behaved in precisely the opposite way. Perhaps relatedly, Japanese firms optimized over longer effective time horizons than U.S. firms, and - not necessarily the same thing - engaged in longer term, more deeply interdependent relationships with their domestic suppliers and customers than did U.S. firms. These long term, stable, vertical domestic Japanese relationships included not only technology and products but also personnel transfers and the supply of capital - frequently through banks, other financial institutions, and other industrial firms in a larger industrial group.
Japanese firms offered and required lifetime employment commitments, depending upon the strategic reciprocity of other domestic firms to enforce them and to permit them to hold down wage costs. Conversely only the larger, more stable U.S. merchant firms offered any employment security at all, and even the largest resorted to large layoffs in recessions. Labor moved fluidly, resulting in U.S. turnover rates five times higher than Japanese, and leading U.S. firms to offer financial incentives - salary increases, stock options - in order to reduce turnover and retain valuable employees.

Altogether, then, the two national industries' strategic behaviors were as strikingly, and systematically, different as their structural profiles. Japanese firms optimized over long time horizons, emphasized growth, and behaved nationalistically while still competing intensely with each other; American firms optimized over short time horizons, emphasized current profitability, and behaved individualistically, generally without regard to national or sectoral goals. To what extent can neoclassical analysis account for this strategic divergence, for its national specificity, and for its correspondence with the national structural divergence described above?

Two neoclassical mechanisms - one associated with newer "strategic" models, the other quite traditional - initially seem to explain at least some aspects of the two industries' strategic behavior, most particularly the higher levels of investment within Japan versus the emphasis upon profitability within the U.S. sector. However, we shall see that even with respect to this behavioral variable, the neoclassical explanation is
incomplete; and other behavioral differences remain entirely unexplained.

The strategic mechanism concerns dynamic scale economies, a.k.a. learning effects. If the Japanese industry was nationally protected and structurally concentrated, each firm within it would appropriate a greater fraction of experience benefits than would be the case within the more fragmented American industry. The result might be a relatively greater Japanese emphasis upon increasing production a way of increasing experience, which would in turn lead to increased competitive advantage in future generations of production.

This behavioral result, however, is not altogether determinate. Indeed, more traditional neoclassical models would predict that a concentrated, protected, partially coordinated industry would be far more likely to harvest rents and to adhere to short term profitability criteria than a less concentrated, unprotected, non-coordinated, highly entrepreneurial sector. Furthermore, the technical desirability of obtaining dynamic scale economies presumably applied to U.S. firms as much as to Japanese firms. Therefore, the higher degree to which the Japanese industry sought them would seem to imply that the Japanese industry had a lower discount rate than the merchants.

This appears, in fact, to have been the case, and this issue brings us to the other, more traditional, neoclassical mechanism alluded to earlier: factor costs. Although there is some dispute as to the statistical evidence, it appears that the Japanese industry has benefited from capital
and skilled labor costs substantially lower than those paid by the U.S. industry. In an industrial sector in which competitive success and growth require incurring high initial and/or fixed costs (for R&D, design, capital investment), higher factor costs in areas pertinent to these activities translate into slower growth, less investment, and shorter time horizons, for example a preference for short term investments with immediate payback.2

National factor cost differentials (for both capital and professional labor) do seem to have played a substantial role in shaping the U.S. industry's behavior and competitiveness. For decades prior to the recent rise of the yen and of Japanese living standards, American salaries for professionals and managers were far higher than those prevailing in Japan. In part this fact reflected economywide differentials in living standards and income distribution; but it also, perhaps, reflected the nature and size of the two nations' investments in engineering education. In part, American salaries were high because appropriately trained personnel were relatively scarcer. Consider the following data:

<table>
<thead>
<tr>
<th>Year</th>
<th>United States</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>16,282</td>
<td>11,848</td>
</tr>
<tr>
<td>1974</td>
<td>15,749</td>
<td>17,419</td>
</tr>
<tr>
<td>1979</td>
<td>16,093</td>
<td>21,435</td>
</tr>
</tbody>
</table>

Roughly similar trends hold for other engineering disciplines as well. By 1978, all engineering graduates (all fields and at all degree levels) represented 4.2% of their age group in Japan, versus 1.6% in the United States.3 And while the strict comparability of the absolute numbers is doubtful because educational standards differ, the trend is not. Since professional wages typically account for half of a semiconductor company's
costs, such a differential in supply surely imposed some cost penalty upon U.S. firms. And, in fact, professional salaries were until recently far higher, and tended to escalate more rapidly, in the United States than in Japan. For front-end costs with long gestation periods (e.g. high risk R&D), these differences could be a substantial fraction of life cycle costs, particularly for any actor with a high discount rate. And many professional wage costs are indeed incurred as such initial and/or fixed costs which can be recovered only in the long run, so this cost penalty shortened U.S. firms' effective time horizons. Several studies have indicated that capital costs faced by U.S. firms generally, and by U.S. semiconductor producers in particular, were substantially higher as well. The Chase Econometrics study for the Semiconductor Industry Association, for example, concluded that capital costs for U.S. merchant semiconductor producers were nearly double those faced by the Japanese industry. Since the semiconductor industry has become dramatically more dependent upon initial engineering costs and far more capital intensive since the mid-1970s, such capital cost differentials presumably shortened the U.S. industry's time horizons and shifted its investment strategies, at least relative to Japanese behavior, even if the two industries were structurally identical. The expected effect would be to shift U.S. investment towards marginal expenditures yielding secure short term profits rather than aggressive, high initial cost, and/or long payback investments.

But acceptance of this neoclassical mechanism as an explanation for the industry's actual behavior generates further questions, and in some respects makes the two industries' structural and strategic characteristics (and
differences) much more puzzling than before. In particular, the negative
effect of factor cost differences upon the U.S. semiconductor industry's
investment levels and resultant international competitiveness appears to
have been increased by the industry's own behavior. If professional labor
was scarce as a result of the failure of government policy and the
educational system to provide sufficient numbers of engineers, the U.S.
industry should presumably have responded with extensive internal training
programs (more extensive than in Japan), use of Japanese engineering labor,
and/or structural change in favor of large, stable firms. The Japanese
industry and large U.S. firms such as DEC and IBM have invested in human
capital, investments which in the author's experience produce a substantial
fraction of these firms' technical labor forces. Conversely, the merchant
semiconductor industry has invested far less in its workforce and
organizational systems than either large U.S. firms or the Japanese
industry; merchants rarely even permitted employees to take unpaid
educational leave. Similarly, DEC's stock options vest over a ten year
period, while the norm in the merchant industry is four years.

Similarly if capital intensity, capital costs, and the appropriation of
dynamic scale economies were growing in importance, the U.S. industry would
rationally have become if anything more coordinated, vertically integrated,
and concentrated than the Japanese. Just as high energy prices stimulate
conservation efforts, high factor costs should have caused rationalization
in the U.S. industry. Instead, industry fragmentation and instability
persisted, and probably even increased. This not only resulted in
straightforward scale disadvantages, but further raised the capital costs of
U.S. firms through their obligation to pay risk premiums for funds and to maintain greater relative liquidity to cushion against external shocks such as recessions or exchange rate shifts. In addition, merchant firms' instability and liquidity requirements reduced their ability to invest aggressively in future growth because as capital intensity grew, the potential consequences of mistakes made at efficient scale became unacceptably large.

For example, by 1980 an efficient-scale semiconductor factory cost well over $100 million, and efficient production demanded both considerable organizational sophistication and vertical technical coordination, particularly for capital equipment and computer systems expertise. By some estimates, minimum efficient plant scale has now escalated to $200 million or more. If X-ray lithography behaves as anticipated, its commercial use could raise plant level MES to $400 million by the mid-1990s. Similar forces have transformed capital equipment and materials technologies. Yet U.S. venture capital financed startup creation actually accelerated in the early 1980s in both the semiconductor and equipment industries, and sectoral rationalization is coming only through competitive crisis and decline, rather than through foresighted strategic decisions. While the Japanese industry's concentration and stability increased in the late 1970s and early 1980s, that of the U.S. industry actually decreased. Steinmueller's estimates, from ICE Corp. data, are that between 1978 and 1984, the five-firm concentration ratio of Japanese domestic integrated circuit production increased from 65% to 76%, and the ten-firm ratio increased from 86% to 96%.
In contrast, the U.S. ratios appear to have stayed roughly constant or even declined slightly, and the U.S. industry remained far less concentrated than Japan's. Steinmueller's estimate for the 1984 U.S. five-firm ratio is 58% including IBM's captive production, but only 47% for the merchant industry alone. Commerce Department estimates of U.S. concentration, using somewhat different definitions, arrive at similar concentration estimates and also conclude that the U.S. merchant four-firm and eight-firm concentration ratios declined about 5% in the 1980s. And Japanese firms continued to form R&D collaborations, while the U.S. industry continued to shun them.

Hence the persistent instability and fragmentation of the U.S. system, in contrast with the integration and concentration of the Japanese system, becomes even more mysterious if one accepts the importance of factor cost differentials. Even if one accepts dynamic scale effects and factor price differences as important, they cannot by themselves explain the primary anomalies of the two national industries' behavior. They do not explain the persistence of U.S. fragmentation after the advent of VLSI, or the deep structural differences between the two national industries. Neither do such considerations explain the simultaneous, asymmetric combination of Japanese supply-side strategic coordination and American individualistic, narrowly self-interested optimizations. Nor, and here possibly is the heart of the issue, can factor costs, exchange rates, or other neoclassical variables explain the characteristics and remarkable speed of the U.S. industry's decline upon the onset of worldwide competition from Japan.
Competitive Performance

Though in neoclassical analysis "performance" usually refers to allocative market efficiency and the presence or absence of monopoly rents, here I will consider a rather wider set of issues including national market shares, dynamic effects (e.g. rates of technological progress), and technological capabilities both within the semiconductor industry and as delivered to users. By all of the relevant measures, the U.S. has fared very poorly since the late 1970s: its world market share declined by one-third, it suffered huge financial losses, and it ceded technical leadership. To what extent can economic analysis explain this enormous shift in national comparative advantage as measured by world market shares, trade balances, operational efficiency, technological capacities, and ability to deliver technology to users?

In general, economic theory offers four explanations for a national industry's performance in international competition, and/or changes therein. They are: factor costs; differential appropriation of increasing returns; exchange rate shifts; and market distortions which affect allocative efficiency, such as might be induced by government interventions. In the semiconductor case, none of them work.

We have already noted one problem with the factor costs explanation: the more force it has, the more inexplicable the remainder of the American industry's behavior becomes. But there are other problems, as well. The
U.S. industry showed signs of inefficiency and competitive decline at a time when its aggregate R&D, capital spending, and resources still dwarfed Japan's, and prior to the dollar's rise in the early 1980s. Even if U.S. resources cost more, U.S. allocations were so much larger than Japan's that the merchants should have been capable of delivering superior products. As early as 1978, Japanese producers captured 40% of the world market for 16K memories. Furthermore, the difference was not simply a matter of price; Japanese products were judged superior in quality to those of the U.S. merchant industry. At the time, the U.S. held over 90% of the world capital equipment market, also held the majority of the Japanese capital equipment market, and accounted for the vast majority of world semiconductor R&D; U.S. merchant capital spending was more than double Japan's. Even if U.S. factor costs were far higher than Japan's, one cannot account for Japanese firms' success simply by saying they outspent the Americans.

Indeed by the next generation (64K devices first marketed in 1981) Japanese firms led the U.S. industry in product introductions, and Japanese production yields and quality levels were again reported to be higher than those of the U.S. industry. And, as in several other U.S. industries experiencing competitive difficulty, the available evidence suggests that U.S. semiconductor producers consistently operated capital equipment less efficiently than Japanese competitors. In fact, it would appear that factor price effects have weighed more heavily in the mid-1980s than during the period in which the first clear signs of U.S. decline appeared.

For somewhat similar reasons, explanations based upon learning effects
are also dubious, at least as primary rather than secondary forces. Once again, they render the U.S. industry's behavior ever more puzzling; and once again, they do not account for the particulars of U.S. performance. Even with its stability, concentration, and closure, the Japanese industry's cumulative production experience was dwarfed by that of the leading U.S. merchants at the time of Japan's initial successes against them. In the late 1970s, the U.S. domestic market was enormously larger than the protected Japanese domestic market, and U.S. firms held 50% of the European market as well. Moreover, as important as operational efficiency was and remains, the Japanese industry's gains also depended upon large scale issues such as the willingness of U.S. firms to license proprietary designs, close cooperation within the Japanese industry, and the propensity of U.S. consumers to switch rapidly from merchants to Japanese suppliers. Japanese producers frequently obtained large shares of world markets for merchant-designed devices despite the fact that they had been created, and their early production had been monopolized by, U.S. firms. For example, until the early 1980s Intel licensed, and abandoned production of, many devices whose profitability fell below the company's 20% pretax profit target. During this period Intel also explicitly practiced "value" pricing to maximize its current profits rather than its market share.  

Exchange rates have often been cited as major causal forces in declining U.S. competitiveness, in analyses of the semiconductor industry as well as more generally. In principle, exchange rate shifts derived from macroeconomic sources differentially affect the competitiveness of some classes of industries, causing large shifts in world market shares which are
independent of real productivity or efficiency. Unfortunately, exchange rates shifted in precisely the wrong directions to explain the semiconductor industry's behavior. Between 1975 and 1980, the period in which Japanese penetration of U.S. markets began, the yen appreciated against the dollar by nearly one-third; by 1985 it had declined only about 15 percent from its 1980 level. Then, between 1985 and 1987, the yen nearly doubled, while Japan's semiconductor world market share rose slightly and the U.S. semiconductor trade balance continued to deteriorate. Conversely between 1980 and 1985, the dollar nearly doubled against the European currencies — and yet the U.S. semiconductor industry's market share in Europe stayed at roughly 50 percent, versus 9 percent in Japan. Moreover, some of the most important real performance indicators show changes which dwarf exchange rate shifts. Over the last decade, for example, Japanese production of CMOS devices has grown at a compounded annual rate 30 percent higher than U.S. production (growth of over 60 percent annually versus roughly 30 percent).

Finally, we have a fourth possible explanation: distortions induced by cartellization, government intervention, or other forces which reduce the competitive discipline and allocative efficiency of the market. And indeed, Japan employed virtually every practice neoclassical theory considers antithetical to competitive success, while the merchant industry by comparison was a model of competitive market efficiency.

And this, once again, should have produced a stagnant cartel in Japan and a vibrant, successful, competitive industry in the United States. Or, if the Japanese industry "succeeded" in semiconductor markets, neoclassical
analysis would anticipate that this success would simply represent
uneconomic, massive subsidies rather than real competitive superiority. On
this view, semiconductor producers should show enormous inefficiencies and
Japanese semiconductor consumers - i.e. the same firms - would suffer in
downstream markets such as the computer industry. Yet, to state the matter
conservatively, this has not come to pass. The Japanese industry is
technically capable and aggressive, and its success in both semiconductor
markets and semiconductor intensive industries is growing rapidly. The
American industry is in retreat and in danger of permanently losing its
technical competitiveness.

Altogether, then, economic theory fares poorly in explaining this
industry's behavior. The question therefore arises as to how and why the
two national industries actually did diverge structurally, strategically,
and competitively. The answer, I will argue, lies primarily in chronic
strategic dilemmas which were resolved differently in the two nations, i.e.
in national divergences in what I have called "strategic regimes."

3. The Japanese and American Strategic Regimes

The Japanese and U.S. strategic regimes which evolved prior to the
onset of internationalized competition represented opposed solutions to a
similar set of strategic dilemmas. In the following exposition, I will
first briefly review the relevant national structural and environmental
conditions, then describe the strategic choices to which they gave rise, and
finally consider how the sum of these choices constituted strategic regimes
with binding consequences for the semiconductor industry's dynamics. These strategic interactions and national strategic regimes will be described in game theoretic terms - as groups of concurrent, linked, iterated strategic dilemmas between governments, firms, and employees. Two broad classes of strategic dilemmas will be examined: those arising within each of the two nations, and those arising between them. The style of the discussion, and the model guiding it, are in large measure derived from theoretical work by Axelrod, Arthur, and others concerning evolutionary processes driven by iterated nondeterministic (usually strategic) decision problems. (In the following analysis, I will assume considerable familiarity with this work; a summary and review is found in Appendix 1.) However, unlike most of the extant theoretical analyses and computer simulations, the complexity of interactions in this industry (and I suspect in most industries) renders a single iterated strategic dilemma inadequate as an explanatory model. Rather, it proves most useful to consider clusters of related strategic processes, and the aggregate characteristics of the strategic behavior they induce; hence the idea of a strategic regime.

In applying this model to the semiconductor industry, government policies and macroeconomic conditions (particularly factor costs and discount rates) can be regarded as steering or guidance mechanisms which affected the differing strategic choices made in the two nations. Their direct role in conditioning performance (i.e. the role attributed to them in neoclassical analysis) was probably modest, but they tilted agents within the two national industries into different strategic choices; and these choices led to the formation of strategic regimes which did determine
structure and performance outcomes. Two interesting examples of arenas in which initially small forces lead to widely divergent large scale outcomes are found in an article by Brian Arthur and, more recently, in Robert Axelrod's "An Evolutionary Approach to Norms." Arthur demonstrated how increasing returns (such as learning effects) magnified initially small variances and produced divergent end results. All of the endpoints of the process, however, were economically "locked in" by accumulated sunk costs.

Similarly, Axelrod's article exhibited a class of games in which iterated strategic interactions will always reinforce one pattern of behavior to the eventual exclusion of all others, but in which the identity of the favored behavior pattern is neither ex ante determinate nor particularly likely to be optimal. In Axelrod's example, the mechanism which forced eventual strategic conformity involved a metagame which included a propensity to punish not only nonconformists, but even other conformists who had failed to punish nonconformists in prior interactions. (For example, a law might both punish smoking in public AND the failure of any nonsmoker to inflict such punishment.) In single-game arenas, this is not a terribly plausible condition. But we shall see that if an arena involves multiple, concurrent strategic processes, and if choices in some games have implications for choices in others, the same result is produced. Effectively, the system restricts long run viability to a subset of distinct, internally consistent, mutually exclusive classes of strategic choices - feasible strategy sets. Others are internally inconsistent. Among those which are feasible, some may be collectively stable in the face of external challenges, while others may not.
This is essentially the form of the argument I will make below: the forces which governed competitive strategy in the semiconductor industry derived not only from conventional economic signals such as factor costs but also, and perhaps primarily, from strategic interactions in which factor costs and other nationally specific environmental conditions promoted certain strategies over others but did not determine outcomes. Given that firms had to make multiple concurrent choices, and that some of these choices were interconnected, each decision pushed the system towards a certain regime - an internally cooperative, productive one in Japan, a noncooperative inefficient one in the United States. Each was internally stable. This will explain, for example, why technological and competitive signals were insufficient to rationalize the U.S. industry: by the time VLSI arrived, a strategic regime inimical to structural and strategic rationalization was already entrenched. Hence the cost of rationalization was no longer simply the cost of, say, purchasing or constructing the required facilities; it was the cost of reversing the behavior patterns of an entire industry. But while change from within the U.S. industry might have been difficult, its displacement by Japan was not.

Hence the argument begins with the assertion that although the two national systems faced similar strategic choices, a variety of governmental, structural, and macroeconomic conditions facilitated the appearance of differing strategic behaviors in the two nations. These strategic behaviors then spread through their national arenas and led to the evolution of stable, self-replicating strategic regimes. One of them - the Japanese
regime - was at least to a first approximation a "collectively stable regime," analogously to Axelrod's definition of a collectively stable strategy: one which cannot be disrupted by any other, in the sense that its members would continue to outperform the invader. However, the other regime - the American one - was only internally stable: it replicated itself stably only until an external predator assailed it, whereupon its practitioners facilitated each other's demise. The stability characteristics of the system, many of which derived from nationally specific economic and policy conditions, were sufficient to prevent domestic production of more than a few "nonconformists," i.e. practitioners of productive long term cooperation. The U.S. regime was such that any individual U.S. firm seeking to deviate would find itself becoming a public service provider to its domestic competitors.

But a protected, efficient foreign industry was another matter. The American system's fragility derived both from its native inefficiency and from purely strategic features which made it vulnerable to exploitation from outside. In other words, it appears that even product market competition alone from an efficient external competitor would have eventually destroyed the U.S. industry and/or its regime. But the additional pressure generated by the strategic predation which constituted a major element of Japanese competitive strategy both hastened U.S. decline and severely reduced the prospects of internal reforms within the U.S. system.

In both nations, the dominant strategic regime became a major force in the competitive environment faced by firms prior to the onset of
international competition. It exercised great influence over their potential efficiency, bargaining power, and effective time horizons. But Japan's regime improved efficiency, lengthened the time horizons of domestic firms, and increased their bargaining power in international strategic interactions. America's regime had precisely the reverse effect. Because for perhaps two decades the deficiencies of the American regime governed and were shared by all domestic participants, the regime appeared viable, and survived, as long as the American industry faced no foreign competition. But the American industry, and the regime by which it lived, were destined to fail when challenged by a system not hobbled by these strategic deficits.

Japanese and American Arena Structures and Their Strategic Effects

Let us take the description of the Japanese and U.S. systems provided earlier to be roughly accurate. The Japanese system had and has an interventionist, protectionist, developmental government; the U.S. system, an aloof one. The Japanese system is dominated by a handful of diversified industrial complexes, protected even from domestic entry; conversely in the U.S. system antitrust policy, tax expenditures, and industrial fragmentation facilitate and even promote entry. At the macroeconomic level, lower Japanese capital costs and mass engineering education shift Japanese firms towards somewhat more aggressive investment strategies and longer time horizons than American firms would employ, everything else being equal. And so forth. Given the general nature of semiconductor technology and demand, how might these distinct national environments have affected strategic interactions, and how might strategic choices have been made?
In what follows, I will seek to answer this question by describing and analyzing eight iterated strategic dilemmas facing the industry, their relations to each other, and the differing choices made by various U.S. and Japanese actors. Four of these strategic dilemmas are largely internal to national systems, while another four are international strategic dilemmas in which Japanese and American actors (governments and firms) confront each other. In somewhat simplistic but broadly accurate terms, each situation involves a choice between cooperation and adversarial behavior, though some interactions permit intermediate choices. All have significant implications for the efficiency and welfare of individual actors and the wider arena. Some are Prisoner's Dilemmas; others are closer to the games of "Stag Hunt," "Chicken," or "Bully."  

These other games, like Prisoner's Dilemma, all make adversarial behavior tempting in the short term, but under different conditions. Stag Hunt strongly favors cooperation unless distrust or information problems make defection by another likely. Chicken is just that, and in iterated versions it is highly unstable because each player has a strong incentive to prove his/her willpower and determination, even to the point of irrationality. But with slight changes in payoff structure - one player faces Chicken while the other defects all the time - the result is Bully. Note that the madman theory, and extreme theories of deterrence, consist in one player's seeking to convince an opponent that he/she can or will outlast the other. If one player really has more short term resilience than the other, in a long term game this can be highly attractive. For example, it
is an excellent rationale for dumping or other forms of unsustainable price competition.

In each case described below, one of these games is involved. And in each case, national systems and the positions of actors within them will be shown to condition their choices of strategy, and these strategic choices will be shown to react back upon the larger industry's structure, conduct, and competitive performance. The systemic factors to which I will ascribe causal roles in conditioning choices of cooperative versus adversarial strategies adhere very closely to those elucidated by the theoretical literature: payoff structures; concentration of the arena (or "number of players," as Oye puts it); time horizons; and the distribution of information and communication regarding others' behavior. Equally important, I will argue that in this case the various individual strategic interactions under discussion are heavily interdependent; each strategic choice in one process affects decisionmaking in the other interactions. The result will be the coalescence of clusters of mutually reinforcing strategic choices which cumulatively generate an entire, binding strategic environment within an industry: its strategic regime.

Strategic Actors in Semiconductor Industry Arenas

At the most general level, there are only three classes of actors in each nation: the national government, domestic firms, and employees. (Occasionally in the American context it may prove useful to distinguish another class, investor / executives, as having interests distinct from
those of either firms or employees.) In the Japanese arena we can for the most part regard all of the principal firms as diversified, vertically integrated oligopolists with, in game theoretic terms, essentially identical payoff matrices in all pertinent interactions.

In contrast, it will prove necessary to distinguish several different categories of U.S. firms. First, the industry is vertically divided into users and/or captive producers (systems firms), semiconductor vendors (merchants), and suppliers (capital equipment firms). Second, it will also prove necessary to distinguish core established firms (IBM, DEC, etc.) from new startups (MIPS, LSI Logic); and finally, it will be useful to distinguish strong firms from weak ones. There are intermediate cases: the larger merchants are intermediate between startups and core firms, and also probably between strong and weak firms. Most or all U.S. startups can be regarded as weak firms for the purposes of considering their strategic interests, while all major Japanese firms can be regarded as strong. The differing payoff structures facing different classes of firms, together with the fragmentation of the U.S. system, will turn out to have a major effect upon strategic dynamics.

The Domestic (or Internal) Interactions

The four "domestic" strategic dilemmas are as follows:

1. Government - Industry: the industrial social contract game. In this game, a government either provides strategic bargaining services,
protectionism, and sectoral public goods to an industry or a firm within it (Cooperation) or fails to provide such goods (Defection). A domestic industry or a firm within such an industry, conversely, either optimizes its domestic investment growth and technological progress (Cooperation) or it uses whatever market power it possesses to harvest rents and stagnate (Defection). Note that if either the industry is growing or monopoly power cannot last forever, the industry's decision will be conditioned by its effective time horizon - or, as Axelrod and Oye put it, by the length of "the shadow of the future."

Consider now how this game was played in the two nations. For reasons beyond the scope of the present analysis, Japan appears to have consistently played Tit-For-Tat (TFT), or Reciprocity, throughout the postwar period. With some exceptions, the Japanese industry did so as well, with the result that a relatively consistent pattern of government - business cooperation emerged. The Japanese industry's strategic choice was facilitated by the structure of the iterated game and by the Japanese economic environment. Because the government played Cooperation whenever the industry did, and furthermore did so by means which reduced players' discount rates (e.g. providing public goods and making low-cost capital easy to obtain), long time horizons and major investments became favored relative to static rent extraction as the preferred strategies of a coordinated industry. Moreover, the government was powerful and was certainly not going to disappear; hence the shadow of the future cast by future rounds of interaction was maximally long. The cooperative strategy in the government's side of the social contract, furthermore, included consistently playing Defection in the
international game of strategic trade behavior, i.e. pursuing a highly strategic international economic policy. So long as trading partners such as the United States did not respond, the result was substantial opportunities for export growth. Hence the favored, though not determinate, result of this interaction was a pattern of reciprocal cooperation in which the Japanese industry used its internal strategic relationships to promote growth and external predation.

By contrast, in the American case the government's strategy, once again for reasons beyond the scope of the present work, might be whimsically but rather accurately described as Random, perhaps biased towards Defection. This is particularly true of the past decade, when U.S. competitive difficulties have been noticeable and increasingly acute. In areas ranging from the strategic trade policy game to antitrust reform to intellectual property protection to engineering education to monetary policy, the U.S. government failed to provide a consistent flow of strategic and/or infrastructural benefits to the relevant U.S. industries. Moreover, it has appeared that the government's "strategy" was nearly independent of the industry's behavior. It is worth noting, however, that to some extent the government's inattention derived from other dysfunctional strategic behaviors within the industry itself. Because the industry's fragmentation and short time horizons biased it against industrywide interest aggregation, collective action, and long term planning, the merchant industry in particular made no attempt to educate the U.S. government (or even itself) as to the nature of Japanese strategy and the threat it posed.
Therefore, as a result of the U.S. government's failure to act as a strategic agent, the U.S. industry's strategic choices (in regard to promoting long run national productivity versus short term, individualistic rent taking) were disciplined only by other elements of its strategic environment, not by the provision of any governmental assistance or punishment. And the other elements of the strategic environment were not favorable to optimal efficiency, collective action, or long run growth strategies, as we shall now see.

2. Industry One - Industry Two: the vertical cooperation game. In this game, an industry or a firm within it either commits itself to substantial relationships such as technological codevelopment with its suppliers and/or customers (Cooperation), or declines such cooperation and betrays its business partners whenever a superior short term opportunity arises (Defection). Here, moreover, there is a related but somewhat distinct game which we might call National Verticalism: a firm or industry can either commit to using domestic vertical partners (Cooperation) or can switch at will to foreign vertical partners (Defection). Presumably, reciprocated cooperation brings substantial long run productivity benefits through information sharing, coordination of complementary activities, rationalization of investments, and so forth. Some of these benefits are purely bilateral, while others (such as technology transfer to an open market supplier) generally create positive externalities. In this case, the pattern of strategic choice also determines the degree to which externalities are generated, and also their national and sectoral distribution.
On the other hand, opportunities for defection can be very attractive over the short run. Note, for example, that as defined here it would be a Defection for a firm to switch to a foreign supplier. In turn, Industry Two faces the same strategic dilemma.

Consider now how the Japanese industry faced this dilemma. First, the vertical integration of the Japanese industry implied that in many cases vertical interactions were contained within the same firm; in this case, following Williamson, we can agree that no bilateral bargaining problem exists. In many other cases, the same structure of diversified, marketized vertical integration implies that domestic vertical interactions occur between different units of competing firms, say between Hitachi's materials producing subsidiary and Toshiba's semiconductor operations, and vice versa. In this case, even though the relationship is vertical rather than horizontal in the strict sense, the strategic problem is exactly the same as that involving potential cooperation between two competitors. In the Japanese industry, strategic conditions favor at least a moderately cooperative solution. There are few players, because the industry is concentrated; there is little or no new entry, so failed relationships cannot be easily escaped; the government sometimes uses coercion to ensure technical cooperation among competitors; failure to cooperate could result in reciprocal action by the other business units of the competitor.

Since these firms are large and stable, the shadow of the future is once again long. Moreover, in rapidly growing industries in which a high
fraction of incremental sales are either captive or come at the expense of foreign competitors, even the direct cost of assisting a competitor in a generic supply technology (e.g. capital equipment) is not likely to be high. Even if such vertical agreements resulted in technology "leakage" to other domestic competitors and therefore to some extent constituted sectorwide public goods provision, this revenue structure plus the concentration of the Japanese arena implied that, at least following Mancur Olson's classic analysis of the problem, significant individual returns would accrue to the provider. Therefore although strategic indeterminacy still existed, it was attenuated, more closely approximating a game of Stag Hunt than an extremely sharp and painful Prisoner's Dilemma.

Hence in the Japanese arena the favored though not determinate result of this iterated game would logically be TFT, and hence a stable history of mutual long term vertical cooperation, even to the extent of sectoral public goods provision, at least up to the extent they made economic sense for the Japanese sector as a whole. Since the economics and technology of VLSI imply that such vertical coordination is in fact extremely important, this result was presumably of substantial benefit; and, in fact, we observe essentially this behavior within the Japanese industry.

Now consider the American industry's strategic problem. In the American case it will be necessary to distinguish relatively stable oligopolists (IBM, Perkin-Elmer and Teradyne in equipment, possibly in some cases the largest merchants) from unstable minor firms and entrepreneurial startups. Stable firms faced some of the same incentives to vertical
cooperation which characterized the Japanese arena, and in fact such firms cooperated far more than any others within the American system. (We have already noted, for example, that IBM has a substantial history of long term cooperation with Perkin-Elmer, Teradyne, and Intel.) Stable firms cooperating with each other could, once again, appropriate substantial gains even if they were effectively providing public goods; and their stability implied that the shadow of the future was long. However, in the U.S. arena such decisions regarding vertical cooperation versus defection, even among the stablest firms, had less echo in the strategic decisions of other firms, because of the vertical disaggregation and fragmentation of the arena generally. So IBM collaborating with Teradyne had no interdependence with any potential collaboration between an IBM capital equipment production organization and another systems firm, whereas in Japan cooperating with Advantest would really, in significant measure, be cooperating with Fujitsu. Similarly, the benefits of public goods were more widely dispersed; even IBM is only about 10% of U.S. capital equipment consumption. Therefore there existed less gain for individual providers, less pressure for reciprocity in the U.S. system, and consequently weaker incentives for cooperation even among the largest, stablest firms.

Probably more importantly, however, there were strong incentives for defection, or more precisely for avoidance of long term cooperation, in the rest of the system. First, all the smaller players were arena takers, which shifted them towards "free rider" (Defection) positions in dilemmas involving sectoral public goods provision. Nor did there exist any central authority such as MITI capable of punishing a firm's failure to contribute
to such public goods. Second, the possibilities of proprietary vertical cooperation were limited by personnel turnover, including defections to startups, and by the instability of existing firms.

Third, the financial fragility of small firms reduced their effective time horizons, at least with respect to investments with high initial costs and long paybacks. Therefore cooperation requiring such investments was disfavored even in a straightforward economic way, independent of strategic interactions; but there was a strategic effect as well. If for whatever reason (financial condition or otherwise) a firm's time horizon is short, the shadow of the future is less long and the propensity to play Defection is increased. This had an effect both upon firms insecure about their own futures and upon those observing difficulties in their vertical partners. Hence, for example, small Silicon Valley firms often abrogated technical agreements in mid-course. Since both participants were small portions of their markets, retaliatory punishment was infeasible and defections therefore went undisciplined.

This behavior was analogous to a pattern Axelrod noted in connection with failing commercial firms: "...once a manufacturer begins to go under, even his best customers begin refusing payment for merchandise, claiming defects in quality, failure to meet specifications, tardy delivery, or what have you. The great enforcer of morality in commerce is the continuing relationship, the belief that one will have to do business again with this customer, or this supplier..."14 In the U.S. industry, this enforced or expected continuity was diminished not only by failure but also by the
continuous stream of new venture backed entrants, whose product technologies were often competitive with those of established firms for several years. This continuous entry reduced pressures to reach accommodations with existing firms. Hence the favored strategic result among small firms and startups was to defect as soon as payoff structure made defection attractive even in a single period of interaction, because the expected force of subsequent bilateral interactions was small. This mechanism would also lead to defection even by large stable firms when dealing with small, unstable ones; and indeed the industry's history includes many episodes in which large firms turned upon their small partners.

The result of these interactions was the evolution of a strategic norm of pervasive distrust and defection, once this pattern became both widespread and explicitly recognized by participants. This pattern, it should be emphasized, not only reduced access to the technical benefits of coordination but also reduced firms' effective time horizons yet further, because they could not trust any dependence upon the nature or membership of future arenas, much less upon reciprocity. This not only had behavioral consequences, but structural and performance implications as well. First, it fostered the widespread development of captive semiconductor production, which might be defined as the production of anything requiring vertical trust and technical coordination. But, of course, few downstream firms could produce the desired number of such products at efficient scale even in the case of semiconductors, and certainly not in the case of capital equipment, materials, and so forth. Consequently many of the returns to long term vertical coordination and reciprocal sectorwide public goods
provision were lost, and U.S. performance chronically suffered accordingly.

This performance effect is difficult to measure, but the evidence suggests that it is substantial. Consider, for example, how vertical noncooperation between merchants and consumers interacts with backlog and purchasing management to the disadvantage of both. Merchants are secretive about their backlogs, while consumers are secretive about their purchasing, but each needs the other's information for capacity and production planning.

This yields the following vicious circle. When cyclical upturns begin, purchasers fear that merchants will become capacity constrained, causing mounting backlogs and delayed shipments. The merchants' estimates are known to be unreliable. Hence purchasers place multiple orders, often with different firms, in order to reduce their queueing time. Merchants, unable to judge the real size of demand, either overexpand or generate huge backlogs, while purchasers unexpectedly cancel redundant orders when their demand is met elsewhere. The result is further instability which increases the strength of the cycle. In some cases, the Japanese industry is able to increase its market share substantially by soaking up backlogs and providing accurate delivery information. This phenomenon appeared in the 1975 U.S. recession and also contributed to the merchants' plight in 1984 and 1985. The cycle punishes both merchants and consumers relative to cooperating firms and/or integrated industrial complexes such as IBM, AT&T, and the Japanese.

3. Firm One - Firm Two: the horizontal cooperation game. Here,
competing firms in the same industry decide whether to cooperate with versus attack each other. Note firstly that horizontal interaction actually, in most cases, includes several related games. Firms can cooperate or defect (compete, fight) in product markets (cartellization versus competition), foreign technology sales (declining to sell technologies to foreign competitors, versus playing Defection by engaging in such sales), political strategy (seeking joint protection or special favors), research and development (sharing the costs of generic technology or going their own way), supplying each other with complementary technologies or intermediates (agreeing to cross supply versus refusing to do so), in hiring and human capital policy (hiring from each other's workforces or agreeing to avoid predatory hiring in favor of internal training), and bidding for inputs or assets (agreeing to avoid bidding wars, or alternatively engaging in them).

As with Industry One - Industry Two, there is also a related but distinct National Cooperation game: firms can either cooperate only with domestic firms (Cooperation) or they can cooperate at will with foreign competitors (Defection).

Some of these decisions are matters of degree rather than purely binary matters; firms can collusively fix prices, or compete by pricing at average cost, or engage in unsustainable destructive competition by pricing below marginal cost (a game described below). Note finally that once again decisions in these games are closely related to decisions in others. For example, if an industry plays a strategy of Cooperation in the industrial social contract game (#1 above), it is probably precluded from cartellistic cooperation in product markets, at least in the domestic market. Similarly,
playing Cooperation in the social contract game probably implies playing Cooperation in the Firm 1 - Firm 2 game with respect to foreign technology sales. Interestingly, playing Cooperation with respect to hiring and human capital policy may depend upon the government playing Cooperation in an unusual way: by restricting entry into the industry which would lead to employee defection and personnel turnover. The same may be true of the final domestic game I will describe, Companies and Employees, which likewise affects levels of human capital investment and labor productivity.

Now, consider how the Japanese industry evaluated the various strategic dilemmas presented by horizontal interdependency. Much of the above discussion of vertical cooperation will apply, since the relevant firms, industries, and structural conditions are the same. Hence once again a substantial degree of domestic coordination could be expected. However in addition to the usual strategic issues raised by bilateral vertical interactions, horizontal coordination raised one further issue of great importance: would the Japanese industry coordinate in order to stagnate profitably, or in order to grow and become more productive? For example, would the industry collude to fix prices and become insensitive to costs, or would it collude to maximize its efficiency? In short, would the Japanese industry coordinate internally by playing Cooperation in the social contract game, or by playing Defection?

While once again the process was not determinate, three factors shifted Japanese strategy towards efficiency-maximizing, farsighted coordination as opposed to rent harvesting. First, the Japanese government appeared fully
capable of playing TFT, punishing the industry if it failed to perform rather than supporting it through protectionism and subsidy. In other words, the nature of one iterated strategic process had a substantial effect upon another. Second, environmental conditions gave the industry incentives to possess long time horizons; for example, capital costs were low and so, too, were other initial costs pertinent to time horizons, such as R&D wages. And third, a variety of cost and strategic conditions suggested that the Japanese industry could eventually become internationally competitive, through a combination of high efficiency and strategic advantage in dealing with the U.S. industry. Therefore (at least if this proved correct) an extremely high fraction of the incremental revenue derived from a Japanese firm's increased competitiveness would be taken not from other Japanese firms but rather from the U.S. industry, which initially held 60% of the world market. Hence strategic reciprocity of the long-run-growth variety offered the likelihood, at least over the long term, of being a positive sum game, rather than the nearly zero sum game which would have characterized the Japanese domestic market alone.

Interestingly, the extraordinary strategic intensity of Japanese strategic reciprocity is indicated by Japanese performance in mature sectors in which product market competition has, in fact, become a zero sum game (such as the steel and shipbuilding industries). The role of the state, the long run strategic interactions of the industrial groups, and the effect of defection upon future recruitment have exerted such force that Japanese firms have avoided unsustainable competition, mass layoffs, or other forms of defection.
Consider now the contrasting American situation. Once again, many of
the observations pertinent to vertical strategic interactions carry over to
the horizontal case, and so within the U.S. industry defection prevailed for
the same reasons. In addition, the U.S. government played a strategy
somewhere between randomness and defection in the social contract game,
which hardly helped matters. Hence in general, horizontal cooperation was
not favored either in product markets or in supply-side activities with
efficiency-increasing potential, such as joint R&D. Hence the prevailing
behavior (horizontally) within the U.S. merchant and equipment sectors was
rather general defection. Only the largest merchants had any incentive to
coordinate with each other, and even their coordination incentives were
limited by the continuous appearance of new, predatory startups.

It was therefore unsurprising that when the industry's first serious
attempt at coordination was finally made, in the form of the 1986 Sematech
proposal for joint manufacturing R&D, it was originated by IBM and came only
after a deep crisis had finally evoked the beginnings of government support
for the industry's survival, independence from Japanese control, and
technological health. Even so, several merchants who felt their positions
differentially threatened by the Sematech proposal, such as Texas
Instruments, provided little or no initial support.

4. Companies and Employees: the human capital game. In this game,
employers can either assist, train, trust, and invest in their employees
(Cooperation) or alternatively exploit and distrust them, for example by
declining to train them and firing them at will (Defection). Conversely, employees can either work for the long run success of their employers (Cooperation) or can use their positions and/or accumulated knowledge to personal advantage by betraying the employer, for example by producing minimal work or defecting to a competing firm (Defection).

In Japan, this game was played with a striking combination of cooperation and coercion, suggesting that the game had a payoff structure similar to Bully. Because Japanese firms and industrial groups cooperated horizontally in refusing to hire defectors from each other's employ, and because government protectionism prevented the presence of Americans who might have engaged in predation, Japanese employees had far less opportunity than Americans to play Defection. And to some extent, they were exploited accordingly; wages and near term wage increases were kept very low relative to American norms, though long term wage growth rates have compared very favorably. However, the game was not, and would not rationally be, a purely exploitive one.

Recall that Japanese firms were playing a long-term-growth strategy, one dependent upon and oriented towards maximal efficiency and eventual international competitiveness. In addition, the Japanese industry's institutionalization of lifetime employment and of unionization at the firm (rather than craft or industry) level implied enforced repetition of interactions, and hence (following Axelrod) the optimality of long term reciprocity, at least to the extent that employee defection would reduce productivity.
Therefore Japanese firms invested heavily in the training and socialization of their workforces, hoping that employees would seek to qualify for such investments and secure that the most extreme form of employee defection was impossible. Employees reciprocated, knowing that the firm’s success affected theirs, and that their individual career prospects depended upon recognition within one firm. Many observers (e.g. Dore, Jaikumar, Clark) believe these patterns of human capital investment and worker-firm reciprocity have contributed substantially to the success achieved by the Japanese industrial system. Recently, the system has come under some duress as mature industries have initiated some layoffs and decreased protectionism has permitted more American predation; but at present, the system remains largely intact.

Yet again, the American contrast is striking and instructive. U.S. employees defect frequently, and U.S. firms return the favor. While a few large captives and downstream firms (IBM, DEC, AT&T) have turnover rates of 5% or less, turnover in U.S. electronics averages more than 15%. Even Intel, among the stablest of the merchants, has a turnover rate of 8%. And in addition to the equilibrium turnover rate, there are layoffs. While once again a few large U.S. firms avoid involuntary layoffs, they are common in the U.S. industry. In the 1985 industry recession, temporary U.S. layoffs totaled 60,000, and about 10,000 employees were permanently terminated. In Japan, no layoffs occurred, even in firms whose semiconductor revenues declined substantially.
The U.S. industry is also, in large measure, locked into this situation. Any attempt at horizontal coordination to reduce turnover would probably violate the antitrust laws, would be difficult to achieve as a consequence of the industry's fragmentation, and would fall victim to predation by startups. Startups with risky futures, short time horizons, and immediate human capital needs serve as permanent spoilers in the system. Aside from a very few firms (IBM is one), hiring persons who have defected multiple times from previous employers is an accepted practice, considered necessary to obtain skilled labor. It is also notable that in high-turnover systems, employees' incentives to give the firm their best efforts are weakened by the knowledge that they can go elsewhere. Hence stagnant firms' condition is worsened by the departure of their best, leaving only those not marketable elsewhere.

The U.S. shortage of trained technical labor, in combination with turnover rates, appears also to have led to bidding up of professional salaries. This not only raised costs per se but also reduced the time horizons of firms with respect to investments to which labor is the principal input, such as long range R&D. In addition, training is disincented by turnover. Most comparative studies have concluded that Japanese firms train their employees far more than U.S. firms. Jaikumar, for example, found that Japanese users of FMSs trained their employees three times longer than U.S. firms, despite the fact that the Japanese workforce already possessed far more formal education than the American.

And, quite apart from providing disincentives to training, excessive
turnover through layoffs and defections reduces an industry's long run productivity. Many times in the semiconductor industry's history, entire R&D groups or design teams have defected in the midst of important projects. AT&T, General Electric, Motorola, Fairchild, and Intel among others have been the victims of mass defections which have caused severe operational disruptions. More generally, learning effects of several kinds are widely considered critical to competitive advantage in the semiconductor industry. Under conditions of high turnover, many learning opportunities are lost.

Two Domestic Regimes: Behavior and Stability Characteristics

We have now described a series of long run strategic interactions in which U.S. and Japanese firms, governments, and employees played different, nationally specific strategies as a consequence of government policy, industrial structure, and macroeconomic conditions. Assuming for the moment that the two national systems interacted weakly or not at all (roughly true until 1980, save for Japanese technology buying), we can consider the behaviors to which these strategic practices gave rise. Two issues are of particular interest: first, the implications these strategic behaviors had for economic structure, conduct, and performance; and second, the extent to which these behaviors were stable. The two questions are closely related; if a set of practices formed a stable equilibrium, forces such as technological change would not result in optimal structural or behavioral adjustments. Firms would be incented away from socially optimal choice of technique, and even those seeking to adopt best technology would be constrained by the network of strategic interdependencies and behaviors.
dominating the arena.

Once again assuming that the characterizations provided above are accurate, the strategic picture indicates that even without international strategic interactions (product market competition or otherwise), the U.S. regime was severely disadvantaged precisely because it was highly stable. (Note that stability was an attribute of the regime, not most of the firms within it.) Consider specifically the plight of a U.S. merchant, systems producer, or equipment firm attempting to respond to the technical, structural, and competitive imperatives of VLSI. Major increases in investments in external vertical linkages were unlikely to be appropriable. Except for the small number of stable firms, the partner presented a high risk of defection or failure; and turnover ensured technology leakage. Purely captive operations were becoming progressively more expensive, and are now prohibitively so for most U.S. users. Open-market sales to justify efficient scale operations (i.e., adoption of the Japanese corporate structure of diversified vertical integration) would also present severe difficulties, because the logical customers would be competitors in upstream and/or downstream markets, and the entire remainder of the regime favored defection over cooperation among competitors. Massive internal investments, particularly in training, would also benefit competitors through turnover.

Paradoxically, then, the U.S. industry institutionalized itself in a manner which condemned its participants to perpetual instability. Once corporate instability, high turnover, and the continuous formation of new ventures became accepted facts within the American industry, subsequent
activity both within and surrounding the industry came to assume and thereby reinforce this behavior. In Silicon Valley, a large infrastructure of venture capitalists, consultants, headhunters, subcontractors, equipment producers, service firms, and leasing companies arose in response to an industry constituted of young, unstable, cash-limited, entrepreneurial firms. Business practices came to assume instability, discouraging efficient scale investments and long term commitments; for example, users required merchants to license second sources, which subsidized further entry and fragmentation. Firms paid thousand-dollar rewards to employees who recruited personnel from other firms, including their previous employers. Stock options, which vested over four year periods, became essential to the recruiting and retention of talented employees until a public offering made founders, venture capitalists, and valued employees wealthy. (Thereafter, performance incentives and loyalty often waned considerably, and firms frequently became net victims of headhunting rather than predators.) Regional concentrations of high technology firms, factor markets, and infrastructure - such as Silicon Valley - grew rapidly, reinforcing fragmentation by providing locally the ingredients for new ventures.16

Moreover, high levels of turnover and new venture formation produced agency problems: differences between executive incentives and decisions optimal for long run firm-level growth. For example, consider technology sales to Japanese competitors, a game discussed below. Even if the practice of technology sales damaged the firm in the long run, the combination of executive personnel mobility and the industry's collective growth implied that such damage had little personal relevance to decisionmakers unless it
became visible quite rapidly - say, in less than five years. Otherwise, their stock options would already be vested, and they might even have moved to another firm.

Therefore although chronic pressure might well have eventually forced a gradual rationalization of the U.S. system, it would have come far more slowly than long term optimizations based upon technology and economics would have dictated. Indeed, the stability of a regime dominated by pervasive defections and internal instability was surely dysfunctional long before Japanese competition destroyed it. But the regime's problems remained submerged for two reasons. First, the United States had an enormous accumulated stock of technological and economic strength; it was exhausted, or fully converted into personal consumption, only recently. And second, as long as no external competitor existed, the U.S. system remained in aggregate internal equilibrium, its aggregate long run deficits shared by all participants and therefore apparently invisible.

Altogether the U.S. system fairly well approximated the condition Axelrod describes as "All D," meaning that all players defect all the time. Such a strategic environment, in the case of a single strategic interaction in which all players face identical payoff structures, has been theoretically shown to be "collectively stable," again in Axelrod's sense: it cannot be successfully invaded by a single player with any other strategy. On the other hand, and unlike an arena dominated by Reciprocity, a defection-dominated arena CAN be successfully invaded either if another player has a different payoff structure, or if the invasion comes not from a
single player but rather from a group of players who cooperate with each other. In fact, both theoretical and simulation results indicate that high-defection, low-efficiency arenas can be invaded and defeated even by surprisingly small numbers of mutually cooperating agents. The reason is that their cooperation with each other generates higher payoffs than are ever available to agents who defect against each other as well as against the invaders.

What is remarkable is that this simple model approximates so closely what happened between the Japanese and American semiconductor industries. While the actual course of events was considerably more complex than a simple invasion of a homogeneous arena and "all D" regime by another strategic player (and some of the differences are important), even the sparsest and simplest model tells a great deal. In Japan, longer time horizons and denser relationships generated intranational cooperation which gave Japanese firms enormous advantages when competing against fragmented, shortsighted, mutually defecting Americans. When the combination of its strategic advantages and growing technical prowess elevated the Japanese industry to parity with its American counterpart, the Japanese industry abandoned its prior self-restraint and "invaded" the world market generally and the U.S. arena in particular.

4. The Nature of International Strategic Interactions

Therefore, it will be useful to consider international strategic interactions in analyzing the sources and course of the Japanese strategic
"invasion." Four games will be considered here which, though not all are inherently international, have played significant roles in the international interactions, including market competition, witnessed by the semiconductor industry over the past decade. They are:

1. Government One – Government Two: the strategic policy game. The one-period version of this game encompasses the strategic models of the new international economics, for example the models of Brander, Spencer, Dixit, Krishna, Krugman, and Helpman. In the iterated game, of course, behavior is potentially quite different. In this game, a government can either play by pure liberal, neoclassical free trade rules (Cooperate) or it can differentially promote a domestic industry, whether through strategic protectionism, subsidies, encouragement of intellectual property theft by domestic firms, or differential domestic procurement (Defect). The other government faces the same choice. Note that playing Defection in this international game is a form of Cooperation (not the only possible one, however) in the domestic social contract game.

Japan has consistently acted strategically throughout the postwar period, and continues to do so, although the need for overt government protectionism has declined as the power of the Japanese industry has increased. The United States, however, has not reciprocated. Early in the industry's history - until the late 1960s - U.S. military procurement, which was limited to domestic firms, was a sufficiently large fraction of total semiconductor production to constitute, albeit unintentionally with respect to trade issues, a form of strategic policy. Since the early 1970s,
however, military procurement has ceased to exercise any substantial effect upon the industry, and now probably constitutes a slightly negative one.

Recently, in the wake of the 1985 semiconductor recession, the U.S. government began to reciprocate Japanese defection to a small degree. The 1986 semiconductor trade agreement, aside from specifying price floors which increased costs for the U.S. computer industry, did contain an informal understanding that merchant firms would double their share of the Japanese market to 20%. When the agreement was violated, high tariffs were imposed upon Japanese imports valued at $300 million; at this writing, they have been partially rescinded. Given that the world semiconductor market now exceeds $30 billion, grows 15% annually, and is critical to electronics markets totalling $1 trillion per year in sales, Japan's rational calculation would be to continue its defection until more serious U.S. reciprocity was forthcoming.

At present, Japan's defection is continuing, and further U.S. reciprocity appears unlikely. Furthermore, the continuation of Japanese strategic nationalism is important for reasons far beyond such relatively traditional matters as scale and learning effects. Much of the strength of the Japanese domestic regime described below depends upon the absence, or at least the relative rarity, of strategic disarray such as might be caused by U.S. firms operating in Japan in violation of U.S. strategic norms. Just as I will argue that U.S. startups cause strategic disarray in the United States, U.S. firms would be dangerous to Japanese strategic coherence, particularly if they began to cooperate among themselves.
Therefore the greatest virtue of strategic protectionism may have been its utility in preventing domestic strategic disarray in factor markets, and of retaining the other forms of coordination important to the Japanese arena. If the merchant industry had significantly penetrated Japan, it would probably have brought along its strategic norms of defection, shortsightedness, and instability. If this penetration surpassed some minimum level, the appropriability of Japanese human capital (and other) investments would have declined. If norms of defection had spread sufficiently, Japanese producers might thereby have been pulled into the regime of inefficient, shortsighted instability which dominated the merchant industry. They might have begun to defect relative to each other; and defections by employees could not have been punished, because defectors would have been accepted by merchants even if Japanese firms continued to decline to employ them.

2. Innovator - Predator: the technology and assets extraction game. Supposing for the present that any given innovation, product, market, or distribution mechanism is first developed within one national industry, other national industries will seek to obtain it. In the resulting game, a firm in the innovating industry can either decline to license the innovation (Cooperation) or it can proceed with foreign licensing (Defection). (Licensing is not the only possibility; equivalently, a firm might sell a controlling interest in itself, as Fairchild sought to do with Fujitsu, or provide turnkey systems and training services, as others have done.) Note that here I have arbitrarily defined Cooperation and Defection domestically;
in the specifically international component of the game, I will refer to the
two decisions available to the innovator as Proprietary versus Licensing.
Conversely, the predatory or follower sector can either leave the innovator
in relative peace (Cooperation) or can attack it fiercely (Defection). As
we shall see, this is not a symmetric game in the case of Japanese -
American semiconductor competition; as a consequence of the fragility of
U.S. firms, its international payoff structure is usually more like Bully
than Prisoner’s Dilemma. In other words, Japanese imitators defect whether
they receive cooperation or not, and insecure U.S. innovators may feel they
have to play License even when they know this.

Several forces induced U.S. firms to license technology to Japanese
competitors. First, the Japanese market was closed; license royalties were
frequently the only possible way of obtaining revenue from Japan. If U.S.
firms had all cooperated in declining to license, it is possible that Japan
could have been forced to open its market at least partially. But precisely
because defection was prevalent within the U.S. arena, and new U.S. startups
continually appeared, and most U.S. firms had short time horizons, such a
strategy was unlikely to evolve.

For example, a number of startups arose specifically to provide
imitations of the architectures of then-leading firms (Zilog’s first
microprocessor was compatible with Intel’s Z80, for example). For such a
predatory startup, licensing represented an enormous potential increase in
revenue, achieved primarily (in the short run, that is) by cutting into the
infra marginal rents of the leader. Hence leaders were pressed to license
preemptively. Perhaps more importantly, Japanese firms frequently stole what they could not license, so license royalties frequently were limited by the cost of imitation. Because Japan was playing Cooperation in its national social contract game while the United States was playing Random or Defection, such systematic theft was effectively unpunishable. And finally, the Japanese government made wide licensing a precondition of investment in the one case in which a U.S. firm, Texas Instruments, did try to use its bargaining leverage to obtain market access. Hence even before Japan entered international competition and thereby increased its ability to retaliate against U.S. firms, merchants were strategically disadvantaged by their fragmentation, habitual defection, and lack of government support.

U.S. firms also tended to sell technology or other assets when they were failing, and this exit strategy may have substantial incentive effects. The behavior of Micron Technologies and the Fairchild - Fujitsu episode are two examples. Micron, a minor firm wholly dependent upon the memory market, suffered enormous losses in the 1985 semiconductor recession. On the verge of collapse, the company licensed its memory designs (which are considered excellent) to Samsung for $3 million. Fairchild too was faring badly, and similarly possessed several technologies and distribution channels of potentially large value to Fujitsu. Rather than continue competition, Schlumberger and/or Fairchild decided to sell. There followed a heated policy debate as to whether the acquisition should be permitted. Most of those opposing the sale focused either upon national security issues or upon the direct value of Fairchild's technology.
But in discussions with U.S. policymakers, I suggested another reason: permitting the sale would send a signal to other U.S. semiconductor executives that they could divest to Japan more profitably than they could operate, a signal which would lead to an avalanche of similar and progressively more important Japanese acquisitions. I was even malicious enough to suggest that some U.S. merchants had lobbied for the semiconductor trade agreement not because it would assist them in retaining long run technological viability, but because it increased Japanese incentives for foreign investment and therefore raised the price merchants could charge to Japanese firms when disinvesting. And indeed, after Fujitsu withdrew its offer under U.S. government pressure, Fairchild was sold to National for $122 million (Fujitsu's agreement had offered $250 million for 80% of the company), and subsequent large consolidations (AMD and MMI, for example) have avoided Japan. Licensing and minority equity investments, however, have continued because they are less visible and more difficult to regulate. Therefore the U.S. arena continues to offer a competitive market in technology to a Japanese industry which possesses considerable monopsony power, and uses it.

3. Global Competition or Autarky: the globalization game. National industries with existing spheres of influence, say their domestic markets, can either content themselves with their existing markets (Cooperation) or they can attack the markets of others (Defection). In this game, defectors have strong incentives to engage in at least limited forms of dumping, since by aggressive pricing in newly entered foreign markets they destroy the inframarginal rents of foreign competitors more than their own. Note that
the consequences of playing Cooperation versus Defection depend upon the strategies played in other games, for example the strategic trade policy game and the industry social contract game.

Prior to the critical junctures of the late 1970s - the advent of VLSI, Japan's achievement of parity in semiconductor manufacturing, and Japan's initiation of global competition - Japan in a sense played Cooperation. The Japanese industry largely refrained from competing against the U.S. in foreign markets even where it might plausibly have done so, say in linear and discrete devices. On the other hand, through both private and governmental action the Japanese domestic market remained protected, and remained the only large semiconductor market in the world not controlled by the American industry. During this period, the government's role was probably critical; the Japanese industry, despite its structure and strategic cohesion, would probably have fared badly if U.S. firms had been permitted full access. One indicator of the degree to which this strategic effect was important was the enormous disparity between Japan's nearly total dependence upon the United States for capital equipment and its modest imports of semiconductors themselves.

It is not entirely clear whether the United States industry played Cooperation in return, because given its regime and the strength of Japanese protectionism there was little effective difference between cooperation and defection. To create such a difference would have required internal strategic coordination within the U.S. system, whether through a decentralized strategic regime or through a central authority such as the
government. Hence the state of this strategic dilemma has been, and remains, a function of other strategic interactions such as the domestic social contract game and the game of intraindustry coordination.

4. Market Control: the unsustainable competition game. In this game, a firm or national industry either competes "normally" (Cooperation) or targets a foreign adversary by engaging in highly aggressive competition such as dumping or predatory pricing (Defection). The opposing national industry faces the same choice. Note that even with "normal" competition (both sides playing Cooperation) a more efficient industry will eventually drive out a less efficient one. Note also that if an industry can wait long enough, it may eventually win by playing Cooperation even when another industry is Defecting, because prices are unsustainably low. In other words, if even one side is playing Defection, this is a waiting game, an instance of Chicken. Only with permanent subsidies can anything but normal competition be sustained. Aside from its specifically international definition, this game is an instance of Firm 1 - Firm 2. But its international component is important; for example, the success of an industry playing Defection may depend upon the status of the social contract game or the willingness of foreign buyers to betray their vertical relationships by playing Defection in Industry 1 - Industry 2.

In an iterated game, extreme boldness in games of Chicken has a potentially strong deterrent effect; and if one of the players can sustain more damage over several generations than another, or for whatever reason has a longer time horizon, a demonstrated willingness to sustain damage can
be very useful. In a way, it is an industrial version of the "madman" strategy in diplomacy. And the Japanese industry has repeatedly demonstrated an extreme willingness to engage in aggressive, possibly unsustainable competition. In combination with its manufacturing excellence and low factor costs (and therefore, frequently, real cost advantage) in commodity markets, the Japanese industry's preference for defection led merchants to exit from markets soon after Japan entered them. In contrast, merchant firms rarely if ever initiated Defection in unsustainable price competition, and certainly never continued it for long. Hence the presence of many iterations and the Japanese industry's greater staying power turned a long run game of iterated Chicken into, effectively, a short term game of Bully or something similar. Therefore, for example, most U.S. merchants exited the DRAM, SRAM, and EPROM markets within two product generations of Japanese entry.

This pattern has also reacted back on the Licensing game, increasing U.S. firms' propensity to license because of their prospective fear of being caught in unsustainable competitions. The knowledge that they would lose in that game shortened their time horizons with respect to other decisions. For such reasons, many U.S. startups are now actively seeking licensing agreements and equity investment from Japanese firms, in some cases even before introduction of their first product. They seek both to capitalize their expected revenue stream in advance of direct Japanese competition, and to increase the probability that when the larger ship begins to sink, they will have a reserved place on the lifeboat.
For example, one merchant executive noted to me that for one period in the early 1980s, a Japanese licensee was selling an important microprocessor for less than the unit royalty fee. But his firm still at least received the royalty fee, while other U.S. second sources simply lost money. Ironically, then, the threat of Japanese competitive attack led weak U.S. firms to become more prone to defect relative to each other and to cooperate with their Japanese competitors. Only a few merchants with strong positions and considerable sustainability - e.g. Intel, with leadership in the microprocessor market, cross-licensing and long term purchasing agreements with IBM, and $300 million in cash - have principally reacted to Japanese attacks with reciprocal defections such as refusals to license, rather than capitulations such as increased licensing and market exits.

Now, given this description of the semiconductor industry's international strategic interactions, consider what led to the particular forms of international competition we have observed, and how they affected the two domestic regimes characterized above. First, the pre-VLSI "bargain" between the Japanese and U.S. industries - technology for autarky - represented a U.S. domestic non-cooperative strategy in the face of Japanese internal cooperation. Even though the U.S. industry possessed collective technical superiority in the pre-VLSI era, it could have defected in the globalization game (i.e. forcibly penetrated the Japanese market) only through domestic coordination or through the agency of a central authority. For different reasons - industrial fragmentation in the one case, failures of government policy on the other - both routes were unavailable. As a consequence, the option of playing Defection in the globalization game
rested permanently and uniquely with Japan, which exercised it only when its
technology extraction activities, domestic strategic regime, and tolerance
for severe price competition together enabled it to enter international
competition with a high prospect of success.

Now consider what happened when the Japanese industry did finally play
Defection, and globalized competition by penetrating the U.S. industry's
sphere of influence. The nature of the Japanese industry's strategic regime
continued to insulate it from invasion by the U.S. regime of defection,
while the U.S. regime was highly vulnerable to invasion from cooperating
predators. Therefore, the increased competitive pressure felt by most U.S.
firms shortened the shadow of the future yet further and led to more, rather
than fewer intramural defections, and similarly led to more, rather than
less, capitulations in international bargaining. Hence the U.S. industry
not only failed to reciprocate Japanese defections successfully, it actually
became more docile.

However, the crisis of 1985 resulted in the development of limited
domestic coordination. Some of its most visible forms were parochial and
counterproductive, as when semiconductor producers and users lobbied against
each other with respect to dumping cases. But the U.S. government finally
began to show strategic reciprocity, IBM and a few large merchants initiated
coordinated actions, and it became clear that most U.S. firms would not be
able to disinvest profitably. At that point, limited forms of productive
coordination (such as the Sematech proposal, government reaction to the
Fujitsu / Fairchild acquisition, and U.S. sanctions on Japanese firms
related to market access) eventually appeared. Thusfar, however, the strategic discipline imposed upon Japan has been trivially small relative to the size of the long run contest, and the principal forms of Japanese domestic coordination and international defection appear to be continuing unabated. Indeed, some forms of Japanese strategic activity, such as the systematic exploitation of the U.S. startup sector in progressively earlier phases of technology life cycles, are accelerating.

Conclusions, Implications, and Further Questions

To the extent that the foregoing analysis is correct, it suggests several strong conclusions. First, neoclassical industry analysis must become a subset of the exploratory analysis of iterated strategic processes if we are to model industrial dynamics effectively. Traditional neoclassical analyses, which have either minimized the importance of strategic interactions or made arbitrary assumptions concerning their character, can lead us seriously astray when politics, technology, production, and competition imply major strategic interdependencies. The strategic regimes which arise in response to these interdependencies can exercise as much influence over structure, conduct, and performance - for either good or ill - as traditional variables such as factor endowments; and indeed even the status of these traditional variables themselves may be determined by strategic processes.

Second, the potential deficits of various arena structures and strategic regimes appear to have two major substantive implications for
policy. The first is that concentration ratios and other such traditional indices are in fact quite poor indicators of long run, or even static, arena efficiency. Under appropriate and apparently reasonable arena structures and payoff conditions, strategic issues dwarf conventional allocative efficiency as a determinant of real performance. The other implication suggested by regime analysis is that government policy, or more generally interventions by central authority, can be far more beneficial, and more widely relevant, than traditional models indicate.

Third, the idea of a strategic regime as an equivalence class of strategic behaviors, and as an endpoint of strategic evolution, would appear to provide a useful point of departure for the development of new models of industrial dynamics, of which most existing neoclassical models would be one-period local approximations. The explicit recognition and investigation of long run strategic interdependencies would permit equally explicit analysis of questions heretofore beyond the reach of economic analysis, for example the effects of widely divergent subjective preferences, discount rates, arena structures, technologies, strategic behaviors, and centrally imposed incentive systems upon industrial organization and international economic behavior. The natural tools in such investigations would be a combination of empiricism, theoretical analysis, and - perhaps most importantly - exploratory computer simulation. As Axelrod has noted, emerging highly parallel computer architectures are ideally suited to the investigation of these problems.

As Axelrod has also noted, iterated strategic processes are inherently
evolutionary in character. Therefore the internal dynamics of these processes, the internal stability of strategic regimes, and the external stability of regimes (when they are attacked or brought into interaction with other regimes) are potentially of as much interest as the analysis of particular iterated games per se. In the above analysis, we have considered how two national regimes evolved independently, how their performance characteristics as independent regimes compared, and then how they behaved when one of them unilaterally decided to compete against the other. The structural and performance anomalies which preclude a neoclassical explanation are thus seen as consequences of the nature of these two regimes, and later of their interactions.

But regimes not only can defeat one another, they can spread from one arena to another. What follows is an example of that phenomenon. By virtue of some of the same technological and strategic forces which transformed the semiconductor industry, the merchant strategic regime is moving downstream into the U.S. computer industry, until recently a concentrated oligopoly, where the consequences of fragmentation and chronic startup formation for growth and international competition are already evident. The following chapter chronicles this process, though in a less detailed way than the preceding discussion of the semiconductor industry. Did Japanese bureaucrats and executives read Thomas Schelling and Robert Axelrod, does Robert Axelrod read Japanese, or do great minds think alike?
NOTES TO CHAPTER FOUR


2. For a discussion of this issue and a direct comparison of U.S. and Japanese conditions, see Ralph Landau and George N. Hatsopoulos, "Capital Formation in the United States and Japan," in Landau & Rosenberg (eds.), "The Positive Sum Strategy: Harnessing Technology for Economic Growth," National Academy Press, 1986. Hatsopoulos, it should be noted, is a strong proponent of the position that Japanese capital cost advantages are large and important.


5. Dataquest. See also Ferguson, op. cit., pp. 19 - 28; and Braun & Macdonald, op. cit., pp. 124 - 128.


8. For market shares, the source is Dataquest. For quality data, see for example U.S. Office of Technology Assessment, "International Competitiveness In Electronics," 1983, pp. 247 - 249, for data drawn both from Hewlett-Packard and from OTA consultants.


13. See Axelrod's "The Evolution of Cooperation" and Oye's introductory article in "Cooperation Under Anarchy" for discussions of these matters. See also Appendix 1 of this essay.


15. In order to indicate the feelings held by some regarding venture capital based startups and their effect upon turnover, let me quote the CEO of one of the industry's largest firms: "The best thing that could happen to this industry would be if every tenth venture capitalist was arbitrarily shot."

16. See Braun & Macdonald, chs. 7, 8, and 10.

CHAPTER FIVE
EXTENSION AND GENERALIZATION: THE COMPUTER INDUSTRY
AND THE CHANGING GLOBAL COMPETITIVE REGIME

1. Are Strategic Regimes Frequently Important?

On the argument outlined above, the behavior of the semiconductor and related equipment industries has been influenced significantly by strategic processes, and by various related phenomena such as the evolution of both national and international strategic regimes. Is the semiconductor case aberrant, or do systems of long run strategic interaction exercise wide influence over industrial dynamics and comparative performance? Here, I consider the applicability of strategic analysis to the computer industry, and then (briefly) yet further to international high technology competition generally. My conclusion is that far from being an isolated case, the semiconductor industry illustrates a broadening pattern in global high technology competition. The fragmentation and systemic shortsightedness characteristic of the U.S. arena, in combination with the strategic cohesion of Japan, suggest that global market integration is now generating an internationalized but asymmetric strategic regime. The combined effects of strategic asymmetry and the life cycle cost structures characteristic of high technology industries are such that this new, internationalized regime may become quite pervasive.

In this emerging regime, the fragmented United States system "specializes" by default in the provision of services (e.g. basic research,
market prototyping, advanced training, sales and maintenance) whose long run economic benefits differentially accrue to more coordinated foreign competitors via their control of concentrated, and competitively superior, engineering and manufacturing systems. Japanese industry selectively uses U.S. services and assets such as university education, basic research, and technologies developed by startups, and then enters commercial markets as they mature. Since the social returns to U.S. provided public goods must generally be obtained through commercial competition, the Japanese system both maximizes the appropriability of domestic efforts generally, and invests differentially in the development of appropriable assets. Hence the Japanese system enjoys both free rider benefits and increased productivity as a result of its internal arrangements, which increase the appropriability of returns to even those investments which, in the United States, would be public goods. Such areas include R&D in basic process technologies, investments in employee training, and manufacturing capability. Only when Japanese firms reach the innovative frontier need they invest in proprietary innovation themselves, since until that time the fragmented U.S. system makes these innovations available. But before making the general argument, I will consider the computer industry.

2. The Development of the Computer Industry

The computer systems industry had its genesis in a variety of university and government efforts which culminated, towards the end of World War II, in the development of primitive, vacuum-tube based, but programmable calculating machines. By the mid-1950s, there arose a substantial industry
dominated by established manufacturers of office and industrial equipment. As with the semiconductor industry developing more slowly alongside it, the early computer industry was heavily influenced by the military. By Kenneth Flamm's accounting, defense contracts (such as the SAGE air defense system and the STRETCH high performance computer) accounted for 35% of IBM's R&D budget in the 1950s. Also as in the semiconductor case, the Federal government's role gradually declined as government procurement became a smaller fraction of the total market and also fell behind commercial demand technologically.

While some early entrants were independent firms founded by technical innovators, these soon disappeared through failure or absorption into larger companies. By the late 1950s, the industry was dominated by firms which diversified into computers from earlier positions in the office equipment industry. IBM was previously a manufacturer of punched card tabulating equipment; other relatively early entrants who grew into major vendors included Burroughs, Remington Rand (which eventually became Sperry), and National Cash Register (NCR). Several large firms which tried to enter the market at various times failed; probably the largest failures were those of RCA and General Electric. AT&T, which might plausibly have become a major force in the industry, ceded its right to participate in the market in 1956, as part of the same antitrust consent decree which led to its withdrawal from the semiconductor market.

By the late 1950s, IBM had become the industry's clear leader through superior marketing and wise use of military contracts which provided R&D
funding and early experience with advanced technology. This leadership was consolidated and guaranteed for another twenty years by the introduction in the early 1960s of the 360 series, the first family of compatible systems to use a modular computer architecture. The upward compatible version of this architecture, 370/XA, still defines the world's largest single computer market. Though IBM's dominance gradually declined, by most accounts it held half the entire world computer market until the early 1970s, versus about 30% presently.2

Three further facts about this earlier (pre-VLSI) period are salient for our present purposes. First, and as with the semiconductor industry, U.S. firms overwhelmingly dominated technological leadership and world markets. Although some excellent early research was produced in England and occasionally other nations, most basic research and nearly all commercial technology came from the United States. Until the mid-1970s, U.S. firms accounted for more than two-thirds of total world computer production, and held at least half of every major national market, including Japan's.3

Second, the industry did not initially depend upon microelectronics; the integration of the two technologies was foreseeable, but its realization is quite recent. Only in the late 1950s did semiconductor technology even begin to impinge upon the computer industry; the first two generations of commercial machines were based entirely upon vacuum tube and magnetic technologies. CPUs were made with vacuum tubes until the late 1950s, when transistors were substituted; main memory was made with magnetic core devices until the early 1970s, when IBM and then other firms introduced semiconductor memories. Then, with the arrival of VLSI microprocessors in...
the 1980s, implementation of entire CPUs and subsystems passed to the level of single semiconductor devices. By the mid-1980s, the semiconductor content of computers reached 6%, and was still increasing steadily.

Third and finally, between the 1950s and the late 1970s the computer industry - unlike the merchant semiconductor industry - was structurally stable, despite its continuously rapid growth and technical progress. Its recent behavior thus differs remarkably from the structure and strategy which characterized the 1960s and 1970s. The market shares and product strategies of the principal firms changed only very gradually. For largely technological reasons, the majority of demand was for mainframes - large, expensive capital goods. System software was supplied by computer vendors, who understood their machines; applications software was supplied by users, who understood their own particular needs. Because most software was necessarily specific to a single machine architecture, vendors with large installed bases held a secure market; within their installed bases, revenues were determined by technological progress and the price elasticity of demand, both of which were high. Hence IBM remained the industry's leader, technical standard setter, and dominant mainframe producer; producers of IBM compatible machines (Plug Compatible Manufacturers, or PCMs) disciplined IBM within the 370 standard, while simultaneously reinforcing the dominance of that standard; other producers engaged in limited monopolistic competition by marketing their own products and serving their own installed bases.

Gradually, and largely as a result of technological progress in microelectronics and magnetic storage technology, the stability generated by
installed bases declined as new architectures became feasible, and as the fraction of systems embodied in open-market semiconductors increased. Minicomputer firms, led by DEC (which was founded in 1957, but became a major force only in the 1970s), secured a rapidly growing but comparatively small niche market for sophisticated users of smaller machines, while CDC dominated the high-end scientific market. Then, in the late 1970s, the advent of open-market VLSI devices and microprocessor-based systems produced an explosion of new architectures and rapidly growing new markets: personal computers, technical workstations, fault-tolerant and redundant systems, mass markets for commodity software, multiprocessors, database machines, networked and distributed systems, array processors, supercomputers, and so forth. Newly formed, venture-capital financed startups could and did dominate most of these new markets. In other words, new computer markets are divided between the newer portions of the U.S. computer industry, which resemble the merchant semiconductor industry as much as the traditional computer industry, and those more established firms - principally IBM and DEC - which have been able to remain strong, innovative, and flexible.

But during their earlier "classical" periods, the U.S. computer and semiconductor industries evolved quite different internal structures and strategic patterns. From the early 1960s until the late 1970s, each industry maintained its characteristic behavior over several product generations. The semiconductor industry was characterized by fragmentation, low entry barriers, small scale production, venture capital funded entrepreneurialism, and evanescent market success. Collectively, the semiconductor industry acted as a non-competing, non-integrated supply
sector which provided commodity components to the computer sector.

Conversely the computer industry exhibited large scale economies, entry barriers, and switching costs which stabilized it. While new firms could enter new markets, in aggregate terms the industry remained stably divided between IBM, the second tier mainframe firms (the so-called BUNCH), and a growing but (then) limited competitive fringe led by DEC.

The Japanese Industry

Japan's response to U.S. dominance of world computer markets was largely similar to its response in the semiconductor industry. The principal differences consisted in IBM's strong leadership position and consequent ability to penetrate the Japanese market. Unlike the merchant semiconductor industry, the computer industry's stability (and, possibly, IBM's unique capabilities) enabled leading firms, and IBM especially, to drive a stronger bargain than Texas Instruments. IBM was able to establish a wholly owned Japanese subsidiary and, until the 1970s, held a higher share of the Japanese market than the entire Japanese industry; but even IBM was forced to license many of its patents, and its market share began declining substantially in the mid-1970s. In most other respects, however, the structural conditions and strategies found in the Japanese computer industry are virtually identical to those described above in relation to the semiconductor industry.

Thus, for example, the Japanese computer industry is composed of the same vertically integrated strategic competitors that dominate the Japanese
semiconductor industry. The computer industry, in fact, is even more concentrated. In 1984, the four largest Japanese computer producers, who are the same as Japan's four largest semiconductor producers, accounted for over 70% of all Japanese computer production (including production by Japanese subsidiaries of U.S. firms), and for about 80% of all computer production by Japan-based firms. In addition, in Japan computer systems firms account for 70% of all system software sales, versus 45% in the United States. The Japanese computer industry's evolution and strategic behavior are also similar to those seen in the evolution of Japanese semiconductor production - governmental protectionism and sponsorship of R&D collaborations, private strategic coordination, large long term R&D investments, U.S. technology imports, progression from imitation to proprietary design, and rapid export drives in maturing markets upon reaching technical parity.

And, also in common with the semiconductor industry, Japanese government strategic interventions, private strategic coordination, patterns of strategic interaction (particularly regions of cooperation versus competition), and incentive structures favoring long time horizons combined to generate a strong, oligopolistic industry from an initial position of weakness. The Japanese government protected the domestic infant industry from both imports and IBM Japan, and also provided considerable subsidies to the industry. MITI sponsored long term R&D efforts in which pairs of major Japanese firms collaborated in developing mainframe systems based upon licensed, stolen, and/or imitated U.S. technology. Following a series of abortive licensing and codevelopment agreements between Japanese firms and
second-tier U.S. producers such as RCA and GE, MITI forced rationalization of the Japanese industry.

Beginning in 1971, Fujitsu and Hitachi jointly developed IBM compatible machines, NEC and Toshiba worked together on GE/Honeywell machines, and Mitsubishi and Oki collaborated on projects which ultimately failed in the market. In 1972, Fujitsu purchased equity in Amdahl and obtained its IBM compatible hardware technology. By purchasing equity, Fujitsu also obtained Amdahl as a distribution channel; as Fujitsu's technology surpassed Amdahl's, this function came to predominate. Amdahl, a U.S. startup founded in 1971 by Gene Amdahl, a defector from IBM, is now 49% owned by Fujitsu and sells $1.5 billion worth of IBM 370-compatible systems, most of them Fujitsu machines, annually. (Mr. Amdahl subsequently departed to found Trilogy Systems, which raised $200 million in the early 1980s but went bankrupt before marketing a product.) NEC licensed Honeywell's architecture and technology, from which its current mainframes are derived. By 1976, IBM was beginning legal action to curb Fujitsu's copying and reuse of IBM system software, a case which has been repeatedly settled and re-opened as Fujitsu continued, allegedly, to massively violate the terms of the settlement. The case was submitted to binding arbitration; in 1987 the arbitrators announced that Fujitsu would be able to continue marketing the software, but would have to pay IBM "substantial" damages. IBM took legal action against Hitachi as well for similar alleged violations, a case settled in the early 1980s. NEC has continued to develop machines based upon Honeywell's architecture, and now resells them to Honeywell.8
Both protectionism and direct financial support began in the 1960s, but have continued until quite recently. By one accounting, between 1976 and 1981 alone direct Japanese government assistance to the domestic computer industry totaled Y206 billion (roughly $1.03 billion). Indirect assistance was even larger. Most indirect support came from subsidized loans provided through the Japan Electronic Computer Company (JECC), jointly operated by the government and the major Japanese computer producers. (Every president of the JECC since its creation in 1961 has been a retired MITI official, and the JECC obtained most of its funds from the Japan Development Bank via loans at subsidized rates.) Including such indirect sources, government support during the 1976-81 period totaled Y748 billion, or nearly $4 billion. Direct assistance represented 25% of private expenditures for R&D and capital investment during this period; total support including loans equaled 92% of private sector investment. In earlier periods the relative size of such subsidies was even larger; direct assistance equaled 52% of private sector investment during the 1960s.

In addition, the Japanese government preferentially purchased machines from domestic producers. In 1982, 91% of the government's installed base came from domestic producers, versus 56% of the total national installed base. In that year the government represented 18% of total Japanese computer demand. In earlier periods, the government's role was even more important. In the 1960s, MITI forced IBM to license its hardware patents, and prevented other U.S. firms from establishing wholly owned subsidiaries.

Perhaps equally important, however, was the internal strategic regime
of the Japanese industry, which once again reflected the same behaviors as
the semiconductor industry, as indeed one would expect given that the same
firms were involved. The industry's time horizons were once again long;
although the Japanese industry lost money for nearly the entire decade of
the 1960s, it continued to invest. Firms supplied themselves and each other
with technology and subsystems; other firms in producers' keiretsu showed
considerable favoritism towards their family firm in computer purchases,
despite the short term penalties associated with using what until the late
1970s was clearly inferior equipment.

Once again, the analogy with the semiconductor case is striking.
Frequently, firms cooperated in attacking established U.S. firms and
markets. As mentioned above, Hitachi and Fujitsu cooperated in developing
IBM compatible mainframes until they became significant and commercially
successful competitors, whereupon they became less cooperative. More
recently 13 Japanese vendors standardized on a single specification for IBM
PC AT compatible machines, enabling sharing of subsystems and designs. All
major producers also invested heavily, and over long time periods, in the
semiconductor and systems software technologies critical to mainframe
systems, typically starting with licensed, imitated, and/or illegally copied
U.S. systems. Once again employee turnover was low, entry via independent
entrepreneurialism was rare and of minor importance, and the industry
avoided export drives until it reached approximate technical parity with the
United States.

So once again the U.S. and Japanese industries developed relatively
independently (with the exception of IBM's presence in Japan) until the Japanese industry unilaterally decided to enter global competition. Japanese technology extraction and protectionism proceeded, but with the exception of the progressive displacement of IBM from its dominance of the Japanese domestic market, the Japanese industry avoided direct challenges to the U.S. industry.

3. Strategic Destabilization and Japanese Competition

Destabilization (A): The Merchant Regime in the Computer Industry

By the late 1970s, a complex mix of technological, strategic, and political processes began to erode the stability and global dominance of the United States industry. Their result has been that with the exception of a few vibrant large firms (particularly IBM and DEC), the newer segments of the U.S. computer industry increasingly resemble the merchant semiconductor industry. And, yet again in common with that industry, this fragmentation increased at precisely the point at which technological and strategic logic favored increasing size, scope, vertical integration, and industrywide cooperation. Consequently the computer industry is increasingly prey to strategic risks similar to those which I described above with respect to semiconductors.

Clearly, the condition of the U.S. semiconductor industry contributed to the increasing fragmentation of computer markets. As VLSI caused semiconductor and systems technology to merge, the vertical split between
the merchant semiconductor sector and its downstream systems customers, including the computer industry, became progressively more important and dysfunctional. Since the strategic dynamics described above prevented rationalization of the semiconductor industry and its downstream relationships in this area just as in others, the result was that the computer industry was increasingly influenced by the fragmentation, instability, and decay of the merchant industry. Computer firms dependent upon merchant suppliers therefore suffered accordingly. In part, also, this increasing fragmentation derived from the fact that VLSI produced a deep change in the computer industry by making possible radically new architectures, shortening computer product cycles and opening huge new markets.

Consider, for example, the technical competition between mainframes and personal computers. Although elaborately cooled mainframe CPUs (which are composed of hundreds of high-speed bipolar circuits connected by dozens of layers of ceramic packaging) remain far more powerful than the individual VLSI microprocessors used in personal computers, they are proportionately much more expensive. Therefore where continuous use of shared resources is not critical, the decentralized use of small computers now proves far more cost-effective than a single large one. The personal computer is the result of this technology trend. The IBM RT PC, for example, uses a 4 MIPS 32-bit CMOS reduced instruction set microprocessor; it is a personal workstation priced at ten to twenty thousand dollars. A 75 MIPS mainframe, conversely, costs several million dollars, yielding a price/performance ratio at least an order of magnitude worse. With the arrival of commodity 32 bit personal
computers such as the Sun 3, the Apple Macintosh II, the IBM PS2 model 80, and other IBM-compatible systems using the 80386 microprocessor, the relative advantage of personal machines is even larger. It is generally agreed that this difference will continue to increase for many years; mainframe cost/performance ratios continue to improve, but less rapidly than those of personal computers.

Furthermore, highly concurrent systems built up from new VLSI microprocessors may soon challenge or at least supplement mainframes in high performance computing. The new systems markets made possible by VLSI included not only personal computers but also mass market software, fault tolerant systems, local area networks, reduced instruction set systems, multiprocessors, highly parallel supercomputers, database machines, and technical workstations. U.S. commodity software markets have grown over 35% annually since 1980, totalling over $10 billion in 1985. And the need for personal computer users to communicate with each other and with mainframe computers similarly created demand for computer networks which, in turn, were made economically possible by VLSI network control circuits. The market for local area networks (LANs), for example, has grown over 40% annually since 1980.

Since all of these markets were new, and most of the required hardware could be designed with openly available VLSI devices, entry barriers were initially low. The installed bases of the existing firms provided no protection in these new markets, and incremental computer demand rapidly shifted from conventional mainframe architectures to novel VLSI-based
systems and associated software. And, of course, the U.S. system contained none of the entry barriers which operated in Japan. To the contrary, the same decentralized infrastructure and subsidies to entrepreneurialism that maintained the merchant industry regime operated equally in the new segments of the computer industry.

But the evidence suggests that this is not the entire explanation for the stagnation of the traditional computer industry and the concomitant rise of entrepreneurialism in novel markets. For reasons which remain at least partly mysterious, by the mid-1970s most of the established U.S. industry displayed an ossification which reduced its propensity and ability to develop and exploit new technologies. This process seems increasingly to be affecting IBM, but its effect upon the remainder of the established firms which had entered the industry - firms such as RCA, GE, Honeywell, NCR, Burroughs, and Sperry - was far more severe.

A possible explanation for this stagnation, to which I will return later in discussing the industry's strategic regime, involves three factors. The first was the collective dominance of the American industry, which lessened external discipline just as it had in the semiconductor case. The second was high U.S. factor costs (once again for capital and skilled labor), also as with the semiconductor case. This condition, once again, both raised the effective cost of R&D, capital spending, and other costs associated with innovation, and also shortened the industry's time horizons. Finally, there were the switching costs associated with the mainframe market, which permitted rent extraction at least over the short run and...
protected even decaying firms from rapid decline. In addition, IBM maintained a high price umbrella which protected its lesser competitors from extreme competitive pressure. (IBM also, however, continued to invest massively in R&D, training, and technology assessment, while most of its lesser brethren did not.)

So the established industry - even IBM, but more severely its competitors - gradually lost its innovativeness and efficiency, and clearly did so well before, and independent of, the external shocks generated by Japanese competition or recent macroeconomic distortions. The principal symptoms of this stagnation, which apparently was underway by the late 1970s, were two. First, most established firms invested and grew more slowly than the industry as a whole. They became progressively more dependent upon outside suppliers, often Japanese competitors, for critical inputs such as semiconductors, displays, printers, storage subsystems, and recently entire computers. (For example, IBM is the only U.S. firm which produces more than 20% of the semiconductors it uses, and the only one to possess its own world-class packaging technology.) Research efforts stagnated, investments became progressively more incremental and risk-averse in character, and growth decelerated. For example, between 1975 and 1986 IBM’s sales grew 73% in constant dollars, and DEC’s sales grew 600% in the same period. But NCR’s constant dollar sales grew only 10%, and Honeywell’s sales actually declined. Total U.S. constant dollar production of CPUs and peripherals roughly tripled. 10

Second, new computer architectures and markets (made possible by cost...
performance improvements and then, most spectacularly, by the advent of VLSI) were colonized principally by startups. Aside from IBM, no established firm obtained substantial shares of the minicomputer market, which is now led by DEC and IBM. Aside from IBM (and DEC and/or HP if we count them as established firms by 1980), no established firm has produced new computer architectures, designed major proprietary microprocessors, or obtained major shares of new markets for microprocessor based systems. Consequently newer, non-mainframe systems markets have become increasingly fragmented. In these newer product markets - which already account for nearly half the world computer market - the earlier established firms are essentially absent. Rather, these newer markets are dominated by IBM; a few entrepreneurial firms which may have reached the critical mass needed for success beyond a single product generation (e.g., DEC, Apple, perhaps Sun); smaller firms which rise and fall in waves similar to those of the merchant industry; and increasingly, as we shall see shortly, the Japanese industry. Therefore whatever its original sources, the effect of the established industry's stagnation was to open a vacuum filled largely by the regime of unstable, noncooperative entrepreneurialism which dominated the merchant semiconductor sector.

The startups which now initially colonize new computer markets are single product firms dependent upon each other and other industries (particularly the semiconductor industry) for inputs, subsystems, manufacturing services, and capital goods. They have also displayed generational instability at least as extreme as the merchant industry. Not only do new products and technologies routinely displace others only a few
years old, but such changes are often accompanied by drastic shifts in market share leadership and firm level profitability. In personal computers, Osborne Computer grew from an idea to a $125 million firm in two years, only to go bankrupt;11 Visicorp, vendor of the Visicalc spreadsheet, suffered the same fate; other firms which declined in varying ways include Eagle, Kaypro, Morrow, Digital Research, Sorcim, and many others. Even Apple, which may now have reached the status of a major competitor, holds less than 20% of the personal computer market, remains a single market firm, and is entirely dependent upon external sources, including increasingly the Japanese industry, for its semiconductors.

Apollo, the first firm to market an advanced workstation in 1981, has already been displaced as the leader in that market by Sun Microsystems, and both firms face increasing competition from IBM, DEC, and the Japanese industry. Apollo's founder, Jim Poduska, left Apollo in order to found yet another workstation startup, Stellar. Cray Research similarly pioneered in the supercomputer market, and now finds itself similarly threatened by IBM, by newer "minisupercomputer" startups such as Alliant and Convex, and perhaps most seriously by Japanese firms. When Cray cancelled a major development project in 1987, its chief engineer, Steve Chen, departed almost immediately to start a new firm partly financed by IBM. Tandem marketed the first fault-tolerant computer system in 1977, and its revenues now exceed $700 million. By 1984, at least eight other U.S. startups had entered the market (August Systems, Auragen, Autech, Parallel Computers, Sequoia, Stratus, Synapse, and Tolerant Systems). Several have already failed, while one (Stratus) may challenge Tandem's leadership; by 1986, Stratus' revenues
exceeded $130 million. Stratus' machines, like most of the other startups which followed Tandem, were heavily based upon open market technology: Motorola microprocessors, the UNIX operating system, and open market semiconductors.\textsuperscript{12}

Perhaps the most extreme case of this phenomenon was the Winchester disk drive market. Between 1977 and 1984, venture capital firms invested $400 million in 43 U.S. startup producers of Winchester hard disk drives for personal computers.\textsuperscript{13} Stock offerings raised another $800 million. By 1983, there existed 63 U.S. and foreign suppliers of Winchester drives.\textsuperscript{14} Many of these firms were founded by defectors from Memorex and IBM. Then, in less than a two year period (1983-84), the valuation of the 12 largest publicly traded startup firms declined 75%. Many failed as mass production became essential, competition intensified for OEM contracts, entrepreneurial customers failed, entrants with newer technology appeared, IBM began manufacturing a higher fraction of its own requirements, and Japanese firms entered aggressively. As one analysis noted, "The only barrier to vertical integration and to massive foreign entry was the fact that a large, standardized market had not yet been proved to exist....Few [of the startup] companies could afford the luxury of pursuing a second generation product while the first generation was as yet unproduced."\textsuperscript{15}

The result has been a segmentation of the U.S. computer industry into three categories of firms: a small number of successful established firms, all of whom are globalized and vertically integrated; a set of decaying established firms reduced to servicing their installed bases; and an
unstable arena of entrepreneurial firms in many novel markets. The relative
deterioration of most of the established industry, together with the advent
of open market VLSI microprocessors, the nature of the merchant industry,
and the systemic incentives associated with new ventures, have introduced
the semiconductor industry’s strategic regime of unstable entrepreneurialism
into the U.S. computer industry. And as noted above, the semiconductor
industry’s condition contributed to this result as microelectronics merged
with systems technology.

But in addition, other forces were transforming the computer industry
during this period as well. The long term direction of technological change
favored increasing automation, capital intensity, globalization, and
interindustry convergence. Thus even as the U.S. system generated
fragmentation in novel markets, the fundamental forces driving the industry
implied the necessity of increasing concentration, vertical integration, and
capital depth. The advent of competition from Japanese and Korean
industrial complexes intensified these requirements. In the face of these
forces, the fragmentation of the U.S. computer industry and its
institutionalization of the merchant industry’s noncooperative, shortsighted
strategic equilibrium therefore imply declining U.S. competitiveness as
strategically coordinated Asian competitors harvest open market U.S.
technologies and enter global competition in maturing markets, just as in
the semiconductor case.

Destabilization (B): Technological and Structural Pressure
Future generations of digital technology imply continued increases in levels of interdependency and competition among various systems sectors such as computers, copying and imaging equipment, consumer electronics, telecommunications services, data processing networks, and switching equipment. Their technology bases, markets, and coordination requirements will converge much as those of microelectronics and computer systems did with the advent of VLSI. This convergence is already visible, for example, in the increasing use of computers to control data communications networks, and of data communications technology within computers. Similar laser-based optical technologies are employed in compact disk players, optical memories, and fiberoptic digital transmission systems. Copying is merging with computing; combined laser printer / copiers and CCD-based fully digital copiers are already being marketed, as are CCD-based electronic cameras.

In time, this trend will also increase their interpenetration with certain information intensive sectors such as publishing and financial services. Advanced electronics and optics will also bring digital information technologies into competition with currently favored analog or physical technologies such as broadcasting and mail. Some of these trends are already visible in product markets, and it is widely anticipated that (given the velocity of the technology) major changes in interindustry structure are only a decade away. Although predictions are hazardous, it appears increasingly likely that the eventual result will be a large, tightly integrated information technology sector dependent upon a technology base of microelectronics, materials science, digital optics and photonics, magnetics, and pure system science.
The transformation of technology and product markets induced by the advent of VLSI is therefore a specific case of a wider, long term process underway in the entire digital systems sector. This general transformation of systems production and markets might be described as one of continually increasing returns to scale and scope. While occasionally and temporarily this concentrationist trend will be counterbalanced by the appearance of new product markets with initially low entry barriers, there will be continuous increases in capital intensity, minimum efficient scale, and vertical coordination requirements.

The technology and cost structure of the systems industry is witnessing a long term shift in favor of capital intensive flexible automation, high initial design costs, lower marginal production costs, and high fixed costs of research, development, capital systems engineering, and customer service. Much of this transformation derives from the interaction of two trends: the increasing power of systems and their concurrently increasing complexity. Their combined result is the ability, but simultaneously the growing necessity, of using highly capital intensive, but ever more flexible, systems-based automation as a means of managing the complexity and improving the functionality of systems products themselves. The exploitation of computer-based flexible automation in production may shift product markets somewhat towards specialized functionality by reducing the cost penalty of low volume production of customized products, but will do so primarily through increasingly flexible mass production rather than small scale specialization. We have already noted these trends, for example, in the

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semiconductor market. As semiconductor technology continues to progress and
the semiconductor market grows, integrated circuits are becoming more like
systems. Initial design costs are increasing; fabrication is increasingly
capital intensive, computerized, and automated, yet more flexible as well.
The result is increasing concentration of production combined, somewhat
paradoxically, with increasing product differentiation.

The same now holds true for computers and even, increasingly, for
software. With the rise of large networks and personal computers, software
is increasing in importance relative to hardware. Two generic technologies
have arisen in response. The first, developed in the United States, is
Computer Aided Software Engineering (CASE): the use of high levels of
computer-based automation in support of advanced software methodologies,
primarily for new product development using very high level languages. The
second, developed in Japan, is the software factory. Japanese software
factories and their products, which have been studied in detail by Cusumano
and by several U.S. companies, appear capable of producing extremely high
quality, low cost products in well-defined domains (IBM compatible system
software, for example). They are highly automated, large (several use over
2,000 professionals), and capable of highly varied output within their
specified product domains. Flexible automation appears, then, to be an
extremely robust trend.

Finally, the systems industries are internationalizing - in sourcing,
production, markets, technology development, and interfirm alliances. This
process of internationalization derives from several sources, some common to
many industries now more global than previously, others particular to information systems. One, of course, is the rise of foreign demand and competition in product markets formerly dominated by American production and consumption. Another is the increasing capital intensity of the systems industry and the progressive shift of its cost structure towards initial and fixed costs. Global marketing, if successful, reduces long run average costs by permitting large investments to be averaged over large markets. Moreover, the increasing internationalization of other industries which consume systems tends to increase the comparative advantage enjoyed by those able to provide globally uniform products, standards, and service. This consideration also operates within the systems industries: as each globalizes, the others tend to do so in response.

Hence the major systems sectors - semiconductors, computers, digital communications, and software - show similar trends in technology, cost structures, and market behavior. All are becoming heavily dependent upon high initial cost, low marginal cost, capital intensive, computerized, and highly flexible technologies. Marginal and direct labor costs will decline in importance, often to insignificant levels. Concomitantly, the boundaries separating various systems product markets will change and often blur. Hence for example we find Sony entering the workstation market, Canon entering the market for integrated digital copiers and facsimile machines, AT&T entering the computer market, and IBM purchasing ROLM (a producer of digital telephone switches).

The rise of architecture and other initial costs appears linked to the
progress of globalization. With assets such as product designs, technology licenses, and software, the specifically transnational costs of replication and transportation are effectively zero. Use of highly architectured modular systems also has a further advantage in multinational operations, namely to reduce the costs of labor immobility and/or training. Replicating standardized, capital intensive systems requires less personnel transfer, and the overhead costs of managing multiple facilities are similarly reduced. Consequently production will tend to be multinational and/or globally integrated; and where production is marketized, the market will tend to be global as well.

Related tendencies favoring the same result seemingly arise from the continuous broadening of digital systems applications. Systems technology is becoming pervasive and inexpensive. Demand will therefore increase in nations whose income levels previously limited their consumption of digital systems. In many cases this demand will be for relatively homogeneous products such as digital switches, microprocessors, controllers, or personal computers. Furthermore, an increasing fraction of demand will be accounted for by goods and services which invite global provision. I noted earlier that VLSI favors digital networks. As multinational organizations invest in large-scale personal computing and networking, they seem to find themselves increasingly desirous of globally standardized systems and services.

Since the decreasing prices for digital communications may reduce the cost of multinational operations, this tendency may prove self-reinforcing, particularly within the information technology sectors themselves. As
decreasing communications costs and pervasive networking combine with the increasingly systematic use of modular, hierarchical architectures, global partitioning of activity becomes feasible. For example, it is now fairly routine for major software efforts - at least within firms such as DEC, IBM, and large banks - to be cleaved into architectural components which are then developed separately. This provides a variety of advantages. One is global workload and capacity balancing. Another is functional specialization which permits local concentration of personnel according to enduring technical categories. For example, IBM centralized much of its worldwide graphics software expertise in Hurseley Park, England. Research is centralized in Yorktown Heights, San Jose, and Zurich. IBM's $4 billion in semiconductor production occurs almost entirely in six sites - three in the northeast of the U.S., two in Europe, and one in Japan.

Or consider another example: the vertical partitioning of the semicustom logic business across both national and corporate boundaries. Vendors such as Fujitsu and LSI Logic provide design software, engineering services, and fabrication services. Customers either purchase software for use on their own computers or use local vendor design centers (LSI Logic has a dozen in the U.S., Europe, and Japan; the worldwide total for all vendors exceeds one hundred). Data General, for example, primarily designs gate arrays with Fujitsu software on its headquarters systems in Massachusetts. Completed design files are transmitted to Japan by satellite link, where circuits are fabricated in Fujitsu's domestic facilities. The circuits are purchased by DG Japan and transshipped as necessary. LSI Logic has similar arrangements with customers in Asia, the U.S., Europe, and Latin
America. Latin American transactions are slowed by the absence of suitable digital communications infrastructure, which obliges reliance upon couriers who deliver magnetic tapes.

The increasing concentration, capital intensity, and globalization of the systems sectors are already evident in their aggregate economics. The semiconductor industry has already been discussed, but a few statistical indicators deserve review here. According to U.S. Commerce Department data, U.S. semiconductor shipments (i.e. SIC 3674) rose at an 18.5% compound annual growth rate (CAGR) between 1977 and 1982. However, total employment grew only 7.9% annually in the same period, and the CAGR of production employment was even lower (5.1%). Conversely, capital expenditures rose at a CAGR of 33%. The industry also continued its internationalization: for example, both imports and exports rose more rapidly than shipments. Other statistical series, for example those compiled by Dataquest and by an M.I.T. economist, support these propositions, as do more recent statistics. The M.I.T. series, for example, indicates that the capital - labor ratio of U.S. based semiconductor production rose by 33% between 1980 and 1984. Available statistics indicate that Japanese capital intensity has risen even more rapidly.

Computer markets show similar behavior. While once again statistics must be regarded as approximate, the general trend is clear, and all statistical sources appear to agree. According to U.S. Commerce Department data, between 1972 and 1982, U.S. computer shipments grew from $6.5 billion to $36.7 billion, a compound annual growth rate (CAGR) of 19%. But
production workers' total employment grew at a CAGR of only 8% (from 65,000 to 140,000), i.e. less rapidly than shipments, while capital expenditures grew at a CAGR of more than 27%. Capital expenditures grew from $213 million (or 3.3% of shipments) in 1972 to $2.37 billion (or 6.5% of shipments) by 1982. Another statistical series compiled by NBER and Steve Kamin of MIT,\(^21\) primarily based upon Commerce Department data, indicates that between 1980 and 1984, the capital - labor ratio of the U.S. office equipment sector (SIC 3570-9) grew 54%. While aggregate statistical indicators of plant level scale are not available, the evidence suggests large and increasing minimum efficient scale in many systems activities.

Japanese software factories have workforces of over 1,000 and whose computer systems and software capital costs sometimes exceed $200 million. IBM's disk drive assembly facility in San Jose produces over $5 billion in revenue; NEC's Kyushu semiconductor plant produced $1.3 billion in 1986; IBM produces roughly $4 billion in semiconductors at only six facilities.

One very partial, crude index of globalization might be constructed by considering total product trade (imports plus exports) as a fraction of U.S. shipments. Using Commerce Department data, this fraction rose from 22% of U.S. shipments in 1972 (all exports, incidentally) to 31% in 1982 (about 80% exports). Between 1982 and 1985, this index rose again to 42% (only 65% exports). Another simple index which captures multinational operations is simply the percentage of firms' revenue derived from outside the United States. IBM now derives over half its revenues from foreign sales, DEC more than one-third, and the Japanese industry over 40%. In addition another indicator of internationalization, digital communications traffic, appears
to be increasing far more rapidly than either GNP, the computer industry, or conventional voice communications traffic. For example AT&T's data communications revenues are growing 30% annually, and an increasing fraction is international. IBM, AT&T, DEC, Hewlett-Packard, and several other firms already maintain large, private, global computer networks considered vital to their corporate operations.

Asian Competition

The Japanese industry's competitive success is already substantial. Japanese producers now dominate their domestic market, and supply large quantities of semiconductors, subsystems, and entire computers to second-tier U.S. and European firms. In some cases, these firms have begun to market their systems directly in foreign countries. Japanese mainframe systems are now roughly comparable technically to IBM's, and all three mainframe producers have also developed proprietary, and technically impressive, supercomputers. In addition, the U.S. industry has already been marginalized in the Japanese market; U.S. firms now hold about 20% of the Japanese market, and their share is declining. IBM's share of the Japanese market has declined to approximately 15%. DEC, which now holds approximately 7% of the world computer market, has been unable to increase its Japanese market share, which is now 1.6%. With each technological generation, U.S. share in new markets has declined. For example while U.S. firms still hold a substantial fraction of the mainframe market, their share of the Japanese personal computer market is trivially small. (NEC is the market leader, with a 40% share.)
In 1980, Japan became a net computer exporter; and in 1982, Japan became a net exporter of computers to the United States.\textsuperscript{23} Between the 1979 and 1984, Japanese computer exports to the United States rose from Y27 billion to over Y652 billion (roughly $4 billion), while imports rose very gradually to Y174 billion in 1984.\textsuperscript{24} And by 1984 Japan generated roughly a $5 billion worldwide trade surplus in computers, versus a slight deficit in 1979. In contrast the United States’ worldwide trade surplus in computers peaked at $7 billion in 1981, and declined to $3 billion in 1987. By one accounting,\textsuperscript{25} world market shares evolved as follows:

<table>
<thead>
<tr>
<th>Share of World Computer Market (Top 100 Companies Worldwide)</th>
<th>1978</th>
<th>1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>77</td>
<td>69</td>
</tr>
<tr>
<td>Japan</td>
<td>12</td>
<td>18*</td>
</tr>
<tr>
<td>Europe</td>
<td>10</td>
<td>13*</td>
</tr>
</tbody>
</table>

*Siemens, BASF, and ICL were counted as European despite the fact that all three now remarket Japanese computers. By a more accurate accounting, Europe’s absolute market share and growth rate would be lower, while Japan’s would be higher.

By 1984, Japanese computer production exceeded $15 billion (versus roughly $50 billion for the United States\textsuperscript{26}); 45% of total 1984 output was exported, versus 12% in 1979.\textsuperscript{27} While some of this increase derives from increased exports by IBM Japan, the relative increase in exports by domestic Japanese producers has been even larger. Computer and total revenues of the major Japanese producers have evolved as follows:

<table>
<thead>
<tr>
<th>Computer Revenues of Largest Japanese Computer Vendors ($B)</th>
<th>1978</th>
<th>1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hitachi</td>
<td>1.83</td>
<td>4.73</td>
</tr>
<tr>
<td>Toshiba</td>
<td>1.63</td>
<td>2.61</td>
</tr>
<tr>
<td>Fujitsu</td>
<td>1.25</td>
<td>6.58</td>
</tr>
<tr>
<td>N.E.C.</td>
<td>0.67</td>
<td>6.33</td>
</tr>
<tr>
<td>Total (Top 4)</td>
<td>5.83</td>
<td>20.24</td>
</tr>
</tbody>
</table>
Fig. 4: Exports and imports of computers

Source: EIAJ
While these statistics already show Japanese gains, they probably 
understate the progress of the Japanese industry. Firstly, Japanese 
progress has become markedly stronger since roughly 1981. Secondly, the 
foreign sales of Japanese firms and their affiliates, have been increasing 
rapidly for several years. Amdahl, which is now 46% owned by Fujitsu and 
increasingly markets Fujitsu systems, reported revenues of $659 million for 
the first six months of 1987, an increase of 60% over the first six months 
of 1986.28 Similarly for National Semiconductor Corporation’s Information 
Systems Group (ISG), which is dominated by National Advanced Systems, which 
markets Hitachi systems including IBM-compatible mainframes and 
supercomputers. National’s ISG revenues rose from less than $450 million in 
fiscal 1983 to over $890 million in 1987. Hitachi product sales contributed 
the vast majority of this growth, and continue to accelerate; sales of 
Hitachi products by National rose over 60% in fiscal 1987.29 (In fact 
National’s remarketing of Hitachi systems now accounts for over half the 
company’s revenues and essentially all of its profits, leading some to 
wonder how long National will remain a U.S. merchant semiconductor 
supplier.) Honeywell, which now remarkets NEC machines, also reported its 
strongest financial results in recent memory.

Conversely the recent performance of the U.S. industry has been less 
than stellar. While several major firms have performed well (particularly 
DEC, Apple, NCR, and HP) most of the established industry has not, and many 
smaller firms encountered serious trouble. For 1987 IBM reported a 6% 
revenue increase, all of which derived from currency shifts. Subtracting 
currency effects, IBM’s revenues declined 1% in 1987, following a decline of
7% the previous year by the same measure. (For 1987, DEC reported 25% revenue growth; Apple, 57% to nearly $4 billion.) Unisys reported increased earnings in 1987, but they came primarily from cost reductions; revenues grew about 10%, mostly from currency shifts. In July 1987 Data General announced a quarterly loss of $65 million, a 3.6% revenue decline relative to the same quarter of the previous year (to $314 million from $325 million), and 950 layoffs. Data General's losses totalled $104 million over the previous nine months. Also in July 1987, Control Data reported a quarterly loss of $5.5 million and a 5% revenue decline (to $786 million from $828 million) relative to the same quarter in the previous year, when the company lost $7.8 million. On the other hand, in the quarter ending December 1985 Control Data lost $298 million.

As with semiconductors, Japanese displacement of U.S. firms began through licensing, imitation, and theft of technologies appropriate to mature markets - initially the mainframe market, and primarily the IBM 370-compatible and Honeywell compatible markets. But as the Japanese industry has developed and U.S. fragmentation has progressed, the intervals between U.S. commercialization, Japanese technology acquisition, and Japanese competitive challenges have decreased. To some extent, the same is true of Korea and Taiwan, particularly with respect to IBM-compatible personal computers. Concomitantly, the U.S. industry's dependence upon its Japanese competitors for semiconductors, subsystems, and manufacturing services has greatly increased, as has the tendency of U.S. startups to license their technologies to major Japanese firms. Established U.S. firms such as Unisys and Honeywell are now extremely dependent upon Japanese semiconductors, high
speed CPU components, disk drives, and (increasingly) entire computers. As their financial condition worsens, this dependence tends to increase; and several of these firms are already in substantial financial difficulty.

The evolution of the personal computer market is one of the sharpest and most important examples of the industry's new cycle of initial U.S. fragmentation, self limiting entrepreneurial success, rapid Asian entry, and consolidation. Among established firms, only IBM successfully entered the first generation of the PC market. The microprocessor-based personal computer market as we now know it was created by startups such as Apple, though IBM had actually marketed a commercially unsuccessful personal computer nearly a decade earlier than Apple.33 In 1980, however, IBM entered a rapidly growing market dominated by 8 bit machines (some, like Apple's, with half screen displays) such as the Apple 2, Osborne, Molecular, and Compupro.

IBM marketed a 16 bit machine using the Intel 8088 microprocessor and a full screen display. IBM's open architecture encouraged the further short run fragmentation of the industry by explicitly permitting others to produce not only complementary products (e.g. software and peripherals) but also competing, imitative products (IBM compatible machines, or "clones"). Such clones indeed appeared as firms such as Compaq, Eagle, and others entered the market. However, neither IBM nor the U.S. startups predicted the astonishing rapidity with which Japanese, Korean, and Taiwanese multinationals entered the market. By 1986 IBM had slightly less than half of the IBM-compatible market; U.S. imitators held perhaps a quarter; the
other quarter was held by Asian imports, whose market share was growing rapidly. Several established U.S. firms, e.g. Sperry, entered the personal computer market simply by marketing Asian PC clones. After severe market share erosion, IBM introduced the PS2 series in 1987, using a proprietary bus architecture and graphics interface, thus abandoning most of the low end of its own market to intense commodity price competition. Apple has been able to perform well, and uses a proprietary architecture open to external connection but not direct imitation. But Apple will soon face the challenge of integrating single machines into enormous corporate networks, an area in which the firm has no experience. Furthermore, it now appears that open architectures - IBM PC and PS architectures, plus UNIX - will hold most of the mature personal computer market. At least eight Japanese firms have already entered the UNIX workstation market, whose intersection with mass personal computing is just beginning.

In addition to existing commodity markets, then, Japanese penetration of U.S. markets is extending into relatively new markets displaying rapid growth and in which U.S. fragmentation facilitates Japanese technology extraction and market targeting. The largest important of these areas of Japanese technology acquisition, U.S. fragmentation, and incipient Japanese entry is probably, in fact, the market for high performance UNIX workstations, currently a $2 billion market growing over 70% annually. Japanese licensing and use of U.S. startups in this area already includes the UNIX operating system and related objects such as C compilers (most major vendors), IBM 5080 graphics terminal emulation (NEC via Phoenix Technologies), the X windowing system (Sony from M.I.T.), reduced
instruction set microprocessors and workstations (Kubota via Mips and Dana, Fujitsu via Sun Microsystems), desktop publishing software (NEC and Fujitsu via Adobe Systems), and a wide variety of established packages such as Lockheed's CADAM system. Fujitsu, NEC, Canon, Sony, and Sanyo already sell UNIX workstations, and have used workstations of their own design internally for several years.

In addition, the Japanese industry appears to be making increased use of the U.S. university system. For example, Sony uses the recently developed X system from MIT's Project Athena and several Japanese UNIX workstations include Berkeley UNIX enhancements, which were developed by the University of California, Berkeley, and are available to any UNIX licensee for a minor fee. One of the two professionals I interviewed at NEC's Fuchu works was a young computer scientist who had just returned from a one-year visiting scientist appointment at M.I.T.'s Laboratory for Computer Science, where he had conducted a survey of reduced instruction set architectures and microprocessor based artificial intelligence systems. The three largest Japanese vendors all send technical personnel every year to U.S. research universities as paid visiting scientists. One has an internal examination administered annually to select thirty employees for one-year and two-year stays as graduate students and visiting scientists. And finally, internal Japanese technical capabilities, particularly those related to commodity technologies and high quality manufacturing, are increasingly impressive. One major U.S. firm purchases 22-layer printed circuit boards from Fujitsu, while Fujitsu is already using 40-layer boards.
in its own products.\textsuperscript{35} Surveys by Cusumano, as well as confidential studies to which I have had access, indicate that Japanese software factories now produce software systems for standardized or mature functionalities (such as mainframe compilers and factory process control systems) of far higher quality and with higher productivity than U.S. vendors.\textsuperscript{36} Japanese supercomputers and IBM compatible mainframes are now considered technically comparable to IBM and Cray products. Japanese high resolution graphics displays and laser printers are generally considered superior to U.S. products, and already lead in world markets.

Statistical indicators and several surveys confirm this general picture. The JTECH panel on computer science summarized its assessment in 1984 by stating that Japan was far behind the United States in basic research; somewhat behind in advanced development; but pulling ahead of the United States in product engineering.\textsuperscript{37} Between 1975 and 1981, U.S. patents granted to U.S. inventors in the field of office, computing, and accounting machinery declined slightly from 993 to 977, while U.S. patents granted to Japanese firms rose from 192 to 282. In the same field and over the same period, U.S. R&D expenditures rose 12\% in real terms while Japan's rose 191\%, albeit from a small base.\textsuperscript{38} Though more recent comparable data is not yet available, the recent evidence which is available - primarily corporate data derived from annual reports - suggests that these trends have accelerated. Since the early 1980s, total R&D spending by Japanese computer vendors (including their non-computer R&D) has increased far more rapidly than R&D spending by the major U.S. computer firms.\textsuperscript{39}
The sum of these various forces - increasing U.S. fragmentation, technological change in favor of capital intensive integrated operations, Japanese access to marketized U.S. technology, and increasing Japanese competitive effort - is likely to produce further U.S. decline in accordance with the strategic arguments described above for the semiconductor case. While I will not provide a similarly detailed analysis for the computer case, it appears that essentially the same arguments apply, for example in understanding the absence of long term cooperation between semiconductor, systems, and software firms or the growth of licensing by startups to Japanese firms as their competitive strength grows.

A Brief Regime Analysis

Consider now a brief assessment of long run strategic processes and strategic regimes in the computer industry. We can suppose that the domestic regime of the Japanese industry was largely the same as in the semiconductor case. What of the domestic U.S. regime, and of the international strategic interactions between the two systems?

Consider first the domestic U.S. system. The early established industry led by IBM cooperated implicitly in extracting rents, while not cooperating strategically in negotiations with Japan or procompetitively in R&D or technology sharing. Among established firms, only IBM provided public goods in substantial quantities, and even IBM was able to do so in a manner which produced largely private benefits; for example, large university donations of IBM equipment trained students on IBM systems rather
than competitors'. Once again aside from IBM, U.S. computer firms failed to invest in semiconductor technology. The industry also failed to cooperate vertically with the volatile merchant sector, and was highly exposed to entry in emerging systems markets by entrepreneurs exploiting novel VLSI-based technologies and architectures.

Hence the result has been a "re-merchantizing" of the previously stable computer industry, and a balkanizing of interests and territory within it. Increasingly, the systems sector has resembled the merchant sector, though IBM and DEC do remain clear leaders. Hence the U.S. regime is, to a large extent, one of mutual defection and U.S. firms do, frequently, license their technologies to Japanese competitors. They also, frequently, exit markets in which unsustainable price competition appears; even IBM has done so to some extent.

The relative stability of the industry did, however, imply that human capital investments were appropriable; IBM and to some extent its second tier rivals did have substantial training programs and low personnel turnover. IBM largely still does; DEC and Hewlett Packard also have low turnover levels and large training budgets. This however, was the major beneficial difference between the semiconductor and systems sectors' internal strategic regimes. Ironically, the stability and leverage given to established computer firms by switching costs and lock-in during the classical mainframe period seems to have performed a strategic function equivalent to the merchants' perpetual instability: it permitted all firms to compete from a similar basis of inefficiency and/or shortsighted rent
harvesting. New architectures and open-market VLSI then shifted the U.S. computer industry towards the merchant strategic regime.

Consequently, Japanese strategies similar to those seen in the semiconductor sector (licensing, technology imports, illegal imitation, market closure, and commodity market entry) became attractive - to the extent that international strategic interactions between Japanese and U.S. actors resemble those of the semiconductor sector. To a large extent, they are. The largest difference, probably, arises from IBM's leadership, including the fact that IBM obtained a far stronger position in Japan than did the merchant sector. To succeed in a maturing IBM market is more difficult than snatching one from a merchant semiconductor firm. But many other elements of Japanese semiconductor strategy - such as licensing from smaller new firms - could be transferred directly to the post-VLSI computer market. Furthermore, the combination of IBM's general, albeit gradual, relative decline in the world market and the strong actions taken within the Japanese arena has gradually reduced the impact of IBM's leadership and initially strong Japanese position.

And in most other respects, the U.S. computer sector faces an international environment rather similar to that faced by the merchant industry. The U.S. government is similarly passive; long term violations of intellectual property rights go unpunished; little government support for the commercial industry is forthcoming; Japanese protectionism and strategic closure permit Japanese firms to exercise unilateral, asymmetric control over the areas, timing, and terms of the industry's globalization.
Therefore it appears that the merchant semiconductor industry was not a wholly anomalous case, in two senses. First, the particular strategic processes which have plagued it have appeared elsewhere; and second, strategic processes are, in fact, important. Indeed, I will now argue that, on the available evidence, much the same analysis holds for the U.S. high technology system generally, including the university system and other high technology industries such as the genetic engineering sector. As Japanese competition grows and technology intensive industries globalize, a new international strategic regime is being created; and the United States is being integrated into this regime on unfavorable terms.

4. The New International Regime

Globalization With American Strategic Disadvantage

The internationalization of technology intensive competition, driven in part by progress in digital information systems, is leading to the formation of a new, globally integrated industrial system, particularly in high technology industries themselves. As a consequence of domestic institutional decline, strategic fragmentation, and a variety of environmental conditions which shorten the effective time horizons of U.S. strategic actors, the United States has increasingly become a fragmented provider of knowledge, services, and markets to strategically coordinated foreign competitors.
This process is further evidence that productivity and competitiveness may not depend only or even primarily upon factor costs or classical determinants of the terms of trade, but rather upon how well economic systems can control, and respond to, strategic incentives. Moreover, the international system now emerging involves more than trade, foreign investment, and product markets. It comprises global production, transfers, and usage of institutions, information, services, human capital, and technology as well as capital and final products. Indeed some of the most important benefits obtained from the United States by foreign multinationals appear to be in these nontraditional categories.  

Consider, therefore, some aggregate indicators of American and Japanese specialization in the international regime of high technology competition, beginning with generic research. The United States has long been, and remains, by far the largest producer of basic research. In 1973 the U.S. produced 38% of the world's scientific and technical literature. By 1982 the percentage had declined only modestly, to 35% of world research output. Aside from substantial declines in biology and pure mathematics, U.S. shares changed very little in the 8 areas of natural science and engineering research surveyed by NSF.

In contrast, patenting activity tells a very different story. U.S. shares of world patenting activity are declining, and far more rapidly than basic research output. Between 1975 and 1982, the U.S. share of world patent activity declined from 27% to 23%. Moreover, the U.S. roughly held its share or improved it in only two high technology areas surveyed by NSF,
drugs and microbiology. In five others, U.S. shares declined steeply.
Between 1975 and 1982, the U.S. share of worldwide new patent activity
dropped from 28% to 14% in robotics, from 47% to 30% in lasers, from 43% to
27% in integrated circuits, from 27% to 22% in telecommunications, and from
26% to 21% in internal combustion engines.45

In contrast, Japan's aggregate share of world patent activity rose from
15% to 20% during the same period.46 Its share of integrated circuit
patents rose from 18% to 48%; of laser patents, from 11% to 37%; of robotics
patents, from 9% to 13%; of telecommunications patents, 11% to 37%; of
drugs, 16% to 20%.47 Japan declined only in microbiology, from 47% to
34%.48 Moreover, it is unlikely that Japan's rise can be attributed to any
artifact of the Japanese domestic patent system, as has occasionally been
suggested. Between 1969 and 1982, Japanese foreign patent applications rose
55%, while those of the United States declined 50%.49

Yet the U.S. trade surplus in license royalties - i.e. net technology
exports from the U.S. to other nations - remained very wide, and actually
rose in both absolute and ratio terms. Between 1972 and 1982, the U.S.
ratio of royalty receipts to royalty payments rose slightly from 8.7 to
9.9.50 In contrast, Japan's ratio of receipts to payments rose slightly but
remained less than 0.7 - i.e. Japan remained a net technology and license
importer.51 The fact that U.S. net license exports were increasing even
while the U.S. share of world patenting activity was declining rapidly
suggests that the United States sells technology more freely than other
nations, and that in fact its propensity to sell technology rather than to
use it has recently been increasing. The same is not true, however, of Japan. Japan's royalty revenues remained less than one-eighth as large as those of the United States in 1982, and Japan's net technology trade was improving far less slowly than its patent position.

And finally, U.S. exports of technology have increased rapidly while U.S. exports of high technology products have not, while again the converse is true of Japan. Between 1972 and 1982, the U.S. trade surplus in high technology products grew rather slowly, from approximately $7 billion to roughly $11 billion (in constant 1972 dollars), and has since become a deficit. Japan's high technology trade surplus grew from $3 billion to nearly $15 billion in the same period, and has continued to increase rapidly since. It is exceedingly unlikely, moreover, that a positive U.S. trade balance in technology could ever compensate for trade deficits in high technology goods.

Hence the picture presented even by the most general, highly aggregated statistics is of two very different national systems. The United States maintains an advantage in basic research; is losing its advantage in innovation; sells its inventions readily; and is losing its comparative advantage in commercial competition. Japan, on the other hand, performs relatively little university or basic research; is rapidly increasing its commercial innovation levels; purchases large quantities of technology from the United States but sells little of its own technology; and is increasingly successful in high technology markets.
Other trends in the functional distribution of activities, and in both horizontal and vertical market structure, are consistent with the proposition that investment patterns and incentive structures encourage commercial appropriability in Japan more than in the United States. Not only is a higher fraction of U.S. (versus Japanese) R&D devoted to basic as opposed to applied research, a far higher fraction is also military as opposed to commercial. While there is considerable controversy as to the commercial spinoff of military R&D, military R&D is surely on average much less effective for commercial purposes than explicitly commercial effort.

Between 1971 and 1983, United States non-defense R&D rose from 1.7% of GNP to 2.0%. But Japanese non-defense R&D rose from 1.8% of GNP to over 2.6% of GNP during the same period. Since Japanese GNP grew far more rapidly than U.S. GNP during this period, absolute Japanese expenditures grew very rapidly indeed.

Furthermore, the fraction of nondefense R&D which takes place in universities is larger in the United States than in Japan, where a higher fraction occurs in large firms. This generic U.S. research and human capital production base is highly available to Japanese firms, while Japanese corporate applied R&D is subject to far more strategic control. Moreover, Japan has systematically provided itself with the capacity to use U.S. institutions, research, and knowledge. For example, between 1972 and 1983 the number of Japanese citizens studying in U.S. universities rose from less than 5,000 to approximately 13,000. In contrast, there are fewer than 1,000 U.S. students in Japan. Less than one tenth of one percent of U.S. technical professionals speak Japanese, and I have not encountered a

The past decade has also witnessed much fragmentation of American high technology industry, once again in notable contrast to Japan and Korea. Japanese and Korean high technology production remain dominated by core oligopolies of industrial complexes. While new firms are often created, they are usually created by, or with the assistance of, core multinationals which hold substantial equity positions, and also often supply executive personnel and working capital.58 The production levels and world high technology market shares held by these diversified industrial complexes have increased more rapidly than U.S. and world production. In contrast, and with a few notable exceptions, established U.S. high technology firms have experienced relative decline.

Rather, the U.S. has seen rapid growth of new venture formation. Between 1974 and 1984, annual total venture capital commitments to new U.S. firms rose from $250 million annually to over $3 billion.59 Venture capital committed to high technology industries behaved similarly. Between 1975 and 1983, annual venture capital commitments to high technology manufacturing firms rose from $75 million to $1.6 billion.60 Between 1976 and 1983, the number of initial public offerings (IPOs) of U.S. high technology companies rose from 4 to 141, and the total amount raised in such offerings rose from $12 million to $1.5 billion.61 A substantial fraction of these high technology startups and IPOs, probably almost one half, were semiconductor, computer, and software firms.
As I argued with respect to the semiconductor industry, this fragmentation probably reduces the ability of the United States economy to appropriate the returns to domestic R&D, and increases the likelihood that technology will be sold rather than used by U.S. firms. Personnel turnover has similar effects. One recent survey indicated that the expected tenure of middle managers in U.S. industry has declined from 13 years to 7 years since 1970.\textsuperscript{62} Personnel turnover in startups is even higher. Not surprisingly, surveys of Japanese business consistently report lower turnover levels, and higher levels of internal corporate training, than are found in the United States. For example Jaikumar's study of flexible machining systems found that Japanese workers received three times as much training as their U.S. counterparts, despite the fact that their average formal educational level was already far higher.\textsuperscript{63}

Hence, a substantial and increasing fraction of U.S. research, development, training, and technology generation is either explicitly open, is not appropriated by the performer, and/or is conducted by small startup firms with little experience in multinational competition. Moreover, the United States is also becoming a net exporter of advanced degrees. Over half of all U.S. engineering Ph.D.s are now granted to foreign citizens, and over half of these Ph.D.s return to their home country.\textsuperscript{64} In contrast, Japan produces far fewer engineering Ph.D.s, but produces more engineering bachelor's degrees than the United States, and exports very few of them.

In many respects, furthermore, the university system mirrors the fragmentation of the startup sector. And indeed as Japan's interest in
advanced research increases, it has begun to use U.S. universities through industrial affiliate programs, employee rotations as visiting scientists in university research laboratories, university research support in return to access to new research results, technology licensing, and donations of Japanese equipment. For example about 25% of all members of M.I.T.'s Industrial Liaison Program are now Japanese, and Japanese firms are widely agreed to be the Program's most sophisticated and aggressive users. Similarly for other services; in 1986, one MIT summer course in VLSI design had more Japanese than American enrollees.

For example, several large software systems for VLSI circuit design and related functions - Crystal, SPICE, Macpitts, Magic, others - were developed at Stanford, Berkeley, CMU, and MIT and are now standard tools in many commercial firms. Berkeley UNIX, developed by U.C. Berkeley with DARPA funds, is available to any UNIX source code licensee for a trivial fee. The X Windowing system developed at MIT has recently become an industry standard for UNIX workstations, and MIT's NuBus architecture is also increasingly popular. The 1984 JTECH Panel report on computer science in Japan noted that BSD 4.2, the then-latest release of Berkeley UNIX, was already widely used in Japan. Several recently announced Japanese engineering workstations employ Berkeley code, including its networking support and file system improvements.

A number of software technologies (languages, software development techniques) and novel machine designs have also originated in American universities. Many other architectures and standards were developed by U.S.
government agencies, private firms, or standards bodies such as the American National Standards Institute. Most of these are now openly available worldwide, as a consequence of U.S. government procurement policies, standardization conventions, intellectual property law, and industry structure. For a large fraction of the computer and software markets, these standards in effect constitute product specifications available to any imitative manufacturer. In some cases, the U.S. government requires compliance with these public standards as a precondition to bidding for government contracts.

Hence, from the point of view of a Japanese or Korean multinational, a wide variety of activities—personnel defections from major U.S. firms, licensing from U.S. startups, advanced education, and university research efforts themselves—increase the technology portfolio available on the open market in the United States. And because these activities do not penetrate the Japanese or Korean arenas, they represent little direct risk to potential competitors, either through market competition or domestic strategic disarray in R&D, technology control, personnel training, or government policy arenas.

So by nature of their subsidized efforts, institutional incentives, and fragmented structure, American startup and university sectors collectively provide R&D, technology assessment, and market research services as worldwide public goods. They also provide access to the technologies and markets themselves, skilled labor, and a variety of information services for would-be strategic entrants. Startup activities collectively characterize
novel markets, their potential size, and relative demand for various product attributes. Entrepreneurial instability lasts until an internal leader emerges, large firms enter, or both. In either case, however, major firms can observe the entire distribution of startup activity.

Then, as the market reaches substantial size, the U.S. and Asian multinationals enter and compete for the mature market; but U.S. firms must contend with the startup sector and the fragmentation of the American arena as well as with foreign competition. Whereas startups rarely obtain strong positions in Japanese and Korean markets, they do sometimes represent significant competitive pressure within the American market. Furthermore, American startups are generally more valuable for Asian firms than for American oligopolists such as IBM. Asian entrants, unlike established U.S. firms, often have little previous experience in advanced American systems markets. Hence startups provide information and direct assistance which cannot easily be obtained by observing oligopolists such as IBM, as a consequence of their vertical integration and attention to protection of proprietary information.

A Final Example: Biotechnology

The U.S. biotechnology sector is extraordinarily analogous to the merchant semiconductor industry. Genetic engineering is a novel generic technology, developed through a publicly funded and publicly available (and primarily American) science base, whose continued development will transform both process and product technology in at least three major industrial
sectors: agriculture, chemicals, and medical products including diagnostics and pharmaceuticals. The United States currently leads the world by a considerable margin in both basic scientific research and commercial efforts. However, U.S. efforts have a characteristic structure reminiscent of the semiconductor industry of the 1960s and 1970s.68

A few of the large U.S. multinationals in the affected downstream sectors have substantial efforts – notably DuPont (chemicals), Monsanto (chemicals and pharmaceuticals), and Merck (pharmaceuticals). Most, however, do not. Most biotechnology R&D, and most particularly the best R&D, is being undertaken either directly in universities, where it is entirely public, or in venture capital funded entrepreneurial firms which resemble merchant semiconductor producers in virtually every way save the nature of their capital equipment.69 Over 200 such firms have been formed over the last decade, often by departing university professors, and entry is continuing; nearly $2 billion has been invested in entrepreneurial firms in this sector.70 However, product gestation periods are long, intellectual property rights are in flux, many firms are losing money, and most obtain the majority of their current revenue from contract research performed for other firms. These research efforts are heavily concentrated upon drug discovery and product R&D.

In contrast, the Japanese biotechnology industry evidences the same structural and strategic configurations as the Japanese systems industry.71 It is dominated by large, stable, diversified, vertically integrated firms such as Ajinimoto and Kirin in food processing, Mitsubishi Chemical in
organic chemicals, and Takeda in pharmaceuticals. Both R&D and experience are concentrated in process technologies such as fermentation, where Japan is generally considered to lead the United States. Collections of firms, in conjunction with MITI, have announced plans for joint R&D efforts, though the amounts committed by the government appear presently to be small. In contrast, regulatory structures in the United States appear to raise the cost and difficulty of commercial drug approvals and exports, relative to other industrialized nations, thereby providing incentives for foreign licensing relative to domestic investment. Some of these policies have recently been changed, but many remain. Court actions by one small activist group, the Foundation on Economic Trends, have reportedly impeded several firms' efforts.\textsuperscript{72}

And once again, the Japanese market is amenable to strategic control, while the U.S. industrial arena is open, fragmented, and unstable.

Ajinimoto has provided funds to M.I.T. research efforts; Takeda has funded research at Harvard and sends five scientists annually to U.S. research laboratories; Kirin has established a licensing agreement with Amgen;\textsuperscript{73} Chiron has technology agreements with several firms, some of them Japanese; and in July 1987, Mitsubishi Chemical announced that they were considering a licensing and reciprocal marketing agreement with Genentech, the largest U.S. biotechnology firm.\textsuperscript{74} Mitsubishi Chemical would supply capital and generic fermentation technology, in return for which it obtains Genentech technology specific to manufacturing albumin, production assistance, and export rights. Mitsubishi Chemical and Genentech have announced that they may also cross-market each other's products.
Patterns of personnel and technology flows, both domestic and international, thus resemble the semiconductor case as well. Genentech’s two founders were researchers at Stanford and the University of California, San Francisco; they were the object of legal action regarding a patent dating from their university research. One of Amgen’s founders was a defector from Genentech. Genentech’s chief operating officer was formerly president of Abbott, a major pharmaceutical producer; the firm’s new vice president of science was recently recruited from the M.I.T. faculty. Other startups have been founded by faculty members of Harvard Medical School and Boston University to exploit colony stimulating factors and wound healing factors. One founder of such a firm told me in 1987 that a delegation of Japanese businessmen had already visited him and asked to license his technology. Laboratories at Harvard and M.I.T. already have several dozen visiting scientists on rotation from Japanese companies, in some cases working on prototypes of automated biotechnology-related capital goods developed by U.S. firms.

Some knowledgeable analysts, for example Professor Mel Horwitch of M.I.T., doubt that the biotechnology/pharmaceuticals case will replicate the path of the semiconductor case. And indeed there are differences. For example, biotechnology-related production may be more fragmented and less capital intensive than semiconductor production, and regulatory requirements constitute national entry barriers to some degree. There are also more vertical collaborations (between large U.S. chemical and pharmaceutical firms and the emerging biotechnology sector) than there were in the early
history of the semiconductor industry. Nonetheless, it would be quite surprising if the structural and strategic fragmentation of the U.S. industry, and the asymmetric openness of the U.S. arena, did not have a substantial effect upon the industry's future competitiveness.

In Conclusion

The importance of this asymmetrical U.S. openness is difficult to assess independent of the other forces which reduce productivity growth in the U.S. system. If the other structures and practices of the U.S. information technology sector were favorable to investment, innovation, and long term technical cooperation among firms, these strategic deficiencies might be considerably less important. At present, however, it would appear that optimal remedial policies would not only provide resources to, and lengthen the time horizons of, U.S. firms, but would also increase the strategic reciprocity of foreign economic systems which currently have more access to the U.S. system than U.S. actors have to theirs. Both investment levels and recognition of international strategic interactions are likely to grow in importance over the next decade, as the globalization of high technology industry continues and competition intensifies.

It would therefore appear that the internationalization of high technology competition finds the United States in a declining structural and strategic position. The final chapter of this essay considers, first, what the consequences of continued decline would be, and second, the potential effects of alternative strategies and policy measures.
NOTES TO CHAPTER FIVE


2. Excluding the centrally planned economies, the world computer market is now (1987) roughly $175 billion. IBM's revenues are approximately $55 billion, of which perhaps 90% derive from computers and related products (not counting copiers, mechanical typewriters, etc.).


4. Japan Electronics Almanac, 1986, p. 90-97. These statistical series clearly contain several errors; however, the statistics and estimates derived here are consistent with those from market research firms and company annual reports.


6. For discussions, see Flamm and also Marie Anchorduguy's Ph.D. thesis.


8. Ibid.

9. Ibid.
10. These statistics are from Louisa Koch, "Data On the Electronics Industry in the U.S. and Japan," unpublished manuscript, prepared for Charles Ferguson, October 1987. The raw data are derived from company annual reports, official statistics, and occasionally market research services. The company data cited here are from annual reports.

11. For an extremely self-serving but interesting account, see Adam Osborne, "Hypergrowth," 1984.

12. For a discussion of the fault tolerant market see IEEE Computer, August 1984, an issue devoted to fault tolerant computing.


14. Ibid.


25. Computations by Louisa Koch, based upon Datamation annual surveys and corporate annual reports.


31. Ibid.


33. This early IBM machine, the 5150, ran APL and BASIC.


42. Ibid.

43. Ibid.

44. Ibid, p. 1.20, p. 205.

45. Ibid.

46. Ibid.

47. Ibid.

48. Ibid.

49. Ibid, p. 9. See also pp. 80-81.


51. Ibid.

53. Ibid.

54. U.S. trade surpluses in licenses and royalties have doubled from $5 billion to $10 billion over the last decade, while its high technology trade balance has deteriorated by at least $15 billion over the same period. While definitions and measurements differ, the trend is clear. According to one study prepared by the firm of Quick / Finan for the Joint Economic Committee of Congress, the U.S. is now a net importer of high technology products at the level of approximately $4 billion, versus a $26 billion surplus in 1980, its peak year. For information on technology exports and licensing, see U.S. Congress Office of Technology Assessment, "International Competition in Services," U.S. Government Printing Office, July 1987, pp. 57-69.


56. Ibid.

57. Ibid, p. 207.

58. I am grateful to Michael Cusumano, Ezra Vogel, Dwight Perkins, Ashoka Mody, and others for discussions regarding this subject. Again, the opinions are mine not necessarily theirs.


60. Ibid.

61. Ibid.

62. Personal communication.

64. "Science Indicators," 1985, p. 3.

65. Personal experience of the author. SPICE is virtually universal in the U.S. semiconductor industry. LSI Logic among others uses Magic and Crystal.

66. While an employee of IBM and later Oracle Corp., the author had substantial involvement in the UNIX market.

67. For example, prior to their successful entries of the IBM compatible personal computer market in the mid-1980s, none of the four major Korean producers had ever sold a computer in the United States.


I am also indebted to Maria Kukuruzinska of MIT, David Botstein of MIT and Genentech, James Gower of Genentech, Eric Lander of MIT, and a number of corporate executives for discussions and information concerning research trends in molecular biology and the biotechnology industry. Once again, the opinions here are mine not theirs.

69. For the relative size and quality of efforts in universities, biotechnology startups, and established firms, I am grateful to several confidential interviews.


71. See Arthur Humphrey, "Status of Biotechnology In Japan - 1986," unpublished manuscript, Lehigh University, 1986. I am also indebted to confidential interviews, particularly regarding Japanese fermentation technology.

72. Genentech has been able to market TPA, a product which dissolves blood clots, in France before obtaining FDA approval for U.S. marketing.
73. Personal communication.

74. Personal communication.

75. Personal communication.


77. An examination of the Harvard and M.I.T. telephone directories amply suffices to make this point.

78. Personal communication, Harvard professor.
CHAPTER SIX
IMPLICATIONS: STRATEGY AND POLICY IN THE FACE OF HIGH TECHNOLOGY DECLINE

1. Introduction

Implicit in the foregoing has been the idea that the retention of competitive domestic semiconductor, computer, and other high technology industries is important to the United States. Here, I consider this proposition and, subsequently, several alternative responses to U.S. decline. Three basic arguments are advanced. First, the decline of the U.S. semiconductor and computer sectors would damage the United States economy, and possibly the international system as a whole. Second, the strategic and institutional sources of this U.S. decline imply that neither market adjustment processes nor conventional economic policy prescriptions such as increased R&D funding would suffice to ensure the future health of U.S. high technology. Third and finally, satisfactory U.S. performance would require policies which not only supply greater resources to American industry, but which also change its incentive structures and the strategic environment within which it operates.

Appropriate policy would therefore not only increase the supply of human, technological, infrastructural, and financial resources available within the United States (for example through increased subsidies for engineering education and international study), but would also increase the likelihood of their useful employment. One way to do so, for example, would
be to link provision of these resources to conditions which increase the
time horizons of actors and their propensity to engage in procompetitive
cooperation. For example, Federal assistance to individuals and firms could
be phased over long time periods, linked to long run performance, and
require matching commitments. Federal policy could also reduce subsidies to
short-term profit taking and defection, for example through changes in the
tax treatment of stock options, pension benefits, corporate profits, and
capital expenditures. And U.S. science, trade, and foreign investment
policies could display increased strategic reciprocity in order to reduce
international asymmetries in market access, intellectual property
protection, and so forth.

An overview of the argument

Relatively standard economic arguments, in conjunction with the nature
of the industries in question, imply that the decline of the U.S.
semiconductor and computer sectors would have a substantially detrimental
effect upon the economic welfare of the United States. First, the
industries themselves are skill-intensive, high value added, high growth
sectors which will constitute a substantial fraction of global industrial
production by the turn of the century. The more a national economy is
composed of these sectors and the more efficiently these sectors operate
within it, the wealthier the host nation will be. Electronics sectors are
the largest high wage, high growth industries; and the U.S. already has a
large investment in these sectors, particularly in organizational experience
and human capital, not easily transferrable to other such sectors even if
they existed.

But in addition, both the semiconductor and computer sectors have strong and important linkages to other, collectively more important, arenas ranging from semiconductor capital equipment to industrial electronics, software, information services, aerospace systems, defense electronics, and military operations. The externalities and system economies of scale generated by their national collocation, and particularly collocation of technological and commercial leadership, are probably large; the costs of losing them are probably large as well.¹

Without economically and strategically sophisticated governmental interventions, market self-adjustment is unlikely to provide any reversal of the declines noted and/or predicted earlier in this essay. It is unlikely that without such interventions, any natural equilibrating mechanism could preserve the institutions and capabilities necessary for future U.S. competitiveness. The capital markets, for example, are unlikely by themselves to yield the large and coordinated financing required, for reasons similar to those which have inhibited other forms of long run cooperation in these industries.

Indeed, the requirement which presents itself is that of an integrated strategic policy of wide scope, coordinated centrally within the Federal government, and with both domestic and international components. It would encompass domestic education, R&D, procurement, sectoral rationalization, cooperative activity, systematic information exchange, long range
investment, and changes in strategic incentives, together with a range of internationalist policies covering trade, access to foreign arenas such as product markets, and strategic regulation of foreign investment in the United States. Since there are presumably learning effects in policymaking as well as industrial production, the development of U.S. policy would necessarily be gradual. Perhaps, for example, it should begin with low risk policy measures such as joint R&D support, pursuit of Japanese market access, and the establishment of high level analytical capacities within the Federal government. In its entirety, the development of such an integrated policy would require many years — perhaps a decade or more. Long time horizons are beneficial to governments too; and arena performance might suffer as much from short time horizons in policymaking as from the shortsighted private behavior thereby induced.

2. Effects of Continued U.S. Decline

U.S. competitive failure in microelectronics and systems would have consequences well beyond the industries directly involved. It would also impose costs upon the wider economy, gradually reduce U.S. military capabilities, and increase U.S. strategic dependence upon Japan. These developments could also, possibly, provoke political conflict within the United States, for example between conventionally protectionist forces and sectors dependent upon Japanese technology, and might also lead to severe political friction between the United States and Japan. Eventually these processes could damage nations competing with the United States as well as the U.S. itself, through trade friction and possibly geopolitical effects.
Economic Implications

The economic consequences of reduced U.S. competitiveness in future semiconductor and systems arenas are difficult to assess, but they would probably be large - within 15 years, a significant fraction of GNP. Both the size of the effect and the difficulty of assessing it arise from the fact that although direct effects are clearly non-trivial, there are several reasons to believe that indirect effects may dominate. Both semiconductors and systems are critical inputs and capital goods for much larger downstream industries. Furthermore the technology available to both producing and consuming industries appears, in significant measure, to depend upon structural and strategic variables connected to international competition. Consequently if United States industry loses its competitiveness and institutional bargaining power, it may also lose access to world class technology. Moreover, this international competition could also affect developments at national and international levels - matters such as the make / buy decisions of large semiconductor consumers, the future location decisions of U.S. and Japanese electronics producers, and the evolution of the Japanese defense industry.

In the case of semiconductors, the principal downstream industries involved are (in no particular order) systems sectors such as the computer industry; military electronics such as secure communications equipment and weapons guidance systems; industrial electronics such as instruments, robots, and numerically controlled machine tools; consumer electronics such
as video games, compact disk players, VCRs, and digital televisions; aircraft and aerospace electronics; and automotive electronics such as dashboard instrumentation and fuel system controls. In addition, over the next twenty years several non-electronics sectors will become dependent upon semiconductors for the first time. Those often mentioned include the construction and consumer durables industries. For example, as digital communications becomes a pervasive infrastructural technology, the engineering and construction of large industrial facilities has begun to include digital systems. The current generation of "smart buildings" is the first example of this process. It appears likely that digital systems such as computers, digital switches, and local area networks will become so pervasive that systems demand will encompass the entire economy. The information systems intensity of advanced economies may reach 5% by the year 2000, and will probably continue to grow for several decades thereafter.

Collectively, the sectors which consume semiconductors are currently twenty times the size of the semiconductor industry itself (some indicative statistics are given in Appendix 2). The same is probably true of systems sectors. In several of these downstream sectors, competitive semiconductor and/or systems technology is critical to productivity growth and competitive success. In addition the systems sectors, because of their size and technologically advanced input requirements, affect the health of several industries upstream from them. The semiconductor industry is probably the most important one; but others of some significance include the construction industry, producers of robots and CAD/CAM systems, parts of the chemical industry, and parts of the educational and basic research system. For
example, an increasing fraction of advanced manufacturing - of photographic film, advanced materials, disk drives, optical cable, semiconductors, and information products generally - occurs in highly controlled environments requiring extreme precision, manufacturing reliability, real time information processing, and purity in materials. The semiconductor and computer industries are major, technologically leading users of such technologies and advanced materials.

Consequently, if the technical competitiveness and growth of U.S. semiconductor and/or systems production has any noticeable effect upon consuming and/or infrastructural industries, long run intersectoral effects could dominate the total economic effects of international competition in information technology. And there is, in fact, some reason to believe that such interindustry linkages contribute to relative productivity growth. However, even on the most conservative assumptions, involving only direct sectoral effects, the economic impact of competitive decline in information technology sectors would be large.

World semiconductor markets are currently slightly over $30 billion; total production, i.e. including U.S. captive production, is nearly $40 billion. This is not a large sum by the standards of international industries; but semiconductor production has grown 15 percent per year for twenty years, and will probably continue to do so for the next twenty. By the year 2000, world semiconductor production will probably exceed $150 billion. Semiconductor materials and equipment production, currently $10 billion worldwide, will probably grow to $30 billion. The systems
industries will be far larger. For example world computer and software
industry revenues are already on the order of $200 billion, and will exceed
$500 billion by the turn of the century. So even if U.S. decline is
confined to these sectors themselves, the economic stakes are still quite
substantial. Each one percent of the world market for these systems goods
will be worth nearly $10 billion by the year 2000.

The "direct" effects of competitive decline (i.e. not counting any
effect upon the competitiveness of downstream sectors) upon the U.S. economy
have two related components. First, decline would impose relative welfare
losses through unfavorable shifts in the equilibrium composition of U.S.
economic activity. While various mechanisms and policies can postpone such
losses or change their distributional structure across interest groups, they
could not be avoided. The decline of the semiconductor, systems, and
related industries would significantly reduce U.S. living standards,
investment, and tax revenues because high technology industries contribute
disproportionately to GNP, productivity, and living standards.

In 1984, for example, U.S. private sector wages averaged $350 per
week. In contrast, weekly wages in the semiconductor industry (as
imperfectly defined by SIC 3674) averaged $516. In the computer industry
(SIC 3573) wages averaged $552, and in the entire office machines sector
(SICs 3570-9), they averaged $546. And information technology sectors are
growing 7% to 30% annually worldwide, far more rapidly than U.S. GNP as a
whole. For example, world semiconductor shipments have grown 15% annually
for several decades, and world computer shipments have grown over 10%
annually during the same period. World software sales, currently on the order of $30 billion, are growing over 25% annually.

These industries are already major employers; in 1984, the computer industry (again, as defined by SIC 3573) employed 374,000 people inside the United States. The U.S. semiconductor industry employed 192,000 people domestically in the same year. In 1982, the U.S. software industry employed 224,000 persons. Hence the decline of these sectors would significantly reduce U.S. GNP growth and welfare by changing the mix of economic activity towards industries with lower wages, growth rates, and productivity gains. In addition, there might be significant multiplier effects due to reduced demand for other sectors' output.

The second class of "direct" effects is associated with trade and capital flows. Deteriorating U.S. competitiveness in microelectronics and systems would create a large negative item in the trade balance, as exports would decline while continued U.S. demand would ensure import growth. While macroeconomic responses might balance the current account in the long run, this would prove scant consolation. First, the fact that aggregate accounts might balance does not imply that sectoral accounts would do so. The United States might still become a progressively larger net importer in critical information technology sectors, and U.S. based systems production might be increasingly controlled by foreign firms. Furthermore, balancing international accounts would occur through mechanisms such as currency depreciation, sale of U.S. assets to foreigners, or real wage reductions. All would imply reductions in U.S. living standards, economic sovereignty,
and/or political independence. Future decline in information technology could therefore produce significantly detrimental economic consequences for the United States. If downstream and supplier industries were also affected, these problems would be even larger.

Indirect Economic Effects

Decreased U.S. access to information technology would probably cause a more general deterioration in the long term technological and industrial base of the United States. A high proportion of all professional activities, products, and process technologies - in manufacturing, services, and government - depend increasingly upon information systems. For example, by the mid-1990s electronic content may account for half of the cost of aircraft, a quarter of the cost of automobiles, and a high fraction of the cost of weapons systems. Computer and other systems purchases will account for a substantial fraction of all private sector capital spending.

The competitive decline of a single national sector can be transmitted to related domestic industries through various forms of efficiency penalties and/or strategic disadvantages. For example, domestic industries might be cost-disadvantaged if they must shift to imports as domestic suppliers fail. The exercise of market power by a foreign oligopoly could similarly raise the costs of an industry whose domestic suppliers declined. In the case of a vertically integrated oligopoly, upstream technology might be withheld from non-integrated foreign downstream competitors. Additionally, there may exist interindustry positive externalities or infrastructural benefits which
exhibit some degree of national specificity, possibly for strategic reasons.

Users faced with deteriorating U.S. suppliers may also be constrained by sunk investments and large switching costs: for example, computer users become locked into their vendors by virtue of complementary investments in software, internal expertise, and operational procedure. Indeed were it not for these constraints, the established U.S. computer industry would probably have already deteriorated more than it has. As the technology of the vendor deteriorates relative to competitors, users are forced to accept declining relative efficiency or bear switching costs. If this "lockstep" deterioration is nationally specific and there is international competition in the downstream product markets, then foreign users will gain world market share. In the case of systems industries, the most likely candidates for such downstream lock-in are information intensive sectors with large embedded systems or software portfolios - for example, telecommunications services, financial services, the aerospace sector, certain parts of the defense industry, and the military establishment.

The character, importance, and national specificity of these various mechanisms in the semiconductor and systems industries are difficult to assess but probably substantial. For example, the U.S. computer industry holds 90% of the U.S. installed base versus less than 40% of the Japanese installed base.\textsuperscript{16} It is likely that some potential drag effect upon downstream U.S. productivity and competitiveness does exist. For example, most relevant studies (such as Tilton's 1971 study of the international diffusion of semiconductor innovations, or Sciberras' 1977 study of
multinational electronics production) have concluded that technology is generally available first where it is developed, while foreign markets obtain it later. Of course, the local availability of a technology is not by itself sufficient to guarantee its use; if systematically short time horizons prevent farsighted investments, we have the American syndrome: a system which often still produces new ideas, but does not use them.

But perhaps as importantly, the availability of technology, its diffusion, and the prices charged for it can be strongly affected by the international balance of strategic conditions, institutional capabilities, and bargaining power in addition to traditional efficiency considerations such as transaction or transportation costs. The vertical integration, concentration, and strategic behavior of the Japanese industry, in conjunction with the fragmentation and competitive isolation of the relevant American arenas, suggest that U.S. bargaining leverage with respect to technology access would be low if the domestic U.S. industry were to decline. The character of the Japanese industry also suggests that its usage of technology denial strategies could become extremely attractive within the foreseeable future. Indeed, there is strong anecdotal evidence that it is already underway in some areas, for example lithography equipment and certain technologies required for high speed computers.17 (In Appendix 2, I describe some of the technologies, product markets, and strategic dependencies involved in the semiconductor and computer systems cases.)

Hence increasing Japanese leverage might generate a feedback process of further U.S. decline.18 For example merchant industry decline would affect
the capital equipment industry; the decline of the capital equipment industry would then react back upon semiconductor production, because neither remaining merchants nor captives will be able to obtain Japanese equipment on terms equal to those available to Japanese producers. The result, absent compensatory actions, would be gradual competitive decline and/or increasing Japanese leverage over U.S. corporate and governmental decisions in a potentially wide spectrum of electronics intensive industries.

**Political and National Security Implications**

The military and diplomatic consequences of this transformation may be comparable in importance to economic effects. The postwar system until recently dominated by the United States has depended upon its technological superiority and has consisted in part of U.S. security guarantees to Japan, accompanied by Japan's commitment to refrain from nuclear weapons development, offensive military deployments, and weapons exports. Gradually, however, U.S. technological and economic superiority are giving way to a situation in which advanced dual use technologies are widely distributed or, in some cases, controlled by Japanese firms.

Hence the United States finds itself attempting to retain primacy in policy and applications areas – East-West technology trade, future weapons technologies, the force structure of the Western alliance, and the use of military power – when other nations increasingly will possess or even control the technologies and industries which ultimately underly these
applications and policy areas.

Semiconductors, systems, and their related infrastructure can now be counted among the technologies and industries in which U.S. hegemony has waned. And the spectrum of military applications and policies affected by information technology is extremely wide. It includes C3I, precision guided munitions, strategic delivery systems, treaty verification technologies, intelligence analysis, strategic and tactical warning systems, and support processes such as system design and administrative data processing. In other words, information technology is as pervasive in the military sphere as it is in the economy. And while the technology now directly embedded in new U.S. ordnance tends to be mature or even obsolescent, much of the information technology employed for other military functions (e.g. intelligence analysis), and in the design of military systems, is quite advanced. The majority of this technology is dual use technology developed and/or employed for commercial as well as military purposes, ranging from embedded microprocessor-based control systems to scientific supercomputers.

Hence as the United States loses its information technology sectors, it will lose the military technology base as well. As with other downstream sectors, the result will be increased U.S. dependency upon Japan and decreased U.S. control over global flows of military technology. For example, it appears likely that United States dual use high technology firms and defense contractors will not obtain Japanese technology as readily as their Japanese competitors, nor will they be able to operate as efficiently as if a domestic industry existed. As the Japanese defense industry grows
and, potentially, begins to export weapons to the United States, this difficulty will become progressively more acute. 19

This situation differs from other forms of foreign dependency more familiar to U.S. defense planners, such as reliance upon imported oil or strategic materials. If high technology decline persists, Japanese technological supremacy will constitute a source of commercial leverage for Japanese industry and, to the extent that the Japanese government can control it, a form of political capital usable for a potentially wide variety of ends. Therefore U.S. military policy may become increasingly dependent upon domestic Japanese politics and upon Japanese foreign policy calculations as dependency upon Japanese technology increases. To be sure, some argue that this would not be an entirely negative development; but it deserves attention.

The evolving structure of information technology markets has several further implications relevant to U.S. defense and foreign policy. Two matters deserve at least brief mention: decreased U.S. market power, and the changing relationships between U.S. military R&D policy and commercial competition. At one time, the United States government could reliably assume that denial or provision of U.S. technology was a source of leverage over other nations because U.S. technology was the best available. While the degree of leverage and the wisdom of its employment can be questioned, it clearly existed.

Conversely, declining U.S. competitiveness implies major increases in
the worldwide availability of dual use high technology products whose markets will not be controllable by COCOM policy, and certainly not by unilateral American policy. Whereas formerly the U.S. tended to assume that any commercial technology used by foreign nations was automatically obsolete relative to that available to the U.S. military, it will increasingly be necessary to assume the reverse. Many dual use product cycles now have distinct international components as a consequence of licensing and second sourcing agreements, increasingly competitive foreign technology bases, and national development strategies. For example, IBM-compatible personal computers appeared in the United States approximately a year after IBM's open-architecture product reached the market.

By 1985, however, IBM PC-compatible machines were produced by literally hundreds of firms in Brazil, Mexico, Korea, Hong Kong, Singapore, Taiwan, Argentina, and other non-COCOM nations. The principal inputs to such machines - Intel family microprocessors, imitations of IBM's Basic Input - Output System (BIOS), various integrated circuits, floppy disk drives, Winchester hard disk drives, and the MS DOS operating system - were available through dozens of original vendors, second sources, imitators, counterfeiters, and remarketers in many nations. IBM's decision to market an open system, given the competitive environment, guaranteed that the United States government would be unable to exercise any control over the distribution of the machine. And while the IBM PC was perhaps an extreme case, it is not a singular one. UNIX workstations, for example, are not far behind.
U.S. Information Technology and Department of Defense Policy

For at least twenty years following World War II, the U.S. military funded a large fraction of both university and corporate R&D in advanced information technology. Furthermore, military procurement represented a majority of early purchases of newly developed products, a major fraction of total demand, and possibly a major subsidy to commercial technological progress. Since approximately 1970, however, the military's role has changed and its contribution to commercial technology development has steadily declined. Military funding of R&D, though difficult to account for precisely, appears to have shifted towards military-specific, as opposed to dual use or generic, technologies, and military technology now lags commercial markets, in some cases by as much as a decade. As a consequence, the competitive decline of U.S. information technology finds the U.S. military in a sharply different position than it occupied previously. Military procurement simply cannot sustain a technically competitive commercial industry; yet U.S. military capabilities and policies depend upon the industry, directly and indirectly.

The majority of advanced information technologies are dual use technologies with major commercial applications. In these dual use areas, commercial markets now often dwarf military markets, and their rates of growth and technical progress now exceed those of military procurement (even those of the Reagan period). Therefore the United States military is now heavily dependent upon increasingly globalized industries over which it has drastically less leverage than previously. To the extent that dependence
upon U.S.-based firms and U.S.-developed technologies is judged preferable to future dependence upon Japan, the U.S. military will necessarily have an interest in the long run competitiveness of U.S. industry in commercial markets. If U.S. competitive decline continues, DOD will inevitably be an interested party in high technology policy debates.

3. Market Self-Adjustment and Laissez-Faire

Given the argument advanced in earlier chapters, it appears unlikely that market adjustment would suffice to ensure the health of the American information technology sectors. In the absence of large scale changes in both domestic and international arenas, at least some of which depend upon government policy, decline will continue. Resource commitments to U.S. information technology activities will remain inadequate, and the resources supplied will be suboptimally employed, e.g. as a result of distributional conflicts and redundant efforts conducted in fragmented sectors. As a consequence of strategic forces, a high fraction of the social returns generated by U.S. activities will accrue to other nations.

Many of the structural conditions unfavorable to U.S. competitiveness involve institutional arrangements which are simply beyond the direct reach of U.S. industry, at least in the absence of collective action or assistance from some central authority. It is difficult for any individual actor to initiate cooperation or lengthen their effective time horizon even if they try, and they have incentives not to try; for, as indicated earlier, the "public goods" characteristics of such endeavors are very strong. Time-
horizon related decisions tend to involve strategic interdependencies or externalities, and tend to imply short-run risks or sacrifices which are rational only for agents with considerable security and resilience. These informational deficiencies, time horizon problems, prisoners' dilemmas, and public goods problems tend to reinforce each other. For many of the reasons that such arenas generate low long run performance and extreme fragmentation, they also fail to change when subjected to external attack.

For example, the short term competitive interest of individual U.S. systems firms is to purchase Japanese components, rather than either purchasing inferior U.S. components or making the enormous investments required for technically competitive captive production. This reduces the long run competitiveness of U.S. semiconductor technology and, thereby, the downstream industries themselves; but it is only in the systems sectors' collective, long term interest to protect the domestic semiconductor technology base. And U.S. firms face a set of strategic choices conditioned by this fact.

Suppose that in the absence of collective action, the destruction of American merchant production by the Japanese industry is a foregone conclusion. In this case, the individual interest of American semiconductor producers, particularly if their awareness is ahead of general market knowledge, is to liquidate profitably - through licensing, mergers, short term rent harvesting, and disinvestment. The collective interest of the merchant producers together probably lies in conventional protectionism which ensures their profitability at the expense of downstream industries'
competitiveness and productivity. Only at the level of the collective interest of the entire systems sector does one find an objective consonant with long run, economywide benefit. Given my description of the strategic dilemmas facing firms, this condition is unlikely to yield to market self-adjustment.

Persistent Fragmentation and Learning Difficulties

It is similarly unlikely that the market will supply the rationalization and capital flows required for competitive semiconductor and equipment production. History is discouraging in this respect, but so is logic; to a large extent, voluntary rationalization is yet another form of long run cooperation discouraged by the strategic environment and by U.S. firms' short time horizons. Consider mergers and acquisitions as a route to structural rationalization and efficient scale. First, the whole is frequently no better than the sum of the parts; by the time a merger is considered, firms have chosen specific technologies and strategies without prior regard to the other, and usually at least one is in dire trouble. Both conditions limit the benefits of rationalization. But there are strategic problems too. A prospective merger presents a bilateral bargaining problem in which zero sum interactions assume major importance. For example, the fact that a substantial fraction of top management will be made redundant makes executives (even if willing to surrender their sovereignty)21 extremely attentive to the organizational terms of the merger and to the valuation of their stock. This tends to generate games of "chicken," in which each party holds out for the other's capitulation. Such
logic applies to joint ventures and cooperative R&D as well as to outright mergers. For example, Texas Instruments reportedly refused to support Sematech until memory manufacturing, which might have competed with TI's products, was eliminated from the project's mission. Of course, Japanese industrial complexes are far more able to weather periods of unsustainable competition than U.S. firms in industries characterized by instability and undercapitalized fragmentation.

Vertical combinations additionally tend to have public goods attributes, particularly in the presence of strong Japanese competition. If the U.S. community could purchase from itself in a coordinated fashion (one possible result of vertical integration), U.S. competitiveness and bargaining power would probably increase significantly. But only if diversified vertical integration is widely adopted could it reliably evolve into an advantageous form of mutual cooperation combined with competitive discipline. Any single firm adopting such a strategy unilaterally would incur substantial cost penalties and strategic risks. Beneficial results from such a structural change would depend upon the industrywide adoption not only of the structure but also of longer time horizons, and of a strategic regime of simultaneous procompetitive cooperation and competition, yielding both information sharing and rationalization. The ability of firms to switch to internal sourcing, and/or to retaliate in kind, would lessen the danger of technology denial while increasing discipline and communication. Hence if widely and stably practiced, vertical integration combined with open market sales of intermediates and capital goods would be an attractive strategy. But the U.S. system is not closed - new ventures
continue to arise and vertical rationalization still faces the strategic
dilemmas described above. Additionally, it might raise serious antitrust
problems and, if not accompanied by measures to lengthen time horizons, the
structure could generate a real temptation to pursue shortsighted,
cartellistic strategies.

Another conventional economic question concerns capital availability.
If firms need capital and could operate profitably if it were supplied, why
does not the market supply it? And if financial institutions do not, why
cannot their customers, who depend vitally upon continued innovation in
semiconductor technology?

First, consider the financial markets' attitude towards investing in
the semiconductor industry. One cannot expect Wall Street to provide major
capital infusions into the merchant industry, given the U.S. industry's
failure to rationalize and the fact that each U.S. firm faces competition
not only from other merchants but from Japan and Korea. Capital from users
is to some extent a different matter, but it is equally unlikely that "the
market" will provide sufficiently favorable results, for reasons akin to
those which inhibit structural rationalization. In addition, the knowledge
and capabilities of many users lag, rather than lead, the supplying
industries. Few U.S. semiconductor users have the enormous sums and long
time horizons required to undertake efficient scale captive operations or to
fund a large merchant, even if they had confidence in a favorable result.

And unless it were massive and coordinated, user investment might not
change the basic dynamics of the semiconductor and/or equipment industries. Therefore to a large extent investment by a user would subsidize consumption by merchants' employees, stockholders, and/or the firm's competitors. Only where two interdependent oligopolists have a clear mutual interest in some technology region will such funding make sense - as it did between IBM and Intel, and IBM and Perkin-Elmer. But even IBM, for example, is only twenty percent of Intel's market. The interdependence of IBM and Intel is enormously larger than that of any other pair of companies; and yet their relations have been far from completely harmonious, largely for the various reasons cited above.

Thus although diversified vertical integration, greater interindustry coordination, increased engineering education, and increased investment levels may be attractive to the nation, "the market" is unlikely to provide them as a consequence of the public goods problems, strategic dilemmas, communication failures, and interest structures which characterize sectors such as the merchant industry. Absent strategically meaningful actions undertaken at a high level, the industry's fragmented decline will continue.

Sematech

The constraints imposed by private fragmentation and the Federal government's paralysis are nowhere more clearly illustrated than in the evolution of Sematech, the semiconductor industry's proposed joint venture for manufacturing research. The Sematech effort, conceived by IBM and others in early 1986 and under development throughout the industry at this
writing, contemplates increased coordination between semiconductor and
equipment producers, centralized development of advanced CMOS process
technology, and R&D in semiconductor manufacturing techniques. Technology
and output would be shared among, but restricted to, the U.S. based
membership. Since the sole government action requested is provision of half
Sematech's annual budget of $250 million (i.e., $125 million per year, a
small sum relative to the industry's importance), the Sematech effort can be
considered a "market" response to the problems of the U.S. semiconductor
industry. Consider, then, the degree to which Sematech could affect the
future competitiveness of the U.S. industry.

Sematech could have several benefits. It would provide increased
opportunities for systematic communication, information sharing, and in some
areas strategic signaling within the U.S. industry. It could play a
significant role in stabilizing the U.S. equipment sector through
coordinated purchasing, technical standardization, and subsidized R&D. And
it might improve the effectiveness of U.S. process R&D, manufacturing
operations, or both through lessened redundancy and improvements in
manufacturing practice. These are potentially important benefits, and if
even a fraction of them are realized Sematech is worth its cost.

However, Sematech's potential impact upon the overall, long run
competitiveness of U.S. semiconductor production is nonetheless quite
limited. First, consider what fraction of the large scale structural
problems described earlier in this essay would be addressed by such an
effort. Sematech will not open the Japanese market, prevent Japanese direct
investment in the United States, reduce Japanese competition, persuade U.S. merchants to merge for the national good, increase the supply of U.S. engineers, relax antitrust constraints, prevent licensing of U.S. product technology to foreign competitors, or provide significant capital infusions to any U.S. semiconductor producer. (Capital infusions to the equipment sector, conversely, might be of significant size.) Moreover, antitrust constraints, political bargaining, the modest scale of the effort, and intraindustry interests place strict limits on the efficacy of pure voluntarism of the kind which Sematech embodies.

For example, early plans calling for a large production facility as part of the Sematech effort were abandoned as a consequence of antitrust problems, funding requirements, and objections from some producers. Congressional support may require suboptimal regional allocations of Sematech's budget to pacify powerful committee chairmen. The debate within the Federal establishment probably imposed a one-year delay in Sematech's activities, not inconsequential given the rate at which semiconductor technology and competition proceed. The evidence suggests that unless the competitiveness and strategic behavior of the relevant sectors improve rapidly, the next recession (or certainly the subsequent one) will destroy much of these industries outright. The merchant industry's losses during the 1985-86 recession, for example, were equal to ten times the annual budget of Sematech.

Therefore if Sematech is to have an effect, some commercial results must show within three years, and major results must be obtained within five
or six. Otherwise the medicine will arrive after the patient has died. But even at best, timeliness will not guarantee success in reinstating U.S. superiority in process technology. For example, Japanese X-ray lithography R&D expenditures alone may exceed Sematech's net annual investments. At current trend rates, commercial X-ray lithography will arrive in two or three technology generations - in the mid-1990s, or about seven years after Sematech would begin operations. The advent of X-ray lithography, which is anticipated to be an exceedingly expensive and capital intensive technology, would also coincide with the U.S. industry's increasing sensitivity to cyclical shocks.

In some cases, in fact, cooperative efforts dependent upon acutely endangered firms may actually reduce time horizons rather than lengthen them. Improving near term performance will be of little ultimate benefit to an industry which underperforms long-range R&D; yet voluntarist efforts involving fragmented, shortsighted firms will tend strongly towards short range activities. In a strategic version of Catch-22, those most in need of cooperative long run efforts will be least able and inclined to provide them. In high technology industries, a clear market signal - i.e. one sufficient to galvanize an industry with short time horizons - is often the weather forecast which arrives just after the hurricane. Almost by definition, therefore, industrywide R&D efforts in high technology industries which are forced by market decline, as opposed to efforts driven by long range strategic assessments, will face serious short term pressures as a consequence of survival pressures.
Private, voluntary, nonexclusionary efforts must also begin with the existing structure and cannot offend any substantial fraction of current market participants. This imposes limits upon "market" action which may be onerous as a consequence of opportunities for short-term rent harvesting. If the arena is sufficiently fragmented or unstable, public goods problems may arise; each firm will desire to obtain the results of collective work without contributing to it, as reportedly occurred in the Microelectronics and Computer Technology Corporation (MCC). Firms may also seek provisions which protect them from market discipline. For example, it may prove exceptionally difficult to subsidize new entry from firms with strong technology bases and marketing skills, analogous to those prominent in Japan. Suppose, for example, that just as Canon and Nikon have emerged as major lithography equipment vendors, future U.S. lithography and/or direct writing equipment could best be developed by Polaroid, Kodak, or Xerox rather than by (say) Perkin Elmer, Ultratech, GCA, and the like. The requisite coalition would be difficult to form within a voluntary industrial consortium composed of existing producers. In sum, efforts dependent upon the consensus of all existing players may be limited by bargaining requirements and the need to please initial rather than eventual participants. For example, it might prove strategically preferable to fund two or three competing Sematech consortia, each with a smaller number of members, rather than a single, monopolistic one.

To be sure, Sematech would likely produce substantial benefits if brought into operation. Information interchange, and the realization that such interchange is important, would in itself be a very important gain to
the U.S. industry. However, efforts bound by the requirements of market voluntarism within the current regime are not likely, in and of themselves, to change the long run fundamentals of international competitive dynamics. Eventually, and preferably soon, major government intervention will be required in order to correct structural distortions, to bargain with Japanese industry and the Japanese government, to change the financial incentives which currently generate strategic defection, to coordinate efforts in institutionally disjoint arenas, and to provide the stable and large resource flows which long term success will require.

In summary, it appears highly unlikely that market adjustments will avert continued decay. More substantial strategic and/or governmental actions would be necessary. What follows is one avenue of argument concerning such actions.

4. Policy Considerations

General Objectives and Difficulties

The foregoing analysis suggests that future U.S. economic and political welfare require that the United States preserve (or restore) a domestic technological and industrial complex in the systems sectors which exhibits roughly competitive rates of growth and technical progress over the next twenty years, and which maintains a strong position in advanced technologies. This would be necessary and sufficient to provide direct benefits such as improved per capita income, and at least the opportunity
for indirect benefits such as continued sovereignty and consistent availability of best technology. However, this objective is not necessarily consistent with the happiness of the systems sectors' current firms or interest groups.

This policy objective has several other nontrivial implications. First, it implies the maintenance of competitive U.S. based and U.S. controlled research, development, training, corporate decisionmaking, and production. It would probably not be satisfactory, for example, to have an industry composed primarily of Japanese-owned firms operating in the United States. Nor, however, is U.S. autarky realistic, or even desirable; indeed continued U.S. competitiveness would probably tend to increase the systems industry's rate of globalization. But global integration can occur on either favorable or unfavorable terms. U.S. technical strength combined with strategic regulation of Japanese penetration of the U.S. arena could yield rather different long run results than would follow from continued unregulated decline.

However, this does not imply the desirability of conventional protectionism applied to current producers, of subsidies such as those given to the U.S. merchant marine, or of stockpiling strategies such as those employed for strategic materials. In fact, these strategies are strongly contraindicated. Conventional protectionism would be essentially equivalent to laissez faire, because in both cases the United States economy would be denied competitive rates of technological progress.
This implies that U.S. interests require policies which are subtly but critically at odds with conventional economic wisdom. The reason lies in the nature of high technology industries and associated technological revolutions. In a rapidly growing arena driven by persistent technical progress, long run welfare is not necessarily optimized by static efficiency or by the absence of excess returns. Economy wide, long term benefits are determined principally by the long run rate of progress in delivered price/ performance. Other things being equal, the welfare benefits of a higher rate of progress within, and/or adoption of, information technology would dwarf the effects of, say, allocative inefficiencies.

In fact the possession of consistently superior technology (which, in these industries, necessarily implies superior rates of technical progress) is probably the best way for a farsighted firm or industry to obtain rents in the presence of substantial competitive discipline. Conversely, the absence of rents as conventionally defined is no assurance that a firm or industry is serving the long run national economic interest. The merchant semiconductor industry, for example, does not seem to have demonstrated industrywide or even firm-level rent taking, as conventionally defined, in any substantial or enduring way. But rents were extracted indirectly - by the professional labor force, Silicon Valley landholders, and others who could partake in the industry's inflationary spiral. Second and probably more importantly, the industry's incentive structure led it to exhibit suboptimal long run rates of technical progress which damaged U.S. users and invited Japanese attack. The Japanese industry, conversely, generated consistently superior rates of progress.
United States policy objectives therefore require two closely related forms of action. First, the resources allocated to information technologies and industries must be increased. And second, the incentives which drive the arena, and which its current structure reinforces, must be changed such that resources are used more productively. Most particularly, the effective time horizon of information technology arenas must be lengthened. Both resource allocations and incentive changes must, to some extent, be provided governmentally. These requirements raise a number of problems which any policy must address.

Any mechanism which provides resources also, at the same time, affects incentives. Many of the incentives generated by resource provision would, in the absence of structural change, reinforce the current structure; therefore the resources would at best be wasted. At worst, they could actually worsen the economy's long run position. Consider, for example, what would happen if the Federal government offered to match the internal R&D budget of every U.S. semiconductor firm. If the argument developed earlier is correct, the result would be a short spike in U.S. merchant R&D, followed by redundant efforts and increased formation of startups, followed by increased licensing of new technology to Japan and Korea, followed by decreased U.S. competitiveness relative to foreign competition. In fact, it might be optimistic to expect even that sequence of events: the increased R&D funding might simply bid up salaries and other costs without significantly increasing real R&D output at all.
Yet under a different incentive structure and industry equilibrium, the
same general policy instrument might have the opposite effect. A recent
experience at M.I.T.'s Sloan School provides some insight in this regard.
Hauser, Fader, and others have recently developed software models of price
competition based upon iterated n-person prisoner's dilemmas, and these
models were used in classes via computer simulations and tournaments
conducted by students. The models and tournament results themselves once
again vindicate the robustness of cooperation and reciprocity as efficient
long run strategies. But the effect of related and concurrent strategic
interactions, particularly those derived from centralized regulation, was
illustrated by an unintentional classroom experiment.

In one course, the professor announced that grades would be given as a
function of individuals' absolute performance in strategic tournaments which
modeled price behavior in an oligopolistic industry. Students consequently
cooperated, achieved high performance, and nearly the entire class received
high grades. In another course, however, the professor announced that
grading would follow a curve. Students resorted to distributional warfare,
defection levels increased, and average performance was far lower. The
signal provided by the professor in the one-period grading game influenced
students' strategy in the second game they simultaneously played with each
other, generating a different strategic regime and changing the total
performance of the class.

On a larger scale, the U.S. government confronts similar choices in
fashioning high technology policy. Policy must encourage cooperative
behavior, and for the purpose of maximizing technical progress rather than short term profits. If merchant firms had long time horizons, favorable factor market conditions, and low turnover rates, matching (or otherwise increasing) R&D funding would probably be an effective policy measure, because it would provide resources without reducing competitive discipline, and the resources provided would yield appropriable technical returns.

But in the case of the merchant industry, the simultaneous provision of assistance and of measures to change incentives represents a substantial problem. Any near term policy which involves resource commitments prior to structural reform must be constructed so that it produces real benefits, and does not inhibit the process of structural change by temporarily propping up the least desirable portions of the existing system. For example, the Sematech proposal clearly satisfies this requirement, while the 1986 semiconductor trade agreement may not. Sematech is explicitly structured so as to raise the level of generic semiconductor technology and manufacturing practice, while maintaining competitive discipline.

In the long run both resource provision and incentive conditioning must involve, at least in part, the Federal government. At the extreme, this requirement may imply the desirability of creating organizations and policy mechanisms explicitly structured to be uncontrollable by electoral and political pressures. But this would require the existence of a highly capable, trusted cadre of policymakers and technocrats. Perhaps as troublesome, therefore, is the Federal government's level of expertise in high technology competition. U.S. public management elites are if anything
less well informed, as a general rule, than the industries in question, and
the foregoing argument suggests that much of U.S. industry is not terribly
well informed itself. Yet in a very real sense, the entirety of the
foregoing argument also implies that policy can and must outperform the
market - and, in many cases, the firm. If there exists no public
institutional or human capital pool with expertise in the requisite areas,
how can any policy meet the test of adequate performance? In some cases,
policy can be highly general, and operate by decentralizing detailed
decisions to the market. But in some areas, particularly with respect to
the evaluation and implementation of measures intended to alter incentive
structures (or to allocate scarce resources properly) considerable
technical, strategic, and industrial expertise will be required.

U.S. policymaking structures, however, show evidence of the same
structural fragmentation and institutionalized communication failures which
have reduced the effectiveness of the private sector. Hence any effort to
increase communication flows within the private sector should explicitly
include actual and potential policymakers. Relatedly, institutional self-
education and the development of continuing institutional intelligence
systems should be among the earliest and most urgent of government policies.

Long Run Strategy and Policy

First, major resource commitments of two sorts are indicated. One is
sufficient financial support for public, shareable assets to ensure
competitive U.S. performance in inputs and infrastructure - education and
training at many levels (and in subjects ranging from computer science to manufacturing science to the Japanese language), scientific and engineering research, information services, public digital networks. The other form of resource commitment required is financial support for private sector activities. Each form of support must ultimately involve net commitments of several billion dollars annually if the United States is to retain a competitive technological and industrial base in systems activities.

Second, the stability and security of firms in the relevant sectors must be increased without lessening competitive discipline. Their time horizons, risk tolerance, and ability to appropriate the returns to their investments must be increased. This implies a combination of positive incentives provided in part by government, continued discipline provided by industrial competition (possibly fostered by procurement policies), and the evolutionary selection of strong long term competitors. This does not imply, however, the elimination of small firms. Rather, small firms should face different incentives - to pursue long range development plans rather than profit-taking, and/or to form complementary relationships with larger complexes. For example, tax policy could favor wide distribution of stock options to employees if they vest over long periods (say 10 years or more), while penalizing narrow distributions to top management and vesting over short periods.

Third, national policy should support information exchange, communication, debate, and analysis within and between private managers, by economic policymakers, the defense community, elected officials, and the
academic community. The subjects involved should include not only technical information but management issues and scientific, economic, policy, and strategic analyses. In the case of private discussions, some form of antitrust dispensation is probably implied. This objective also suggests support for foreign language education, support for research in applied economics and policy analysis, and perhaps the establishment of Federal institutions devoted to economic policy analysis. But in addition to these diffuse measures, tax and R&D policy could for example be used to reward long term cooperation, for example by facilitating lending of personnel between firms, joint product development expenditures, and the like.

Fourth, Federal policy should redress asymmetries in the United States industry's position relative to other nations, particularly Japan. Obvious candidates include the antitrust laws, export controls, technical standards policies, intellectual property protection, regulation of direct foreign investment, and the relative accessibility of U.S. versus foreign markets, research, and educational systems. Many of these asymmetries are imposed by the United States upon itself. Some, however, arise from international strategic interdependencies and their manipulation by Japanese industry or government. In these areas, strategic reciprocity would be appropriate.

For example, it may be reasonable to link Japanese access to U.S. markets to certain forms of reciprocal U.S. access to Japan. Such strategic bargaining, to be sure, can be perilous. It is frequently tempting to force others to pay for one's own deficiencies. Furthermore, unless policy objectives are evaluated with great care, strategic activity could degrade
into cycles of reprisals. These could damage the United States as well as Japan, and could unleash uncontrollable internal reactions within both nations. But strategic reciprocity is also important for both economic and political reasons. The Japanese semiconductor market is now larger than that of the United States; exclusion of U.S. producers is a significant matter. Continued Japanese dependence upon U.S. technology and suppliers is also likely to have beneficial effects in political arenas.

Support for Education, Training, and Research

A gradual but major increase in relevant education and training would bring diffuse but probably large benefits. This area is one in which relatively obvious (though expensive) measures - scholarships, teacher training, direct funding of science and foreign language education - would appear to yield highly favorable returns.

Increasing the quality and supply of U.S. human capital would reduce the growth of professional labor costs and dampen the inflationary compensation and cost spirals which have characterized highly skilled labor markets and regional industrial concentrations in American high technology. The result would be increased use of skilled labor, particularly in areas in which such labor is currently in scarce supply, for example manufacturing engineering and foreign technology assessment. Turnover might also decline, which would yield direct productivity improvements, longer time horizons, and increased appropriability of firm-specific training. Employees would become more solicitous of their employers' needs, and more interested in
long run organizational success relative to high current income. This result might also be furthered by tax subsidies for long run (ten to twenty year) stock option plans, versus the four-year period typical of current Incentive Stock Options.

Increased technical literacy, particularly at precollege levels, might also reduce barriers to computer use across the entire economy. A diffuse but substantial increase in the adoption of and demand for advanced technology, including information systems, might therefore follow from having a more educated and capable workforce. It is worth emphasizing that these effects - those derived from the general education level of the entire labor force - could potentially prove as important as increased training of elites. This conclusion is driven by the expected pervasiveness of systems in economic activity, including the production of systems themselves. (For example hardware manufacturing currently absorbs 30% of DEC's entire worldwide workforce of 100,000, and the skill levels demanded for the company's systems manufacturing are increasing more rapidly than the actual skills of the workforce.) Within twenty years virtually all manufacturing, clerical, administrative, professional, and managerial work will be computer supported, and work in an advanced economy will automatically involve computer use. Additionally, there will be computers in many households. Increased skill levels throughout the labor force in relevant linguistic and technical areas might, therefore, translate into rising systems related demand and labor productivity.

The U.S. government could also test and implement such training
policies internally. For example, the U.S. military inducts large numbers of relatively unskilled personnel and increasingly depends upon their training in order to cope with complex weapons and support technologies. Basic instruction in systems technology for all military personnel might prove an attractive route for wide diffusion of education and for testing its efficacy.

In addition, there might be substantial benefits to the establishment of quasi-national laboratories or similar research organizations open to private firms. In a number of systems related disciplines, long range R&D and future technologies imply a need for large scale, centralized research facilities with permanent administrative and technical staffs. X-ray lithography is certainly one example, but others include materials research, manufacturing engineering, large scale networking, and possibly software engineering. Several large laboratories devoted to systems-related R&D, with boards of directors selected from firms and universities, might therefore be able to provide generic technology, communication among firms, and coordination benefits similar to those anticipated from Sematech. Intellectual property rights could be granted to performers, with the requirement that licensing be restricted to U.S. based firms. Exceptions might be granted according to principles of strategic reciprocity, e.g. access to foreign patent portfolios. Participation in such research consortia might be required as a precondition for receiving other forms of Federal support such as the tax expenditures suggested below.

Private Sector Support
The design of private sector assistance and its integration with other requirements is probably the most difficult problem in American high technology policy. First, it is difficult to design policies which reliably alter incentive profiles towards long time horizons and long run productivity growth. And second, it is even more difficult to do so by using neutral market incentives. For example, there is substantial agreement among knowledgeable analysts as to which firms, technical activities, and disciplines deserve increased support. It is much more difficult, however, to specify a neutral, abstract market signal which selects for such firms and activities. Given the strategic conditions described earlier, how could policy provide resources and yet ensure that they are invested rather than consumed, wasted, or transferred to competitors? Yet proposals based upon market signals are likely to be more politically realistic, and probably more successful, than those which gamble on the wisdom of a bureaucracy whose detailed choices replace the market.

And there do exist policy options requiring only minimal assumptions as to specifics but which nonetheless provide industrial assistance, beneficial incentive changes, and continued competitive discipline. The following discussion provides an example for analysis and refinement, one which might also serve other sectors facing similar difficulties, e.g. biotechnology-related industries.

Federal policy might employ tax based measures to lengthen the time horizons of U.S. decisionmaking, at levels ranging from individuals to
entire sectors. One such device might increase the correlation between long run employee compensation and the long term success of his or her current employer. The intended effect would be to reduce turnover and to lengthen the time horizons of the workforce. One important special case, for example, consists of the incentives facing the founders and senior executives of firms. One policy option would be to provide tax-based capital gains benefits for very long term holdings of an employer's stock, and/or tax penalties for its sale. Somewhat analogously, firms themselves might be rewarded for farsightedness and long run growth through the structure of corporate taxation.

The level of support available to qualified firms might be some fraction of its U.S. production, whether captive or open market, within the supported envelope of activities. To qualify for support, a firm and its executives could be obliged to meet requirements associated with its R&D record, training investments, and employee turnover. Support might consist of a mix of R&D grants and unrestricted low interest loans, both disbursed over a long period in annual installments. Principal and interest might accrue unpaid for the first five years of disbursements, and repayment might be partially forgiven as a function of later performance.

Moreover, the program could include a requirement that loans be partially collateralized - with stock options, escrow accounts drawn from salaries, or pension fund contributions made during the support period. Supported firms and their employees should be clearly aware from the onset of support that if the firm defaults on its obligations, a substantial
portion of employees' personal assets will be at risk. Finally, no firm should be eligible for support if its current executive officers include any person previously an executive officer of a firm which defaulted on a support loan. In other words, long term success would be generously rewarded, while long term failure will be punished, at both corporate and individual levels. One example might be an arrangement whereby executives' stock options receive favorable tax treatment as a function of their firms' long term performance, beginning some period after the options are granted.

Such a linkage between support, rewards, penalties, and long run conduct potentially yields positive externalities which affect both intrafirm and arena-wide behavior. First, firms with short time horizons would not request support. Second, those accepting support conditions would increase their attentiveness to turnover and employee development. In turn, employees would also be given an unambiguous signal that their future depends upon the long term success of their employer. As less successful (and hopefully, predominantly unsupported) firms lost competitiveness, the desirability of secure employment would increase further. In the event that a supported firm encountered competitive difficulty, there would be powerful incentives in favor of an alliance or merger with another firm which itself qualified for support, since the alternative would be painful for employees and executives alike.

However, there would be no detailed government intervention in corporate behavior, and participation would be optional. If support was sufficiently generous it would migrate the basis of competition towards long
run learning and investment, rather than short run rent seeking. But - to repeat - this is no more than an illustrative suggestion for consideration and refinement. Its primary intent is to establish that, although the problem is difficult, the design of useful market incentives is not completely implausible.

Procurement

One technically sensible project might be a Federal contract for the national provision of fully compatible public ISDN services, using private vendors such as AT&T, GTE, MCI, IBM, and the regional telephone operating companies as prime contractors. Another might be the provision of network services within the U.S. government. Such large projects, though not without a variety of risks (as recent Federal scandals connected with procurement of telecommunications systems indicate), could if properly administered lengthen time horizons and advance the industrial state of the art. The use of large, private, multiyear contracts controlled by the U.S. can also be used to promote strategic reciprocity. For example, foreign bids might be permitted as a function of the degree to which U.S. firms are permitted to bid on roughly equivalent foreign projects. Since at present foreign bids are rarely permitted, an increase in Federal systems contracting accompanied by reciprocity provisions might yield significant improvements in both foreign market access and domestic competitive discipline.

The principal risk to the policies described above, most U.S.
executives would argue, involves the nature and history of Federal procurement regulations. For example, current Federal standardization requirements promote industrial fragmentation and eventually imitative foreign competition. Hence, the productive use of direct Federal purchases would probably require substantial changes in these policies. Additionally, some might argue that Federal procurement as industrial policy, e.g. in the defense industry, has proven consistently detrimental to efficiency and commercial competitiveness. Nonetheless, if adequate competitive discipline and flexibility could be maintained, there is room for useful modernization of Federal systems hardware, and of systems employment in Federally supported programs, for example public education. Federal purchasing programs based upon generally accepted commercial guidelines could contribute to demand stability in commodity markets, and to Federal and/or commercial infrastructure provision. Procurement of commercial technology is a relatively benign activity in this respect, e.g. relative to military R&D programs.

Coordinated Strategic Education

Systematic analysis and greater communication among governmental, university, and corporate professionals and executives might improve U.S. performance as much as any expenditure of funds per se. But in addition, the problems and long run requirements of U.S. systems sectors are sufficiently large that major government actions will become politically inevitable. The quality of these interventions will depend in part upon the sophistication of public elites and the private organizations with which
they bargain and debate. Consequently, the production of sophisticated
industry analysts and analyses (technical, economic, strategic, political,
managerial), and their increased use within and by government and industry,
would be highly valuable, as would the development of institutions which
systematically develop them.

Unless this process begins very soon, future policymaking will suffer
from the poorly informed debate and structural difficulties which have
surrounded the Sematech proposal. This educational process must therefore
be initiated by the strongest, best informed agents - those who could afford
the inevitable short term risks, but who could also appropriate the long
term benefits. In this arena, IBM and a few universities are the best and
possibly only current candidates. If an industrywide joint venture for
advanced manufacturing R&D becomes a reality, such an organization could
perhaps become another widely shared source of industry analysis, education,
and debate. The establishment of permanent research centers devoted to high
technology industry and policy analysis (perhaps housed within universities,
national laboratories, or Sematech) would be highly desirable. Until now,
for example, Sematech has not explicitly included industry analysis, global
technology assessment, or competitive intelligence among its principal
functions. The inclusion of such an analytic mission could be of great
benefit; for while resource flows and strategic incentives are important, so
is understanding the structure of the problem we face. The more we know,
the more wisely we might be able to act.
NOTES TO CHAPTER SIX


3. Ibid.

4. Ibid.

5. Ibid.

6. U.S. Industrial Outlook, various years. See also estimates of Dataquest Corp., Input Corp., and IDC.

7. Dataquest Semiconductor Industry Service.

8. U.S. Industrial Outlook; Japan Electronics Almanac, various years.


13. For a more general discussion of the same issue - i.e. the consequences of declining real competitiveness upon welfare - see Lester Thurow, "Losing the Economic Race," New York Review of Books, September 27, 355


15. For a brief and simplistic discussion which perhaps says more about the current state of analysis than about the substantive issues, see the "Economic Report of the President," February 1986, pp. 119 - 120.

16. The U.S. figure is the author's estimate based upon production and trade data and assuming a five year life for systems. The Japanese figure is from Japan Electronics Almanac, 1986, p. 98.

17. Confidential industry interviews.

18. These issues are discussed in the so-called "Upstream - Downstream Report" of the National Security Council study of the semiconductor industry, for which the author served as a consultant.


20. For a discussion of this issue in the semiconductor arena, see the report of the Defense Science Board Task Force on Foreign Semiconductor Dependency.

21. One member of IBM's board of directors described the issue of personal and corporate sovereignty as the largest barrier to rationalization. An IBM executive concurred, noting that in contrast to corporate survival, when one's physical survival was threatened "One cannot turn into three other people."

22. Confidential interviews.

24. Confidential interviews, 1987. This is my opinion, not necessarily that of DEC or the interviewees.
1. Introduction; Theoretical and Empirical Motivations

The growth of international competition in the semiconductor and computer industries offers an unusually clear and important opportunity to explore and test alternative theories of industrial behavior. Examination of these industries sheds light upon the sources of industrial dynamics, declining American competitiveness and productivity growth, and the relationships between the nature of this decline and various possible responses to it (both domestic and foreign, private and governmental). In all of these areas there exist large outstanding problems and multiple, contending schools of thought. Here, I argue that recently developed (indeed, still emerging) theoretical models of evolutionary dynamics offer a potentially substantial improvement over the traditionally dominant models of such issues, namely those of neoclassical economic theory.

Theoretical Models of Industrial Arenas

Significant contributions from political economy, management, and sociology notwithstanding, the principal theoretical models specifically devoted to explaining industrial structure, national competitive performance, and international trade have until now come from neoclassical
economics. These models are mathematically rigorous, and the elegant optimization processes upon which they rely account for many features of economic behavior. But neoclassical economics depends heavily upon highly idealized assumptions for both its analytical elegance and substantive conclusions. And as intensifying international competition has sharpened both academic and policy debate, neoclassical theory (and the policy analyses it generates) has increasingly been found wanting.\textsuperscript{1} Its logical and empirical problems are now sufficiently severe that its descriptive accuracy and prescriptive utility must be considered limited.\textsuperscript{2}

Most obviously, perhaps, neoclassical economics has failed to produce a reasonable account of the large scale structure, behavior, and performance of industrial sectors (or, indeed, whole economies) over time and across nations. Only recently, however, has there appeared an avenue of theoretical inquiry which, by eventually complementing or superceding neoclassical theory, might offer an improved general understanding of competitive performance. Essentially, this line of inquiry considers the dynamic and/or strategic behavior of systems in which neoclassical considerations play a significant but not determinative role.

Several problems imply the need for a strategic and dynamic theory. First, neoclassical theory tends to omit a number of supposedly extra-economic issues such as politics, the behavioral propensities of actors, and the strategic norms prevailing in competitive arenas.\textsuperscript{3} Second, traditional neoclassical economics minimizes apparently significant economic forces (externalities, information costs, increasing returns) and/or their
implications for the principal foci of economic theory (such as competitive market equilibria). Third and relatedly, neoclassical theory employs highly stylized, sometimes arbitrary assumptions in modeling those arenas upon which it does focus its attention, often influenced by considerations such as mathematical elegance or tractability. As a result, neoclassical theory is often applicable only to relatively special cases, and when applied to more common situations tends to generate conclusions which are contrary to intuition and fact.

However, the strong implication of more natural, and less idealized, alternative hypotheses is that industrial behavior is significantly unstable, nondeterministic, dependent upon institutional dynamics, and affected by the strategic behavior of firms or governments. For example, two features characteristic of many economic arenas are (a) uncertainty in decisionmaking (arising, say, from incomplete information, rapid technical change, or strategic interdependency) and (b) increasing returns (or at least opportunities for increasing returns) at the level of organizations and industry structures. Yet these forces are powerfully, deeply subversive of neoclassical models and their principal conclusions. This combination (i.e., uncertainty as to the future and increasing returns) suffices to generate strategic processes absent from neoclassical models, and ones which cannot be cleanly analyzed in one-period or two-period models. Rather, the resulting processes are iterated strategic dilemmas of the kind modeled by Axelrod. The first, still quite recent, application of these processes to modeling microeconomic behavior, namely simulations of oligopolistic price behavior by Fader and Hauser, suggest that the use of iterated strategic
models can yield promising insights.

It seems plausible to believe that economic actors face many options which can give rise to long run strategic processes. Firms can refrain from stealing each other's employees, or alternatively can hire them at will. They can refrain from unsustainable price cutting, or they can engage in it and retaliate for it. They can ask the government for mutually exclusive private goods, or they can group together to press for collective benefits. They can cooperate with their users in order to secure long term relationships, or exploit them to obtain short term revenue. They can share technical information amongst themselves or impose secrecy. They can compete by making long term investments designed to produce superior productivity, or alternatively through nonproductive means such as predatory pricing and disruption of each other's operations. And they can cooperate in some areas while simultaneously competing in others. Moreover, if such strategic choices have real economic effects, they can alter the ensuing structure and performance of firms, arenas, and perhaps economies.

To the extent that industrial and political arenas in fact display such characteristics, the role of actions taken within regions of instability or indeterminacy (and factors affecting the size of those regions) could in the long run be as important as traditional neoclassical competitive equilibrium considerations in determining the development, structure, and efficiency of industries or other arenas of self-interested agents. (Since Axelrod makes a persuasive case that such forces can decide whether opposing armies actually fight each other or not, they would seem to have some salience.)

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Moreover, the logic of stable or ex post arena behavior would necessarily be sought at the level of industrywide strategic and institutional regimes, and the evolution of such regimes, rather than through the straightforward operation of determinate technical and competitive forces.

Under such assumptions politics, behavioral tendencies, strategic decisions, coincidence, the weight of institutional history, and the logic of strategic evolution become major determinants of economic behavior. Rather than being simply second-order distractions from equilibrium market processes, they are primary, independent forces deserving of explicit investigation. An understanding of these forces - i.e., of strategic decisions and their relationship to traditional economic variables - could reinforce, or mitigate, the action of "economic" variables themselves in long run industrial behavior. Unfortunately, we have until recently lacked any coherent model, or even any prospect of one, capable of ordering the potential universe of strategically based behaviors and their large scale, long run consequences.

Such a model might provide an explanation for the appearance and persistence of historical specificity, and of observed regularities in dynamic behavior inconsistent with smooth, foresighted, and determinate neoclassical optimizations. Rather paradoxically, we shall see that an evolutionary, strategically informed, and somewhat historicist view can yield determinate predictions, and can also account for regularities inexplicable through more traditional neoclassical mechanisms. For example, evolutionary models have begun to elucidate the processes by which
competitors begin to cooperate,\textsuperscript{11} the degree of cooperation evidenced by them,\textsuperscript{12} and the sometimes large benefits of such cooperation.\textsuperscript{13}

Important economic arenas (such as high technology and/or strategic industries) appear, in fact, to exhibit high levels of uncertainty, increasing returns, and strategic interdependency. Hence, the factors which determine the evolution of cooperative versus competitive behavior in such industries - across various arenas of interaction, across the total population of agents, and over time - might prove important to explaining and/or affecting their economic performance and the distribution of its returns.

2. The Evolutionary Model

This class of models considers the behavior of various arenas characterized by the presence of structures, agents, or forces which give rise to behavioral indeterminacy and evolutionary processes. In economic arenas, such forces include stochastic effects, imperfect foresight and other information limitations, sources of increasing returns such as network externalities or learning effects, and strategic interdependencies such as those described by Prisoner's Dilemma and other games. Behavioral or dependent variables of interest in economic activity would include market structure, comparative advantage, growth, and income distribution.

Our very limited theoretical knowledge pertaining to these and other forms of nontraditional dynamic behavior represents the state of what I
shall variously call the theory of evolutionary, strategic, and/or nondeterministic dynamics. It should be emphasized that the theory is not specific to economics, and thusfar noneconomic applications have received more attention. The theory remains in its infancy. It currently exists as a collection of fragmentary, quite heterogeneous, but conceptually related models developed from within several disciplines, and with applications in both the social and natural sciences. These include models of stochastic processes; of diffusion limited aggregation and fractal growth; of critical phenomena and catastrophe theory; the mathematical theory of chaos; and simulation models of aggregate behaviors associated with decentralized strategic interactions.

While their assumptions, explanatory power, and domains of application are quite different, these models share an underlying respect for mechanisms by which local, initially small fluctuations can collectively affect long run and/or macroscopic behavior. Their common agenda, perhaps, is to explore the limits of determinacy, and the nature of behavior under conditions of indeterminacy or structural discontinuity, in dynamic arenas. The formal theory of chaos, for example, describes how arbitrarily small perturbations in simple, deterministic dynamical systems can give rise to macroscopically turbulent behavior which obliterates structural regularity.

Among these various models, several appear particularly suggestive for industrial dynamics. These would currently seem to be "population ecology" models of market structure (perhaps an application by analogy more than a model); stochastic models of economic dynamics under conditions of
increasing returns; and Robert Axelrod's analyses of the evolution of behavior under conditions of repeated strategic interaction.

The more complete development of these and perhaps other evolutionary, nondeterministic models offers the prospect of a deeper understanding of industrial organization, of the political economy of international competition, and of economic dynamics generally. Neoclassical economics would thereby become an integral part, and often a special case, of more general theories of strategic dynamics in political economy and industrial behavior. As such, the role of economics would be the description of the "payoff structures" which condition, and also result from, alternative strategic behaviors. Indeed such a model of political economy - in which arenas are collections of interdependent, self-interested private and governmental actors whose actions flow from but also reshape economic, strategic, and structural conditions - might in turn become a special case of a highly general theoretical account of nondeterministic arena dynamics. 18

The natural base elements of this general theory would be four. 19 First, there must be an arena populated by individual agents and endowed with some given structure. The population and structure might be capable of change over time, or they might not. The population might be real or hypothetical, sentient or inanimate. Examples might be grains in a material, 20 organisms in an ecosystem, 21 individuals in a society divided into socioeconomic classes, citizens in a state of nature or governed by a central authority, 22 firms in an unregulated market, firms and nations in an
international economic system, or rational individuals preparing to choose moral rules from behind a "veil of ignorance," as in Rawlsian ethics. Elements of arena structure beyond the number of agents might include their information levels, rules of entry and exit, and the number of generations of interaction.

Second, we must have a specification of the behavioral propensities, and/or "objective functions," of the arena's populace. In the case of physical systems, these propensities will typically be reflections of parameter values relative to invariant physical laws. Grains of a material, for example, orient themselves according to their masses, dipoles, and other characteristics in response to electromagnetic and gravitational forces. In the case of strategic actors such as people, firms, or governments, propensities may either be durable or subject to revision through experience. Individuals might be altruists, egotists, or some combination of the two; they might be prone to trust others or prone to distrust; they might act according to specified cultural or strategic norms. They might heavily discount the future, or have very long time horizons. These kinds of propensities might be thought of, and sometimes may literally be, the boundary conditions of individual strategic behavior.

Third, each member of the arena must face a local decision space and incentive structure: a class of alternative courses of action and some specification of the direct consequences, both to the member and others, of "choosing" each alternative in a given generation of interaction. Often such incentive structures will show some indeterminacy, through a random
component or an interdependency with the behavior of other actors. A gambler playing a round of poker, for example, faces the choice of folding or continuing play. The consequences of continuing depend in part upon what cards the gambler would then receive, which is a random variable. They also depend upon the subsequent actions of the other gamblers, which is a strategic interdependency. The prisoner's dilemma problems explored by Axelrod are pure examples of the latter, while the urn processes described by Brian Arthur are based upon randomized incentive structures. Industrial competition shows many examples of both. A firm can decide to open its computer architecture, permitting direct imitation, or close it. Its optimal decision depends, among other things, upon market acceptance of the architecture (often an unknown) and upon competitors' responses (a strategic variable). Imitators might remain content with a minority share under a price umbrella or they could try to overwhelm and destroy the market leader.

Potential alternative actions and their consequences - i.e., payoff structures - might, again, either remain fixed or change over time; they might depend upon prior actions or be independent of them; they might be the same for all agents, or might be unique to each. For example, the rewards to a specific firm of alternative investment or pricing decisions might depend upon its technological strength relative to that of competitors, or the size of its installed base, both of which might vary over time as a function of prior decisions.

Fourth and finally, each member must be endowed with a decision rule which specifies how, when facing any given strategic position and incentive
structure, the actor will choose to "behave." In the case of self-interested agents such as neoclassical or game-theoretic ideal optimizers, one can think of this rule literally as a strategy. Decision rules, like other elements of the model, might be either deterministic or randomized, and might also be either dependent upon, or independent of, the behavior of other parts of the arena. For example in an iterated prisoner's dilemma, pure reciprocity is a strategy which specifies decisions which depend upon the other player(s); an alternative would be uniform defection, a strategy which yields actions independent of the actions of others.

Together these four categories constitute the elements of any evolutionary model. They are simultaneously the tools and the object of a theory of evolutionary arena dynamics, but they are of course not the theory itself. The goal of such a theory, should it be possible to develop one, would be to elucidate general relationships among these various elements, and between the elements on the one hand and various aspects of long run aggregate behavior on the other. Put another way, we wish to understand the relationships between the goals or forces acting upon individual agents, the structure and demographics of the arena in which they find themselves, the decisions they face, the strategies used to make those decisions, and the aggregate evolutionary behavior generated by these local, individual decisions. Many specific questions of both academic and practical interest arise. For example, in an arena populated by national governments and firms engaged in international economic competition, we might wish to know which incentive structures and decision rules will maximize the performance of firms, sectors, nations, and/or the entire international system. Of course,
the maximizing conditions for any one of these units might not maximize the performance of the others; that is one question we might wish to pursue.

The principal difficulties with this theoretical structure derive from its wide scope, its inhospitality to analytic solutions, and the extreme heterogeneity of the specific cases it includes. We have only just begun to explore it, and thus far few general results have been obtained. It is far too early to be able to say how rapidly progress will be made, and whether it will predominantly depend upon induction from case studies, analytic solutions, or exploratory analysis via computer simulation. Nor do we yet know the extent to which aggregate behavioral determinacy can be shown to exist despite the indeterminacy postulated by initial conditions in these models.

Axelrod's results for iterated prisoner's dilemmas go some distance towards establishing the proposition that repetition and natural selection favor certain strategies and end results over others, generating aggregate determinacy from local indeterminacy plus selection effects. In the particular case of iterated prisoner's dilemmas played in "small" or "dense" arenas (fixed small populations, complete information, intense selection pressure), pure reciprocity or slightly more aggressive variants of it seem to be heavily favored strategies. In larger or less stable arenas, however, betrayal becomes more tempting, and may crowd out nicer strategies. Hence in some cases the structure of an arena can be shown to imply predictable, specific relationships between a given local interaction and long run, aggregate behavior.
More recently, however, Axelrod has investigated strategic settings giving rise to behavioral norms; and here, aggregate behavior seems highly indeterminate. While for several reasons the "meta-norms" game he considers in greatest detail is unpersuasive as a generator of behavioral norms in most settings relevant to industrial dynamics, it demonstrates clearly the magnification or lens effect often produced by strategic dynamics. Under many conditions, iterated strategic interactions appear to select for certain forms of conduct to the eventual exclusion of others, even when they are not clearly favored in any individual encounter. While sometimes the form of behavior selected appears to be one which is inherently and uniquely favored, in other cases it may be chosen at random. The triumph of reciprocity in iterated prisoner's dilemmas seems to be an example of the former situation, while the selection of particular norms in Axelrod's meta-norms game is an example of the latter case. Sometimes a norm emerges; sometimes none does. Somewhat analogously, Brian Arthur's analysis of urn processes demonstrates that under some forms of increasing returns, one class of the arena population will always become dominant in the long run, but which class it will be is a random variable. Hence in some strategic arenas, it may only be possible to develop typologies of possibilities and specifications of the parameters upon which alternative results depend.

At present, however, we simply do not know how strong this kind of theory can ultimately become. Those results which do exist have been derived from extremely sparse, highly stylized cases which in this sense resemble the neoclassical models I shall soon criticize. The limited
predictive utility of the current theory in practical affairs reflects this fact. Its application later in this essay to international structure and competition in the semiconductor and computer industries is therefore relatively heuristic and ad hoc: individual interactions can be analyzed, and the evolution of an industrial regime can be reconstructed, but no general model determines the effort. Not surprisingly, therefore, most attempts to apply rigorous formulations of iterated strategic models have focused on unusually sharp, univariate arenas in international political economy and diplomacy - arms races, currency devaluations, trade wars. Von Hippel has applied a prisoner's dilemma model to the problem of long term information sharing between partially competing "minimill" steel firms, but microeconomic applications remain a novelty.

Nonetheless it will be useful, first, to review the results of early investigations of evolutionary dynamics and, second, to consider how economic arenas and neoclassical models of them relate to the general framework provided by evolutionary models. The discussion concentrates upon processes likely to be relevant to political economy; other models more specific to physical or biological systems are omitted.

Results from the theory of strategic processes

In considering international industrial competition, a model which incorporates iterated strategic interaction seems necessary, for several reasons. First, and unlike some dynamical systems, the success of economically motivated agents is mediated by arena-wide (sectoral,
economywide) pressures and disciplinary mechanisms - market forces and entry threats, domestic political competition, national trade policies. These mechanisms give rise to strategic interdependencies which affect individual success; hence, agents are inherently competitors. "Competition" in this sense means pursuit of self-interest; it does not preclude cooperation, but cooperation will occur only when it suits the interests of individual actors. Defection is potentially rational, in that individuals can sometimes become more successful at the expense of others, perhaps even by causing them to fail. Ecosystems, for example, are at least partially "competitive" in this sense, while many physical systems are not.

The actors in industrial arenas - individuals, firms, nations - also tend to be rational egotists: they have interests, and they can be assumed to pursue them, at least up to the limits of their social habits, autonomy, and knowledge. And because underlying facts of economic life seem to give rise to interdependency (through increasing returns, for example), there are many opportunities for cooperation and defection, and the process of "competition" takes the form of multiple, concurrent strategic interactions. Furthermore, the ability of agents to predict the future is often quite limited, even though long term competition is the rule. This implies that a model of iterated strategic choice is more appropriate than a single choice of strategy fixed for eternity, or a deterministic market outcome based upon all competitors optimizing over all potential future strategic choices. Objective conditions can change, and so can the behavior of other actors. The long term success of each agent is in large part determined by the degree to which direct cooperation in local interactions can be elicited,
and also by the level of cooperation and trust in the arena generally. This last will depend heavily on arena-wide norms of strategic conduct, whether produced by a central authority or by decentralized strategic processes. These, as commonsense indicates and Axelrod’s simulations have shown, can make the "state of nature" of an arena into either a Hobbesian world of brutal conflict or a Lockeian world of long term cooperation.31

Consequently in comparing evolutionary dynamic models with neoclassical economics, the evolutionary model whose results are most relevant is essentially a generalization of Robert Axelrod’s arena of self-interested actors confronted with a repeated prisoners’ dilemma – an arena in which alternative choices, payoff structures, and the success of agents are determined economically. The payoffs, information problems, and strategic choices which confront executives, firms, and national governments are of course vastly more complicated than a single, iterated prisoner’s dilemma. Hence in many ways current game-theoretic, evolutionary models are still as stylized as those of neoclassical theory. For example, many models do not include central authority, multiple concurrent interactions, the formation of competing cliques of cooperators, or entry and exit – all of these phenomena being critical to the dynamics of many economic arenas including the information technology sector.

Simple models of iterated strategic dilemmas, and their analysis via theory, computer simulation, and empirical testing, have nonetheless yielded several noteworthy results. First, certain parameters strongly condition the degree of cooperative behavior and the population dynamics of arenas.
Second, alternative strategies offer different levels of individual success as a function of these arena parameters, and selection processes will therefore yield systematic patterns of arena dynamics. And third, arena-level welfare (say, the discounted sum of individual performance levels over many generations) is in turn related to these arena parameters and to individual strategy choices. I will briefly consider each of these issues, beginning with arena structure.

Arena parameters and rational strategies

The degree of cooperation likely to evolve in the face of iterated strategic decisionmaking depends upon four characteristics of the arena: payoff structures in force in each iteration; the importance of the future; the complexity and difficulty of coordination and communication; and finally, the values of agents (e.g. their discount rates and propensity to trust others). Each of these singly, and all in combination, affect the prevalence of cooperative versus antagonistic behaviors.

Under some payoff structures, there is no indeterminacy: players have flatly consistent or uniformly inconsistent interests. Under many others, a strategic indeterminacy exists: cooperation brings benefits, but only if others cooperate too, and defection is tempting. The intensity of the indeterminacy, and the payoffs to unilateral defection, cooperation, victimization, and mutual betrayal, strongly affect the rational propensity to cooperate. These effects, however, differ between one-period and multi-period games. (In a microeconomic context, payoff matrices might be

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interpreted as reflecting current costs, demand, and profit opportunities. One example of cooperation would be joint profit maximization in pricing; another very different one would be sharing of R&D. Defection would consist in, say, highly aggressive pricing, or refusal to share one's R&D results.) In most cases which have been studied theoretically or by simulation, payoffs are held constant over iterations. But in many actual strategic dilemmas, payoffs change - sometimes endogenously, through prior strategic decisions. For example, market growth, technological change, and market structure dynamics alter payoff opportunities, which in turn affect subsequent technical and market developments. Many such attributes of markets are subtly embedded in payoff structures, but not easily captured in a realistic way by existing models, most of which leave payoff structures constant for simplicity.32

The nature and extent of future interactions is another important consideration, one closely associated with the structure of the arena and the amount of information agents possess about it.33 If the same agents must interact repeatedly and are aware of this fact, cooperation will be more favored because the prospect of future retaliation for prior defections weighs heavily, and so do the benefits of long run cooperation. Other patterns of interaction yield different behavior. If interactions are blind and/or random, for example, this implies that the greater the number of agents, the lower will be the incentives for cooperation generated by the shadow of future iterations. Analogously for coordination and control problems: in general, the complexity of coordination, and the likelihood that at least one agent will defect, increase with the number of agents and
with the difficulty of directing responses to particular agents. The
greater the effort required to achieve and enforce cooperation, and the
greater is uncertainty regarding the identities or decisions of others, the
less likely cooperation will become. Once again there is endogeneity in
these relationships, not easily captured in simple models. Cooperation
yields information, trust, and efficient coordination which in turn
facilitate future cooperation, while defection increases the likelihood of
future defection for similar reasons.

Finally, the level of general cooperation depends upon the strategic
propensities of agents. Their strategies are influenced by their degree of
trust, their subjective discount rates, and so on. A small change in these
can affect general conduct, even holding other conditions constant. For
example, sometimes one agent can significantly affect the general level of
cooperation, as when defection by an unknown individual breeds distrust and
increases the general propensity to defect preemptively. Similarly, actors
with higher discount rates defect more, because retaliation - even if
guaranteed to occur well into the future - weighs less heavily upon them.
So the introduction of short-sighted agents into an arena can reduce the
general level of cooperation it displays. Moreover, strategic processes can
lead to the development of arenawide norms of conduct which might become
internalized, e.g. in corporate or professional cultures. And finally, it
might not be entirely foolish to assert that under some conditions, altruism
and/or a basic propensity to trust others can affect strategic conduct.

The nature of optimal individual strategies
The evidence suggests that different strategies are rational under different arena conditions, and yet that certain strategies are surprisingly robust. Axelrod's early simulations indicated that Rapaport's simple strategy of reciprocity, named Tit-For-Tat (cooperate as long as others do, retaliate as long as they defect), proved extraordinarily successful against a wide variety of opponents. But under certain conditions, e.g. an arena with high levels of change (entry, exit, and/or mutation), it seems less successful than somewhat more aggressive behavior. Later simulations by Axelrod uncovered a strategy which first defects, but then reverts to reciprocity if interaction persists and the initial aggression elicits retaliation. This strategy often outperforms pure reciprocity. It seems, also, that under conditions of poor information (when the agent responsible for a defection cannot be identified with certainty) simple reciprocity may be less successful. The simplicity and robust success of strategies which include long-run reciprocity nonetheless remains striking.

Arena-level performance

Optimal individual strategies are related to, but not coincident with, optimal arena-wide behavior; that is the nature of strategic interactions. When will the performance of the entire arena, considered as the sum of individual results over time, be maximized? In simple models of iterated prisoners' dilemmas, this is equivalent to maximizing the total level of cooperation. From the foregoing, it is evident that this occurs when agents interact with each other repeatedly and consistently, when defection elicits
targeted retaliation, when individuals have low discount rates, when the number of actors is small, when reliable information is available, and when agents are predisposed towards trust and cooperative strategies. This list suggests a variety of possible strategies for reshaping arenas to increase the levels of cooperation they exhibit. For example one can decompose lumpy interactions into successive smaller ones in order to lengthen the shadow of the future, or establish central authorities to discipline defectors. 36

However, relationships between strategic choice and performance are less direct in industrial arenas than in international relations. In the latter sphere, uniform cooperation is often assumed to be desirable. However, increased cooperation does not necessarily make good economic policy, and truly complete coordination is considered infeasible in most complex economic systems. (Indeed, that is the benefit of markets: they decentralize decisionmaking.) In applying the analysis of iterated strategic dilemmas to industrial dynamics, it is therefore necessary to ask how various forms of cooperation and competition among firms and governments affect the performance of units or groups ranging from individual corporations to an industry or national economy. Certain forms of cooperation will be beneficial, while others may not. (Traditional neoclassical economics focuses forms of microeconomic cooperation which are detrimental - collusion, cartels, etc. - while only occasionally considering forms of coordination, usually macroeconomic, which might be beneficial.) Some individually rational strategies or forms of industrywide cooperation improve technical progress and efficiency, while others increase costs. Behavior which yields benefits for some groups may also impose losses upon
others (foreign nations, other industries, future generations). Moreover, the benefits of cooperation in one arena (say, R&D or interfirm trade in intermediates) may depend upon the maintenance of competition in others (say, final goods markets).

It may even be the case that competition in certain activities is intensified by precluding it in others. If competing firms can and do poach (i.e. hire away, steal, bribe) each other's experienced employees, they may compete less aggressively in entry level labor markets and in internal training efforts. Hence the dynamics of industrial "competition" will derive from a complicated, integrated system of competition and cooperation in many arenas of interaction, one likely to be governed by relatively complex regimes composed of explicit regulation, norms of conduct, and bargains. Industries may tend to evolve stable behaviors which constitute, in effect, a strategic "regime" which might have strong implications for sectoral productivity and international competitiveness. At least in principle, the "regimes" characterizing various arenas - domestic politics, labor markets, foreign politics, product markets - could evolve independently and into rather different environments. Whether this is so depends upon higher level strategic processes concerning "linkage," an issue not yet well understood. This suggests that in industrial arenas, regularity and explanatory logic is to be found at the level of complex, integrated politico-industrial regimes and their histories, in addition to factor endowments or markets.

The decline of the American semiconductor industry, in fact, is in some
sense the result of just such a strategic regime. In this case, early history and strategic decisions, sometimes aided by the characteristics of technology and by secular trends in the economy, combined to produce stable patterns of cooperation and competition in exactly the wrong places. But while inspection of a particular case may produce clear conclusions, we presently lack a general framework for the analysis and optimization of strategic industrial interactions and their correspondence to aggregate economic performance. Further effort in this domain would therefore appear valuable; for an understanding of such processes might lead to policy disciplines capable of improving upon the prescriptions derived from neoclassical economics. The attribution of a central role to strategic interactions, incentive structures, and institutional history in conditioning the long run performance of industries almost necessarily elevates government policy to a major role. Unless further analysis yields the unexpected conclusion that strategic interactions under conditions of increasing returns and uncertainty guarantee optimal results, we are faced with the strong likelihood that central authority can affect performance by conditioning arena and payoff structures.

3. Neoclassical and Evolutionary Models Compared

In general, neoclassical models and the economics discipline remain heavily weighted towards static determinacy and against iterated nondeterministic decisionmaking. Most neoclassical models are either static or, if dynamic, they assume that enough information exists to generate a smooth trajectory, and/or to permit actors to collapse their
entire futures into one or two decision periods. Second, the strategic intensity of arenas is assumed to be low, in at least two senses. One concerns local interactions: the regions and extent of strategic interdependency existing between agents at any given time are restricted, typically to price and production decisions. The other concerns global interactions: indeterminacies (random variables, strategic interactions, and alternative decisions with respect to them) are assumed not to generally affect long run structure and performance in a very profound way.

Indeed some of the most natural candidates for strategic indeterminacy are simply left out. National government, for example, was until recently neglected as a strategic actor; it was rarely considered save as a provider of public goods or a source of dysfunctional market distortions. Cost structures which provide incentives for technical cooperation among competitors, for example, are rarely modeled. In general, then, neoclassical models deemphasize those market structures, technologies, and forms of interaction in which distinguish dynamic strategic behavior causes deviations from determinate and optimum equilibria.

Hence truly strategic models of political economy - in which cooperation and its absence are important variables and open questions, rather than being assumed away - are actually based upon rather different ideas than neoclassical theory. For these newer models, economic forces (technological opportunities, market competition) and government policy alike primarily provide the structure of interaction: behavior will be constrained by economically determinate payoff opportunities, but behavior
will largely be the consequence of behavioral choices with respect to strategic options. Indeed, strategic considerations can even affect economic variables, as for example by increasing the experience obtained with one technology versus another and thereby shifting cost advantages, or through appropriability effects which determine investment in R&D, human capital or other assets.\(^{41}\)

The evolutionary model therefore views economic, political, and other arenas as dynamic systems whose large-scale patterns are created by repeated, concurrent, local interactions. These local interactions will often be reciprocally conditioned by the larger environment, because when local interactions reshape the larger arena they thereby reshape the incentive structures faced by individuals in subsequent local interactions. For example, both local and global behavior can be strongly affected by the effective time horizons of actors. These are determined in part by arena structure (e.g. by the likelihood of repeated future interactions) and partly by subjective factors such as actors' discount rates and propensity to trust each other. Over the long run, each affects the other; for example, transitory interactions and opportunities for cheating will breed distrust, while predictable and repeated interactions reduce it. Hence in these models there is a continuous interplay between individual, short term action and aggregate, long term, arena-wide dynamics - or, as Schelling puts it, between "micromotives" and "macrobehavior." One is perhaps forced to refer to a "dialectical" relationship between individual and aggregate behavior.
The roles and importance of these processes in shaping industrial behavior have potentially substantial implications for economic theory and political economy. But equally important are their potential implications for the practice of strategic decisionmaking and government policy. Industrial competitions whose results can turn upon historical accidents or strategic dilemmas may yield widely differing aggregate performance, particularly over long time periods, as a function of private strategic choices and the incentives provided by central authority. The potential effects of policies or actions which shift incentives towards different patterns of cooperation and competition may therefore be larger and/or different than traditional economic theory would suggest. Moreover, these decisions and their consequences might themselves turn on strategic interactions between competing nations, industries, and firms.

Strategic protectionism is one example. A critical industry might show opportunities for technical progress deriving from scale economies, either static or dynamic. In such a case, government and industry face each other across the following strategic dilemma. Government protectionism could eliminate foreign competition, yielding larger and more secure markets for domestic producers. The domestic industry, however, could then either "cooperate" by investing in productivity growth and future competitiveness, or it could "defect" by using its increased market power to extract rents while stagnating technically. But the industry's response might depend upon whether "defection" would result in future reductions in protectionism, or would pass unpunished - an iterated strategic dilemma. The industry's reaction might also depend upon other levels of strategic interaction - for
example among competing firms within the industry, or between firms and their employees. For example if personnel mobility is high, firms will be disinclined to invest in training their employees, and employees will feel less commitment to the future welfare of the employer, because conditions for long term reciprocity are not propitious. One important avenue for investment in productivity gains will therefore be foreclosed. There is some evidence that precisely this issue is an important source of U.S. problems relative to Japan.\textsuperscript{42}

Neoclassical theory cannot generally predict behavior under such strategic conditions, and often cannot even explain it. Thus if the presence of forces which generate chronic strategic dilemmas is the rule rather than the exception, and if these forces interact strongly with traditional economic variables such as investment, market structure, prices, and costs, then strategic processes might sometimes be as critical to large scale economic behavior as scale economies or factor costs.

So for the purpose of analyzing industrial performance and international competition, there exist two general theoretical alternatives. They can be described as deterministic market equilibrium economics versus nondeterministic (usually strategically driven) evolution, together with various intermediate possibilities.

Since both neoclassical economics and the strategic (or nondeterministic) views possess an internally consistent logic, their evaluation as theories must be primarily based upon the plausibility of
their assumptions, the prevalence of the conditions and mechanisms they posit to be important, and their ability to explain and/or guide actual behavior. Do industries, national economies, and international competitive arenas behave more like economic machines or like regions of repeated strategic interaction? What fraction of industrial behavior and performance can be accounted for by competitive equilibrium optimizations, as opposed to strategic forces, historical conjunctures, and accidents? How strongly do the two classes of behavior interact? While the explanatory potential of nondeterministic models cannot yet be fully assessed, a review of the relevant portions of the neoclassical terrain suggests that change in this direction is needed.

4. Neoclassical Models and Their Limits

Neoclassical models have traditionally been, and largely remain, based upon assumptions of equilibrium stability, fixed or exogenously determined conditions of technology and demand, complete foresight in decisionmaking, and (frequently) perfectly competitive markets. Traditional neoclassical models such as Hecksher Ohlin trade theory and most of the microeconomics of industrial organization model static behavior under conditions of perfect competition or, at their most nuanced, static scale economies. Recently, these traditional models have been supplemented by new neoclassical models which emphasize "imperfections" such as learning and externalities in competitive behavior, and which takes economics some distance towards nondeterministic models. But where "imperfections" such as increasing returns and oligopoly have been considered, the strategic behaviors modeled
have been largely confined to price and output decisions. Economic models of industrial behavior — principally industrial organization, international trade, and growth — have serious limits as a consequence of these simplifications, as do the policy analyses derived from them.

In each of these three areas of economic theory, serious questions arise regarding the realism of assumptions, the match between theoretical predictions and observed behavior, and the nature of relationships between microeconomic and macroeconomic forces. These problems become more severe when considering problems which transcend the traditional categories of economic analysis — problems such as the international competitive performance and comparative productivity growth of national industries. Because the models developed within neoclassical theory for various specific problems and levels of aggregation often employ unrelated or even inconsistent assumptions, analysis of complex problems is limited by the inability to integrate the various pertinent models as well as the general difficulties shared by all of them. For example many industrial organization models assume or explain the presence of market power, while until very recently trade theory almost uniformly assumed the existence of perfectly competitive markets. And while microeconomics continues to view market power as welfare-reducing, the new international economics views it as welfare-increasing.

The most profound limits of traditional neoclassical models derive from their shared underlying view of the principal determinants of industrial structure, conduct, and performance. Aggregate market behavior is largely
seen as the determinate, collective result of rational actions by noncooperating market participants with perfect information about the future. Agents' optimal decisions are largely made for them by a macroeconomically determined external environment and by the degree of market discipline implied by scale economies and horizontal industry structure. Individual actions are in essence dictated by conditions of demand, technology, competition, and factor costs usually assumed to be beyond any actor's control. The possibility that these conditions might be the result of strategic, historical, and institutional processes as much as their cause is generally considered remote. More generally, chronic strategic interdependencies and nondeterministic behavioral norms are considered second order effects.

Given this relatively static, predictable, and constraining environment, firms maximize their profits by manipulating (usually at the margin) the few major variables they can control - primarily capital investment, production levels, price, and product differentiation. Firms are treated as black boxes, and the determinants of the boundaries between firms and industries receive scant attention. Market behavior is thus analyzed with little reference to the determinants of intraorganizational activity, the efficiency of markets relative to hierarchies, or the interactions between them.

To a first approximation, then, industrial behavior is seen as the equilibrium result of supply and demand forces rather than the consequence of strategic, institutional, or random processes. Competitive forces are
generally assumed to operate rather fully and rapidly, at least in the long run and in the absence of distortions from government policy. Institutional forces and restrictions upon markets are generally considered rigidities or distortions which interfere with market adjustment and reduce efficiency, rather than as potential sources of efficiency gains, when they are considered at all. The relevant equilibrium processes are generally thought to be convergent and stable in the long run.

To the extent that neoclassical models of this sort have included dynamics and strategic behavior, they have generally been confined to the same traditional microeconomic decision variables—price, output, and product differentiation in the product markets of oligopolistic industries. Hence in this traditional vision, industrial market structure is predominantly static and determinate, even when nominally dynamic in the sense of modeling market behavior over time. The external environment contains most of the determinants of market structure or comparative advantage. Change in these fundamental variables is assumed to be sufficiently predictable and well-behaved that dynamic behavior is smooth and determinate. Or if not, e.g. when an external price shock changes boundary conditions and relative costs, the system moves to a new, but equally well specified, equilibrium.

The strategic interactions considered to exist within industrial sectors are simple and limited in scope to one or two decision variables, as with Cournot-Nash equilibria or Stackelberg behavior. Where situations involving repeated strategic decisions are considered, traditional theory
generally looks for criteria which produce determinate solutions based upon optimization over a discounted infinite time horizon, and across the entire set of strategic possibilities.

Analogously, international production and trade patterns (in Hecksher-Ohlin theory) are determined by factor endowments and the relative costs of capital, labor, and resources in various nations. Changes in the international distribution of an industry's activities are explained through changes in factor costs or, perhaps, shifts in relative demand for various factors of production (for example caused by use of increasingly capital intensive techniques). Aggregate patterns of comparative advantage and trade are both determinate and globally optimal - modulo distortions caused by domestic market imperfections and national trade barriers.48

Therefore in both national and international markets, traditional neoclassical analysis posits that individual optimizers are disciplined by the market and constrained by externally determined cost and demand structures. Hence most decisions are really made by the system, which both determines the nature of optimal behavior and penalizes deviations from it. Broadly speaking and with some important exceptions (public goods, concentrated oligopolies), market competition undistorted by government intervention yields aggregate resource allocations and patterns of industrial behavior which are both determinate and desirable.47 And even in the "imperfect" cases, the need for intervention is objectively determined. Public goods and "natural monopolies," for example, are defined by the inability to provide a good selectively in the former case, and by extreme
scale economies in the latter. Neoclassical theory generally has not investigated the proposition that these conditions are made not born: that they can be created or eliminated, local or global according to strategic conditions, and the result of market imperfections as well as their cause.

Not surprisingly, traditionally derived economic policy analysis has also opposed government intervention in industrial markets—whether through protectionism, sectoral subsidies, export promotion, investment targeting, or strategic coordination of sectoral activity—except to provide public goods, curtail monopoly power, or perform similar technical functions in cases of well-defined market failure. For example, traditional neoclassical analyses often assert not only the global optimality of free trade, but also the futility of intervention even for the home nation; production or export subsidies are held to benefit foreign consumers if anybody. On the traditional view, the optimal goals of policy are to ensure that the conditions of perfect competition exist to the maximum possible extent and, where necessary, to provide public goods such as basic research, infrastructure, safety regulation, and the like.

The new neoclassical economics

Recently, the "new neoclassical economics" itself has yielded a somewhat broader spectrum of models with divergent behavioral predictions and policy implications. Their common feature is an interest in conditions which generate market imperfections and strategic interdependency. In part, this change was a response to empirical evidence that neoclassical models
were seriously incomplete. For example, Hecksher-Ohlin theory corresponds
poorly with observed patterns of international trade; and in some
important cases, sectoral dynamics contradicts traditional models of
industrial organization. In part, the new models were also, apparently, a
response to mathematical developments which eased formal modeling of
nontraditional cases.

In response, the new economics has produced models of market dynamics
and trade which, though based upon apparently reasonable assumptions, yield
a wide variety of strikingly unconventional results (at least relative to
traditional theory). For example, several models have explored the effects
of compatibility economies and network externalities. Some models imply
that strong network externalities in industries undergoing technological
change can produce suboptimal welfare results in the absence of
regulation. Under certain conditions the welfare optimizing market
structure is a monopoly. Moreover, the existence of network externalities
implies that domestic government procurement policy affects comparative
advantage in international markets, and can therefore effectively
represent a neomercantilist trade policy.

Other recent models have explored the implications of increasing
returns - static or dynamic or both - for market structure and international
trade. Compared to traditional factor proportions theory, the results are
once again startling. In a model world in which major nations have domestic
oligopolists, for example, such firms have direct incentives to engage in
dumping. By lowering their prices in foreign markets, firms increase their
revenue while cutting into the rents of their foreign competitors rather than their own. Moreover, increasing returns (including dynamic scale economies, i.e. learning effects) provide a potential rationale for protecting a domestic market, if (a) the resulting opportunities are invested rather than simply used to raise prices, and (b) foreign retaliation does not eliminate the domestic advantage.

This "new neoclassical economics" has therefore significantly widened the range of theoretically consistent models of economic forces, outcomes, and policy recommendations. Consequently it has cast further doubt upon the presumptive superiority of traditional views, a presumption partially based upon the previously inferior theoretical rigor of the alternatives. The new models have therefore improved economic debate, largely by incorporating issues long recognized as significant in practice. (Indeed one observer of these matters remarked that it was rather as if someone announced a theory demonstrating that the world might not be flat.) And some models - e.g., Brian Arthur's analysis of "lock-in" caused by small events early in an industry's history - approach the spirit of the evolutionary models with which I contrast the neoclassical view.

However, the appearance of the new economics leaves many prior questions unanswered, and raises some new ones as well. First, a variety of behavioral, institutional, and political questions are still neglected. For example, many new models still confine strategic interactions among firms to price and output decisions, and continue to assume that agents possess relatively complete information, at least about costs. Many also still
assume that large scale structural features, such as whether an industry is fragmented versus concentrated, are relatively determinate and derive from objective features of technology and demand, and perhaps now cumulative production experience. Few consider iterated strategic dilemmas or linkages between strategic actions in international product markets and domestic sources of industry structure. Nor are multiple concomitant strategic processes modeled, for example in markets and politics, despite clear evidence that they occur.56

Nor do the new neoclassical models appear to improve the practical utility of economic theory. For example, many of them imply the existence of strategic indeterminacies without describing their optimal or actual resolution in a convincing way. Will firms act cooperatively or will they attack each other? Will agents use market power to raise current profits, or conversely to invest in future competitiveness? Will they voluntarily surrender sovereignty to create arena-wide institutions, or insist upon acting individually? Will they be able to cooperate in some domains while competing elsewhere, or will their behavior in all domains be equally cooperative? If protectionism and nationalist procurement policy have domestic economic benefits, but might cause retaliation by trading partners and/or multinational firms, what will nations do?

Given these divergent possibilities, some models obtain a specific or optimal result by assuming some particular strategic response, or none at all, or by assuming only one or two iterations of strategic choice. Often these assumptions seem rather arbitrary. So while there now exists a wider
spectrum of neoclassical models, it is not evident that this has brought a corresponding increase in our power to account for economic behavior. Furthermore economic theory still, in the main, focuses upon relatively deterministic equilibrium explanations to the neglect of institutional and evolutionary considerations, and upon the effects of technology and product market structure to the neglect of factor markets, markets for corporate control, political contests, and so forth. Ironically, however, the result is still to subvert the determinacy of economic theory as a whole. Small changes in assumptions produce wide variation in predicted outcomes, even for these traditional variables. Attempts to measure precisely all the parameters necessary to decide which models apply, and to what degree, are likely to fail. The result is to discredit economics.

Industrial Organization

The neoclassical theory of industrial structure, conduct, and performance has proceeded from its traditional emphasis upon static scale and horizontal concentration to a more recent concern with dynamic scale economies and externalities. In both traditional and new analyses, however, the central source of structure is some version of scale, and the central source of performance and market power is some version of structure. Neoclassical theory has not yet accepted the proposition that network externalities, learning effects, and economies of scale at the level of organizations and systems of institutions (such as multinational firms and industrial sectors) are as much the rule as the exception in industry. The continuing presence of these economic forces implies the existence of long
term indeterminacies and strategic interdependencies in industrial arenas (in factor markets, product markets, political strategy, control of information and intellectual property, and markets for corporate ownership, among others).

Consider, for example, the coexistence of cooperation and competition between firms - say, R&D sharing among firms which compete in product markets. First, such phenomena are rarely considered by neoclassical theory at all. The phenomenon of cooperation is generally neglected, and when considered is modeled simply as a source of market power rather than of efficiency gains. Furthermore the existence of such cooperation, and more strikingly its coexistence with real competition, cannot readily be explained in neoclassical terms. Nor, therefore, can the presence of various forms of cooperation in some industries, with respect to some variables, and in some periods, in contrast with their absence in others. Yet in high technology industries, the combination of network externalities, learning effects, and scale economies in R&D might imply that cost-side cooperation among firms would maximize welfare. The evidence suggests that Japanese industry has, in fact, cooperated extensively, that Japanese government policy has promoted such cooperation, and that it has proven beneficial (at least to Japan).

Moreover, learning and dynamic scale economies at organizational and sectoral levels imply that the construction of institutional systems involves commitments and switching costs potentially as large as those associated with any technology or factory. In effect, institutional
structures and components of them possess a degree of market power. As with conventional learning effects attributed to cumulative manufacturing experience, organizational experience increases efficiency but also increases power, and does so in a manner open to strategic manipulation in many alternative directions. It also raises the possibility of forms of institutional or systemic "lock-in" analogous to those created by technology adoption in the presence of conventional network externalities or switching costs. If the wrong system or set of institutional relationships becomes entrenched at some point in an industry's history, later sectoral or institutional adjustment may prove difficult and highly resistant to normal competitive pressure. Hence the idea of organizational or procedural learning economies is rather subversive to traditional microeconomic theory. But systemic learning effects and the economic importance of institutions might account for much which is otherwise puzzling.

Two examples might illustrate the impact of these considerations. First, consider the problem of industrial market structure. Suppose industry A produces inputs to industry B, that both industries show growth and dynamic scale economies, and that there also exist at least some economies of vertical integration. We wish to understand what determines the degree of vertical integration between them, the degree of horizontal integration in each, and the extent to which there exists a market for good A, as opposed to its production being fully internalized. (Notice that vertical integration is compatible with full marketization: the producers could sell to each other.) We might also want to understand the degree of effective competition in the various markets, and the distribution of market
power or rents across firms and industries.

Suppose now that we make the further assumption that there exist opportunities for system economies of scale, dynamic scale economies, and bandwagon effects, at the level of market structure itself - for example through institutional learning, procedural refinement, and strategic dynamics. Whatever large scale decisions a firm makes, it then acquires experience in appropriate complementary techniques and progressively increases its efficiency in using them. This pushes the firm down one developmental path - whether in structure, scope, technology, or other variables - while raising the costs of switching to others. Similarly for entire industry structures: over time, they institutionalize and reflect patterns of organizational investments and strategic interactions.

Under such conditions, strategic decisions at critical junctures could lead to widely divergent subsequent structures and performance levels. If a substantial fraction of increasing returns derive from organizational improvement (at whatever the organization is doing) as opposed to simply static investment scale or manufacturing experience, then opportunities for such institutional, dynamic, and systemic scale economies could exist simultaneously in several different structural and behavioral directions. In this case, the evolution of the arena will be determined by the relative progress of several potential sectoral regimes, as mediated by competing positive feedback processes - e.g., system economies of scale versus vertical integration. For example, suppose an oligopolist in either industry decides upon vertical integration with both marketization of the
intermediate good plus at least some internal consumption. This withdraws demand from the remaining market, thereby revising other firms' scale opportunities and positions. This, in turn, might lead to later, countervailing structural changes by other producers seeking to avoid depending upon endangered upstream firms, or their competitors, for inputs.

The nature of such changes, however, may also depend upon strategic interactions between competitors, customers, and suppliers. As a function of such behavior, firms will invest in their employees, their organizational systems and activities, in horizontal and/or vertical capacity, and their patterns of cooperation and competition with other firms. Such decisions will probably ramify throughout the firm's entire panoply of strategies and operations - technical practices, hiring, purchasing, R&D, capital investments, pricing, marketing. Cumulatively, these investments will effectively institutionalize the industry's evolving structure and strategic regime.

The second example, somewhat related to the first, concerns relationships between market power, technological change, and performance (competitively, in welfare terms, or both). A deep indeterminacy exists in considering the impact of oligopolistic structure and scale economies upon performance. On the one hand, concentration, scale, and protectionism reduce competitive discipline and confer market power, whose abuse (in most neoclassical models) leads to diminished welfare. On the other hand in the presence of strong scale economies and/or learning effects, these same structural conditions also permit greater operational and technical
efficiency because concentration increases firm-level returns to scale. As indicated above, a similar indeterminacy exists with respect to firms' decisions to cooperate versus compete with each other. Firms (and the industry collectively) will acquire more experience, and will be able to invest more in R&D or in facilities, if supply side coordination is permitted but product market competition continues. Given these contending forces, how industries actually behave is not uniquely determined by traditional neoclassical considerations.

The answer depends critically upon at least two related variables: firms' time horizons, and the strategic environment. The more farsighted the firm, the more likely it is to invest its current market power in the generation of future market power by creating future competitive advantage, as opposed to consuming monopoly rents immediately. But the effective time horizon of an organization depends upon the subjective discount rates of those who control it, and also upon the nature of the strategic arena. For example we noted above that the "shadow of the future" as a factor in strategy is lengthened by a structure which enforces repeated interaction with the same set of agents. If so, high personnel turnover and/or a high frequency of entry and exit in an industry could reduce the effective time horizons of firms, even those which are stable, with respect to training or interfirm coordination.

More generally, it is possible (even likely) that strategic norms will evolve in the industry: expected patterns and habits of behavior with respect to strategic interactions. One example might be an unwritten rule
that firms will not attack each other individually in political arenas; another might be a norm of unconstrained price competition in product markets, but a concurrent norm of cooperation in purchasing inputs; yet another might be traditional cartelization, i.e. a norm of contributing to joint profit maximization at the expense of customers. In many cases, there evolve norms of conduct which are intermediate between complete competition and complete cooperation, even within (say) product markets; for example, firms might agree to compete for new customers but to refrain from attacks on each other's established customer base. In practice, such norms appear to be extremely important, but also highly variable, in industrial behavior. How they arise is not yet well understood. Axelrod recently described one mechanism for their evolution, the meta-norms game, which depends upon punishing not only deviance but also the failure of others to punish it. While this mechanism seems unlikely to be important in industrial arenas, it represents a first effort towards a more general evolutionary and strategic explanation.

To the extent that phenomena such as these are important, one is drawn to a substantially different conception of industrial dynamics than is offered by neoclassical economics in its current state. Industrial structure, conduct, and performance become the (potentially highly contingent) consequences of highly complex stochastic and strategic processes. These processes are presumably constrained to some degree, possibly strongly, by exogenous, determinate economic conditions and by the operation of competitive forces. But if institutional learning effects, system-level scale economies, and strategic interactions are sufficiently
dense, long run structural evolution and systemic performance might be
strongly conditioned by these processes. Whether they would wash out in the
long run becomes an interesting, but very open, question.

Moreover patterns of institutional conduct and relationships,
comprising not only technical practices but organizational decisions and
strategic behavior, might prove highly resistant to conventional forms of
market discipline. For in this conception, the evolution of industries
involves competition not only among actors such as firms, but also a contest
between alternative strategic and institutional systems. Such a competition
can end "monopolistically" if a single institutional system, comes to
dominate a national or even global arena. (One example of such a dominant
institutional system might be the domination of a complex of related
industries by diversified, vertically integrated multinational firms whose
strategic norm is to exchange intermediates while competing in final
markets.)

Hence although power within the resulting system might be
decentralized, the system itself might be strongly entrenched. Such
institutional factors might play a major role in the system's efficiency,
and in the distribution of its costs and benefits across firms, industries,
and nations. For example, some arenas of interaction might be globalized,
while others might be nationally specific, as with domestic politics, the
executive-level labor force, or nontraded intermediate goods. Even in
industries exhibiting global competition in product markets, there might
evolve distinct strategic regimes in nationally segmented arenas affecting
firm-level efficiency and competitive advantage in the globally traded final
market.

If such behavior is important, it should be possible to model it
theoretically and to observe it empirically. Theoretically, two classes of
developments appear promising. One is the development of mathematical
models of relevant processes. Recent work in the theory of network
externalities and innovation shows promise, as do stochastic models by
Arthur and others, and possibly theoretical developments in the modeling of
other nondeterministic dynamical processes. The other promising area is
exploratory analysis via computer simulations which enable the
classification and evaluation of strategic behaviors and their large scale
results.

Thusfar, both of these avenues have been restricted to simple,
unidimensional processes in a manner reminiscent of the neoclasscical
competitive equilibrium models to which they are conceptually an
alternative. For example, Arthur's work analyzes univariate urn processes
and a particular process which can result in the early "lock-in" of one
technology over another within an industry. Axelrod's work emphasizes the
evolution of behavior in single-threaded repeated strategic dilemmas, and
the evolution of individual behavioral norms under such strategic
conditions. But most actual strategic arenas - including industries - are
messy; they involve multiple, concurrent processes involving different
interactions but the same actors. For example, firms which sell in the
same product market also lobby Congress for favorable treatment, buy and
sell technology, and hire in the same labor markets. This complexity has two related effects upon behavior which any successful theory must ultimately capture. One is that actors might consciously decide to link their strategic behavior in different regions of interaction. The second is that even if they do not, large-scale dynamics will be the result, and not necessarily the simple arithmetic sum, of several concurrent strategic processes affecting the same set of agents.

Consequently the dynamics of any sizeable industrial arena might be a complicated amalgam of multiple long run strategic processes and the somewhat haphazard institutionalization of resultant strategic norms in personnel policies, technical practices, vertical and horizontal industry structures, government relations, supplier and customer relationships, prevailing norms of cooperation and competition, and so forth. While the development path of such an institutional system might show a coherent logic, it may often be a contingent, non-universal one. Certain features will be shared with other sectors and historical periods, while others will be unique. The question then arises as to whether historically contingent, but systematic, institutional dynamics can be discerned empirically, and whether this behavior can be distinguished from neoclassical equilibrium behavior, on the one hand, and from random noise, on the other.

Suggestive empirical evidence appears to be abundant, but it has not yet received highly systematic analysis. Moreover, there is at least one major difficulty in providing it. The assertion of nondeterministic theory is that observed behavior will often be historically contingent and path-
dependent. Current behaviors may have their origins in past technologies, strategic decisions, or incentives which have themselves disappeared without a trace. Hence - at least in the absence of a suitably general, testable theory - the exploration of the nondeterministic hypothesis requires, at least to some extent, a rather detailed examination of the technological, institutional, and strategic history of the arena in question.

Paul David's economic history of typewriters provides an example of a relatively simple case of technological lock-in: the entrenchment of an inefficient keyboard (the Qwerty design). The Qwerty design arose as one - not the only or the best - response to a technical difficulty facing late 19th century mechanical typewriters. A combination of economic pressures and coincidences led subsequently to the dominance of this design and to large barriers to replacing it with superior designs, even after the appearance of new generations of hardware - such as personal computers with nonmechanical keyboards. There were system economies of scale - network externalities, essentially - between keyboards, employers, and the training of users. If users could be trained for only one keyboard, and could then use any typewriter they encountered, the total stock of typewriters and typists would be more efficiently used. And both of these investments were sunk costs which depreciated slowly.

Moreover, although conversion costs for typewriter manufacturers would be low, the costs for users were potentially very high. In part this is a result of the costs of switching frequently between incompatible designs, but in part it reflects a strategic dilemma arising from the structure of
the labor market. Any single corporate user seeking to convert would have to train typists in a way which would be useless or even detrimental unless many others converted to the same new keyboard too. Labor mobility among clerical workers implied that if the new standard began to take off, those trained in it could be hired away by new converts. Hence the first users of any new standard would pay high costs but would be unable to appropriate all of its benefits.

This, however, is a relatively innocuous example. Typing is a widely diffused activity, but probably not one sufficiently critical to powerful organizations that they would be willing to pay large costs, and take sufficiently large risks, in order to improve it. And precisely because the activity is widely diffused, the costs of inefficiency are equally shared and relatively minor in each individual setting. Nor is the technology directly critical to other major industrial institutions. In short, the existence of such an isolated case, or even of a significant number of such cases, says little about the structure, strategy and competitive performance of important industries over long time periods. Do similar effects show on larger scales, in more important cases, and can they have a major effect on structural and competitive outcomes?

Studies of a variety of industrial sectors and economic institutions suggest that they do. There is much evidence that the structure, technological choices, and efficiency of industries differ strikingly across nations independent of, or even in contradiction to, expectations derived from competitive market models based upon factor costs, technological
opportunities, and demand. A portion of this evidence will be reviewed in connection with the discussion, below, of American productivity and competitiveness performance.

But in addition, my own analysis of the semiconductor and computer industries supports this conclusion. In their large-scale structure and behavior, the U.S. and Japanese industries differ in nearly every possible respect. These differences are sufficiently large and have persisted sufficiently long that they cannot be considered accidents or aberrations, and they entail virtually every dimension of behavior considered important by neoclassical economics. They arose through a historically dependent process of institutionalization, and are closely linked to national differences in sectoral strategic norms, i.e. the patterns of cooperation, competition, and reciprocity which prevail in interactions among firms, including several markets and political arenas. I argue that the severe failure of the U.S. semiconductor industry in recent international competition derives in considerable measure from aspects of these institutional regimes which, although detrimental to the U.S. industry's competitiveness, were entrenched by switching costs, sunk investments, and strategic dilemmas. This pattern, I also argue, places the future of the U.S. computer industry in substantial jeopardy. In short, the evolution of international competition in the semiconductor and computer industries is not principally a story of factor costs or other traditional economic considerations. Rather it is a story of strategic choices, incentives, institutionalization, and the efficiency consequences of an arena's norms of strategic conduct.
To the extent this account is accurate, however, it raises questions not only with respect to the theory of industrial organization, but about other domains as well. In particular, the foregoing implies that even if international product markets provide strict discipline upon producers, the evolution of international competition may depend upon such processes as strategic interactions in domestic markets, or the institutionalization of the industry prior to the advent of foreign competition. Such matters are quite different than those invoked by traditional models of trade and comparative advantage.⁶⁴

**Trade Theory**

Traditional economic models of the terms of trade, and of the distribution of comparative advantage, have emphasized relative factor endowments and macroeconomic variables such as exchange rates. For example, Hecksher-Ohlin theory posits that nations will specialize in the production of goods for which their factor ratios give them a comparative advantage, or at least the smallest comparative disadvantage. In such traditional models, the relevant factors of production are taken to be capital, labor, sometimes human capital (labor weighted by education or skill level), land, and raw materials endowments. Hence nations with large capital stocks will produce goods requiring capital-intensive technologies, and trade them for the labor-intensive output of other nations. One consequence of this vision is that free trade maximizes welfare and efficiency, while protectionism lessens it, sometimes even damaging a unilateral practitioner.
These factor endowment models have been extended through consideration of factor market imperfections (unionization which increases the cost of labor, government controls which increase the cost of capital), simple models of multinational corporations, and exchange rate effects. However, it has long been clear that these considerations could not account for trade behavior. Empirical analyses have shown that long run trade patterns depart from those predicted from factor endowments in several respects. First, national patterns of imports and exports simply do not match national positions in factors. Second, much trade is between nations with similar endowments and indeed represents international competition between firms in precisely the same industries. Third, patterns of trade and national comparative advantage over time cannot readily be explained through factor proportions theory, nor even through the learning effects employed by the "new" international economics. Why did the United States have a positive trade balance for seventy-six consecutive years, followed by an increasingly negative one for the last fifteen? And why, for example, did the United States become a net importer of semiconductors relative to Japan by 1980, even though the assets of the U.S. in that industry still dwarfed those of the Japanese industry of the day?

Several models have been developed to account for the portions of trade behavior which deviate from factor proportions theory. An early attempt was the industry life cycle theory developed by Wells, Vernon, and others in the late 1960s. The life cycle model posited that new products were first developed in nations with an appropriately skilled workforce and advanced
markets - i.e. the United States at that time. As markets widened and the technology standardized, mass production could be transferred to locations with lower labor or materials costs, and the originating nation might become a net importer of the mature, low cost, low technology good. But the life cycle model, though useful in some cases, cannot account for two phenomena increasingly central to current economic history: the course of international competition between advanced nations in high technology industries, and the declining competitiveness of United States industry in global competition.

More recent is the "new international economics" developed by Brander, Spencer, Dixit, Krugman, Helpman, and other neoclassical trade theorists. This has consisted principally in the belated inclusion of increasing returns - scale economies or learning effects or both - into neoclassical trade theory, together with some modeling of the international strategic alternatives thereby offered to oligopolistic firms and governments. Once again, however, the ability of these models to explain actual trade patterns is extremely limited. The theoretical problems are analogous to those of microeconomics, and in fact include most of them; for example, institutional effects and iterated strategic interactions are neglected. The empirical problems are if anything worse.

For example, American competitive difficulties and relative productivity decline in several industries, including both mature and high technology sectors, began when aggregate U.S. scale, assets, and experience were enormously larger than those of any foreign competitor. If scale and
learning per se determined comparative advantage, most troubled U.S. sectors (including semiconductors and computers) would not have lost their competitiveness when and how they did. Indeed, enormous U.S. advantages in cumulative experience should have compensated for factor cost differences. Moreover, the new international economics relies upon the neoclassical theory of industrial organization by transferring parts of this theory into an international market segmented by trade costs. But we have seen that neoclassical models of strategic industrial behavior are seriously incomplete. In fact, cross-national comparisons of firms and national industries competing in the international market raise yet further questions regarding neoclassical models not only of trade but of industrial organization as well.

Such comparisons indicate that a high fraction of comparative advantage cannot be attributed either to factor costs or scale effects (whether dynamic or static). The sectors to which this conclusion applies appear to include consumer electronics, steel, and automobiles. In these sectors among others, declining productivity growth and competitiveness appear to have been the result of institutional, managerial, and strategic processes which reduced efficiency, led to dysfunctional distributional struggles (e.g. between management and labor), and impeded the adoption of practices known to yield superior efficiency. (Below I will argue that semiconductors and computers illustrate this point even more sharply.) And finally, neoclassical models encounter similar explanatory difficulties at another level of analysis, that of national productivity and output growth. In particular, the nature, composition and sources of America's declining
productivity growth and competitiveness are substantially inconsistent with a neoclassical interpretation. 68

5. Growth Accounting and U.S. Economic Performance

Using conventional measurements and U.S. government time series, U.S. productivity growth has declined from over 3% per year in the 1960s to less than 1% per year presently, and shows no sign of improvement. Traditional neoclassical models cannot account for this decline, nor can they explain major aspects of its internal structure. Similarly, U.S. trade competitiveness has declined severely over the same period, and the composition of trade has changed, again in many respects which cannot be explained by neoclassical analysis. 69

Productivity growth began to decline substantially earlier than competitiveness. Neoclassical analysis - both the microeconomics of production and the macroeconomics of growth - suggest that the determinants of productivity behavior, including declining growth, are to be found in two general areas. First, inputs can grow more or less rapidly, for example through changes in net human or physical capital formation. Second, there can be growth in total factor productivity, i.e. the efficiency with which inputs are converted into outputs. This is usually thought to involve payoffs to research and development which yield new knowledge; vintage effects, as new knowledge is embodied in new equipment and brought into use; and the exploitation of returns to scale (either static or dynamic). For some time, it has been agreed that most output growth in most nations.
derives from total factor productivity, which is usually calculated as a residual category (after accounting for input growth).

Unfortunately, declining U.S. productivity growth cannot thus be accounted for. All major econometric attempts to account for the last 20 years' decline fail to explain substantial fractions of economywide behavior, sometimes more than half. Often, these accounts disagree with each other as much as they agree. Moreover, econometric and other examinations of particular industries, technologies, and functional economic aggregates (e.g. services versus manufacturing, or knowledge workers versus production workers) reveal even greater puzzles.

First, consider the behavior of several industries which have fared particularly badly in international competition, and/or whose productivity growth, relative to both other nations and other U.S. industries, has been poor. Steel, automobiles, and machine tools are among the clearest examples of manufacturing industries failing in international competition; construction, electric power, and financial services are among those facing limited trade competition but whose productivity performance has been exceptionally poor. In all of them, there is considerable evidence that the causes of declining American performance are largely to be found outside standard neoclassical variables.

This evidence comes in several forms. One is that detailed examination of industry practices reveals large inefficiencies associated with strategic, institutional, and political factors. These include poor choice
of technology, such as the steel industry's failure to adopt continuous casting; poor industrial relations; antagonistic relations between industry and government; high scrappage rates and quality control problems; and a general inability to make optimal use of existing capital equipment. In the case of the steel industry, for example, capacity rationalization is now impeded by huge exit costs associated primarily with severance pay and pension funds. The inefficiency of the traditional sector, moreover, led to a structural divergence between the U.S. and Japanese industries. The Japanese industry was and remains dominated by large integrated steel firms operating integrated plants of extremely high capacity and efficiency. In the U.S. the inefficiency of integrated firms provided a high price, low quality market umbrella which permitted the formation of a highly efficient but fragmented domestic "minimill" sector of inherently limited size (through its dependence upon the supply of scrap).

Similarly, evidence from factory studies suggests that the U.S. automobile industry greatly underutilizes its capital stock as a consequence of managerial and industrial relations problems. The Toyota-managed NUMMI joint venture produces automobiles using a GM plant constructed in the late 1960s. Using the original capital equipment and a unionized workforce, Toyota has obtained levels of quality and productivity twice as high as GM management ever did, and which are roughly comparable to Toyota's performance in Japan. A Honda plant in Ohio has obtained similarly impressive results with low levels of capital investment and automation, indicating that neither capital intensive automation nor U.S. production labor quality account for Japanese efficiency.
Similarly for studies of specific functions and technical practices. One of the most striking is Jaikumar's study of flexible machining systems (FMS) utilization in the United States and Japan. Similar hardware systems were employed differently in the two nations, and with divergent results. Japanese firms manufactured eight times as many different products per system as U.S. firms, and Japanese capacity utilization was twenty percent higher than U.S. levels. Another case concerns the adoption of just in time manufacturing (JIT) in discrete manufacturing sectors in which its benefits are demonstrably significant. Suitable users clearly include the automobile and semiconductor industries, and perhaps others as well. Yet the U.S. automobile and semiconductor industries have been remarkably slow to adopt the practice.

Another anomaly concerns the pattern of investment, productivity, and employment in manufacturing versus services industries, and for production versus nonproduction workers. Since the onset of U.S. productivity decline, manufacturing productivity has grown more rapidly than services productivity despite the fact that services' share of capital investment has increased substantially. Moreover, the productivity of production workers in manufacturing has increased far more rapidly than the productivity of white-collar workers, whose productivity in some sectors has declined substantially in absolute terms. U.S. firms in declining industries have reduced their production workforce more sharply than their overhead, and seem to maintain considerably larger and less efficient administrative workforces than their foreign competitors. Some of the occupations
experiencing most rapid employment growth - computer programming, accounting, clerical work - are those which have also been the object of the largest capital investments intended to increase productivity. Yet the productivity of affected industries, such as financial services, has stagnated.

Given the foregoing, we might summarize the limits of neoclassical theory via the following observations. First, neoclassical theory tends to neglect important cost-side forces which tend to generate lock-in, instability, and indeterminacy in economic models. Among these are uncertainty and random fluctuations; learning economies at the level of organizations, institutions, and interorganizational relationships; network externalities; and increasing static returns to diversification and vertical integration as well as horizontal scale. Second, neoclassical models tend to focus upon product market interactions to the neglect of other arenas of strategic interaction which can be quite important: information; investment; R&D; technology; technical property rights; skilled labor; politics. Third, neoclassical theory also neglects considerations, such as rapid technological change and uncertainty, which might force strategic interactions to be iterative and evolutionary. Traditional models tend to assume that strategic decisions can be made once, under conditions of perfect foresight, over an infinite discounted time horizon, and without the presence of destabilizing dynamic forces. At worst, such a decision is made after a preliminary period of maneuver which yields a final strategic position for eternity.
6. Evolutionary Explanations Revisited

Since neoclassical predictions do not accord well with observed behavior, it is unsurprising that the empirical evidence suggests that other forces than those incorporated into neoclassical models must be in operation. On the other hand, any attempt to explain aggregate phenomena such as national productivity or trade performance through the evolutionary, institutional, and/or strategic processes alluded to above encounters substantial difficulties, at least upon first examination. Perhaps the largest puzzle would appear to be as follows. Application of the nondeterministic model at the sectoral level would predict any sectoral decline to be sectorally specific, historically conditional, and rather idiosyncratic. Instead, we apparently find widespread decline, much of it occurring simultaneously in separate industries, and a number of important regularities which transcend sectoral boundaries. One might argue that these observations cast doubt upon the proposition that evolutionary, nondeterministic forces are central to the U.S. problem. Unobserved neoclassical forces or some pervasive political or cultural failure might, on this argument, be more likely.

Such neoclassical or social forces may be present, but the observation of widespread simultaneous decline and major cross-sectoral regularities in its characteristics do not, in fact, disqualify the evolutionary models. To the contrary, the regularities we observe, and likewise the coexistence of these regularities with cross-national variation and historical specificity, themselves reflect the importance of evolutionary, strategic processes. Two
distinct considerations are involved in this apparent paradox.

First, there may exist strategic dilemmas and nondeterministic processes which generate similar behaviors and evolutionary patterns across a wide spectrum of industries, possibly the entire economy. The strategic dilemmas themselves might be rather different across industries, or they might be the result of some economywide condition or government policy which systematically gives rise to strategic dilemmas. The regularity of resulting behavior, however, is still a consequence of evolutionary and strategic processes. In a general way, this is the strongest result of Axelrod's analysis of the evolution of cooperation: under conditions of repeated interaction, a local strategic indeterminacy paradoxically favors, and gives rise to, a long term aggregate regularity. Cooperative behavior is favored and if a selection mechanism exists, it will come to predominate. However, other general arena conditions or payoff structures - for example high levels of entry and exit - could lead to different, less cooperative, and less favorable behaviors which might become pervasive, stable features of the arena.

Conditions generating incentive structures over a wide spectrum of industrial arenas might include the large scale sectoral structure of the economy, prevailing conditions in markets used by many sectors (capital, labor, energy), government policies, the structure of political competition, or widely diffused behavioral norms (such as the extent and acceptability of labor turnover). Likely sources of such effects might include the cost of capital (via its effect upon time horizons); the structure of equity
markets; the prevalence of industrywide versus company unionization; a variety of regulatory, trade, and procurement policies; and the strategic norms prevailing in major infrastructural industries (steel, energy, automobiles, semiconductors).

Consider, for example, the effects of general conditions of high capital costs, high levels of entry and exit, and high labor turnover. These will tend to produce (though not guarantee) forms of behavior which reduce long run productivity, and not solely through direct economic effects such as increased transaction costs or lower capital investment. They will also reduce the effective time horizons of actors and their propensity to engage in productive cooperation. For example, firms may decide against human capital investments for fear that their employees will be lured away by and/or defect to competitors. Long term technical cooperation will become less likely if firms exit unpredictably, orphaning joint projects with sunk costs. And firms will in general be more tempted by defection if the future weighs less heavily than the present.

The forms in which these centrifugal forces manifest themselves may differ from industry to industry, and they may sometimes be overcome. For example, one industry might shift its operations offshore, while another might cartelize and pass its high costs on to consumers. Alternatively, a small number of leading firms may tacitly agree not to steal each other's employees, thereby increasing the appropriability of human capital investments. Hence a source of general, economywide pressure to shorten time horizons and to defect rather than cooperate in economic relationships.
will produce aggregate decline, but a decline which may take a number of specific forms and which may include notable exceptions.

A second process also generates similar regularities: once established, strategic patterns can spread from one agent or arena to another. For example, if one industry falls into a strategic equilibrium of shortsightedness, defection, and vengeance, it may show this in its relationships with neighboring industries - suppliers, customers, producers of substitutes - and thereby influence their behavior in the same direction. Or alternatively, the individual failure of an organization or sector (one important to other sectors, or the entire economy) might produce a general cost disadvantage and/or pressure for dysfunctional strategic behavior.

7. Strategic Decisionmaking and Government Policy

These evolutionary, strategic explanations depend heavily upon the extent of institutional economies and/or lock-in, the effective length of agents' time horizons, aspects of arena structure which condition strategic calculation, and norms of strategic conduct. To the extent that such institutional and strategic processes are important to international industrial competition and national productivity performance, they will also probably be important considerations in designing strategies or policies intended to improve them.

Here, however, we have even less general understanding or experience than in the positive theory and modeling of evolutionary dynamics. Our
current knowledge suggests that if long run strategic processes are important, then strategic bargaining, the design of incentive structures, and hence government policy are in fact substantially more important than traditional neoclassical economics has led us to believe. But we have as yet no systematic discipline for the construction of appropriate strategic or policy instruments. Axelrod and Keohane discuss a variety of possibilities for increasing levels of cooperation in international diplomacy, but their relevance to maximizing industrial performance seems quite limited. The policy discussion which ends this essay considers this problem in the particular context of the semiconductor and computer industries, and some of these observations may prove more generally relevant. But to a large extent, this area remains unexplored and demands further analysis. Further understanding of strategic decisions and policy effects, however, may depend upon and therefore await an improved theoretical understanding of evolutionary processes generally.

But one large issue can at least be debated immediately: namely, whether evolutionary and strategic considerations, and by implication the forces which give rise to them, are important. The substance of this essay is a case study and a policy discussion which suggest that they are. The comparative evolution, structure, behavior, and competitive success of the U.S. and Japanese semiconductor and computer industries do not derive primarily from considerations such as factor costs. They derive largely from historical and technological conjunctures, incentive structures, and strategic interactions which led to a particular international strategic regime, and from the characteristics of this regime.
NOTES TO APPENDIX ONE

1. For one survey and very critical assessment by a (somewhat apostate) economist, see Laura Tyson, "Creating Advantage: An Industrial Policy Perspective," unpublished manuscript, University of California, Berkeley, August 1986.


4. See Bruce Scott’s article for a discussion of this issue. See also Lester Thurow, "Dangerous Currents: The State of Economics," Vintage, 1983; and by the same author, "The Zero-Sum Solution," particularly chapter 4. For nontraditional neoclassical analyses which consider these issues (and thereby invert traditional conclusions), see for example Kala Krishna, "High Tech Trade Policy," unpublished manuscript, Harvard University, 1986, for an analysis of how network externalities and learning effects imply that domestic government purchasing policy affects international competitiveness.


8. See "The Evolution of Cooperation," chapter 4, for a discussion of the "Live and Let Live" tacit agreements which arose spontaneously in trench warfare during WW I.

9. See for example Axelrod's analysis of norms for simulations in which the development of a norm is indeterminate and depends upon small events early in the simulation history. See also Paul David's history of keyboard standards, discussed below in more detail. For many interesting examples and a variety of hypothetical situations, see Thomas Schelling, "Micromotives and Macrobehavior," Norton, 1978.

10. In the preface to a reissued version of "The Strategy of Conflict," Thomas Schelling states that he had hoped the book would give rise to a new discipline devoted to strategic processes. He may see the birth of one yet.

11. See Axelrod, "The Evolution of Cooperation."

12. For the determinants of cooperation, see particularly the essays by Oye and by Axelrod & Keohane in "Cooperation Under Anarchy."

13. In the absence of central authority, the provision of public goods is one such benefit. But it has been shown that under most conditions envisioned by neoclassical theory, such public goods will be underprovided. There appear to be many examples of public goods which are "local," for example specific to an industry but "public" to everyone in that industry. R&D, political lobbying, and personnel training are often said to be such local public goods. For the classic economic analysis of the public goods problem, see Mancur Olson, "The Logic of Collective Action," Harvard University Press, 1965.

14. W. Brian Arthur's work is in this category. So perhaps is the recent work of F.M. Scherer on the dynamics of market structure.

16. See for example Christopher Zeeman, "Collected Papers On Catastrophe Theory," for various applications including voting behavior.


18. This appears to be the agenda of several analysts of critical phenomena and strategic processes. Axelrod is one example.

19. The following description owes much to the work of Kenneth Oye and Robert Axelrod, but it is my formulation - and responsibility - not theirs.

20. Some analyses of local interdependencies have, for example, considered how microstructures and small scale interactions affect annealing processes or the formation of glasses.

21. Axelrod and others have applied strategic processes to ecological processes and biological evolution.

22. In at least stylized form, the political theories of Locke and Hobbes can be formulated as views regarding incentive structures, time horizons, and subjective propensities in strategic arenas initially devoid of central authority.

23. Rawls' theory of justice is actually a rather classical economic problem, as opposed to a newer strategic one, in the sense that is formulated as a strategic choice made once and for all time, as opposed to a periodically revisable one.

24. As Axelrod has pointed out, the high degree of parallelism in local interactions suggests that highly concurrent computer systems may provide considerable increases in our ability to explore these questions. Axelrod's work already relies heavily upon computer simulation.
25. Thusfar Axelrod's work, and to some extent Brian Arthur's as well, suggest that strong regularities may exist, but that they are likely to be statistical in nature.

26. See "The Evolution of Cooperation."

27. Ibid.


29. See "Cooperation Under Anarchy" for examples from international economic relations and security policy.


31. In contrast, Olson's formulation of the public goods problem had no provision for iteration or for elicitation of cooperation from others, except through straightforward reward systems coupling individual goods to collective ones.

32. Axelrod's simulations keep payoffs constant. For lucid discussions of payoff structures and their relation to strategic processes, see the essays of Kenneth Oye ("Explaining Cooperation Under Anarchy: Hypotheses and Strategies"), Duncan Snidal ("The Game Theory of International Politics"), and Downs, Rocke, & Siverson ("Arms Races and Cooperation") in "Cooperation Under Anarchy."

33. Ibid.

34. See "The Evolution of Cooperation" for a detailed analysis of the performance of Tit-for-Tat.

35. Personal communication, 1986.

37. See Axelrod & Keohane in "Cooperation Under Anarchy" for a discussion of linkage in the context of international politics. They don't seem to understand it either.

38. See for example Hal Varian, "Microeconomic Analysis," 3rd edition, University of Michigan; or F. M. Scherer, "Industrial Market Structure and Economic Performance." Both are standard texts in their field. While Varian now includes some material on information asymmetries, the overwhelming thrust of both books is that competitive markets or at most static oligopoly are the norm. For critiques, see for example Bruce Scott's essay in "U.S. Competitiveness in the World Economy," and S. Cohen & J. Zysman, "Manufacturing Matters: The Myth of the Post-Industrial Economy," Basic Books, 1987.

39. For an example of such an attempt to squeeze a strategic process into a two-period model, see Michael Katz & Carl Shapiro, "Technology Adoption in the Presence of Network Externalities," Princeton Economics Working Paper 85-7, 1985. For an example of a smooth-trajectory model, see Paul David & Trond Olsen, "Anticipated Automation: A Rational Expectations Model of Technological Diffusion," Stanford Center for Economic Policy Research #24, 1984. These examples are not selected because they are bad economics (quite the contrary), but simply because they exemplify the dominant style of neoclassical analysis.

40. Strategic trade theory shares this deficit. The overwhelming majority of the new models are of smooth, deterministic equilibrium processes - different ones than perfectly competitive markets would generate, but still devoid of any consideration of behavioral changes, coordination among competitors, or the development of strategic norms.

41. David Teece and Eric Von Hippel among others have pointed out the importance of appropriability in determining sources, forms, and rates of innovation. See for example Teece, "Profiting from Technological Innovation: Implications for Integration, Licensing, and Public Policy," Research Policy, vol. 15 (1986).

42. Jaikumar's study of Japanese versus U.S. FMS systems found that Japanese employees received three times as much training as their U.S. counterparts. A study by Stephen Sheffrin and Lester Thurow found that on the job training had large productivity benefits, and that reduced turnover also produced large productivity gains. See Sheffrin & Thurow, "Estimating the Costs and Benefits of On-The-Job Training," Economie Applique, Vol. 30 (1978), #3. As I indicate below, turnover is enormously higher in the U.S. semiconductor industry than in the Japanese industry, at least in part as the result of norms of strategic conduct between the large integrated electronics companies which dominate Japanese production.

44. See for example the contrast between Varian or Scherer (microeconomics) and Brander, Spencer, or even Krugman in Krugman's edited volume "Strategic Trade Policy." Some newer microeconomic models, such as that by Stiglitz & Dasgupta just cited, include learning effects and arrive at the conclusion that if markets are contestable, the optimal market structure is a monopoly. If markets are not contestable, the result is indeterminate. That doesn't help much.

45. For example, even the new learning-dependent models are generally of this type - e.g. the work of Stiglitz & Dasgupta, or the rational expectations model of technology adoption by Paul David, cited earlier.


47. Ibid.

48. Ibid. For a particularly extreme view, see Milton Friedman, "Capitalism and Freedom," in which only externalities, neighborhood effects, and public goods are deemed proper objects of governmental action.

49. Ibid.

50. This view is prominent even in particularly striking cases of strategic industrial interaction. See for example the unreleased economists' report for the National Security Council interagency study of the semiconductor industry, 1986. I cannot quote from it, although I would like to.

51. See P. Krugman, "New Thinking About Trade Policy," in "Strategic Trade Policy and the New International Economics." For a less generous account, see Bruce Scott, particularly "National Strategies: Key to International Competition," in "U.S. Competitiveness..."

53. Kala Krishna makes this point in her "High Tech Trade Policy."


56. Consider for example the U.S. semiconductor industry's continuing market competition, and therefore of course sales to customers, while lobbying for the Semiconductor Trade Agreement of 1986, which imposed costs upon those customers, while concomitantly individual firms were negotiating with Japanese competitors for individual deals (e.g. Fujitsu and Fairchild), and major firms such as IBM were seeking to create Sematech, a joint venture to develop semiconductor manufacturing technology.

57. This notion has not yet been modeled neoclassically to the author's knowledge. For a "new neoclassical" treatment of the excess inertia and excess momentum problems associated with traditional microeconomic technology adoption in the presence of compatibility economies, see J. Farrell and G. Saloner, "Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation," American Economic Review, vol. 76, #5, p. 940.


59. Several related special cases are treated in Helpman and Krugman, "Market Structure and Foreign Trade," particularly chapters 11 and 12.

61. For an informal discussion restricted to international politics, see Axelrod & Keohane in "Cooperation Under Anarchy," pp. 238 - 247.


63. For a rather comprehensive survey of these structural and behavioral differences, see U.S. Congress Office of Technology Assessment, "International Competitiveness in Electronics," 1983.

64. For one exploration of these questions, including a very particular but also very interesting argument concerning American industry's allegedly excessive postwar dependency upon commodity mass production strategies, see Michael Piore and Charles Sabel, "The Second Industrial Divide: Possibilities for Prosperity," Basic Books, 1984.


69. Ibid.

attempts to compare the contributors to productivity growth rates in different nations as well as across time.


74. Ibid.

75. In "Cooperation Under Anarchy," part IV.
U.S. TECHNOLOGICAL DEPENDENCIES AND INTERNATIONAL COMPETITION

Semiconductor Capital Equipment, Materials, and Services

Capital equipment and inputs to semiconductor production include capital goods such as direct steppers, reactive ion etchers, logic and memory testers, CAD / CAE tools, and electron beam machines; materials such as silicon, gallium arsenide, reticle glass, and ultrapure gases; and services or inputs such as facility construction, mask making, or circuit design. For brevity, I will call the collection of these activities the "equipment sector." This sector is perhaps one-third the size of the semiconductor sector it serves (including captive production).

The U.S. equipment sector is deteriorating in the face of the merchant industry's problems and the rise of direct Japanese competition. This in its turn threatens American semiconductor producers - both merchants and captives. In many respects, the equipment sector's decline results from the same structural problems which handicap the semiconductor sector itself. The Japanese equipment industry is primarily composed of firms which are either diversified, vertically integrated complexes themselves, or firms which, while specialized, have exceptionally close relationships with their customers. The Japanese industry is far more concentrated than its U.S. counterpart, invests heavily and stably in R&D, and is supported by large parent groups and by government policy. Critical technologies are developed at efficient scale by small numbers of firms - usually two to four.
Comparatively, American equipment firms and subsectors are often fragmented, shortsighted, poor R&D performers, overly entrepreneurial, and undercapitalized.

Effects of semiconductor market losses upon the equipment sector

In the particular case of memory products, U.S. merchant decline reduces the size, profitability, and technical competitiveness of American equipment firms in the most advanced technologies used in the industry, with the possible exception of design systems. This effect is the consequence of the large size of memory markets and of the role of memory production as a "technology driver," i.e. a testing ground for advanced process technology. Memory production requires the most sophisticated lithography and process technology available - in wafer processing, initial testing and automated defect removal, packaging, automated assembly, and final testing. The technologies involved include not only individual pieces of equipment but process "recipes," process control software, and turnkey automated production systems. Memory production facilitates the development and use of these technologies for memory production itself, and then for subsequent logic production. Memories are technologically favored for advanced process development because they are mass produced, standardized, geometrically regular, functionally simple, and easily comparable. Hence the implications of technical alternatives are readily assessed.

Moreover, competitive advantage in memory markets is inherently based primarily upon integration levels, reliability, and production costs rather
than upon functional uniqueness. The market is large and continually
growing, encouraging maximal exploitation of automation, scale economies,
and new equipment. Hence the market (as well as the technology) motivates
firms to produce memories using the most advanced processes available, and
to use memory production as the testbed for these processes. Conversely in
logic production, the equipment areas most affected are CAD systems,
advanced logic testers, electron beam and laser writing systems, maskmaking,
and flexible automation systems (since logic production usually involves
producing a considerable number of designs in the same facility). An
analogous argument applies: as U.S. firms lose logic markets, demand for
advanced design and other logic-specific equipment declines.

The damage to the equipment sector thus takes a similar general form in
both product areas. As American semiconductor producers decline, they buy
less capital equipment for both R&D and production. Their time horizons
shorten as they seek to avoid immediate financial crisis, and their
inclination to invest in long term cooperative efforts declines. This
process has been most severe in equipment oriented towards mass production
and/or memory devices. Since memory production increased rapidly for
fifteen years, American decline has shifted equipment demand from American
to Japanese producers, and therefore caused enormous growth in Japanese
equipment demand.

And Japanese semiconductor firms tend to buy from Japanese sources, for
several related reasons. First, major Japanese investments have resulted in
development of Japanese equipment which is now highly competitive. Second,
Japanese semiconductor producers often have strong relationships with
domestic equipment firms. Fujitsu owns 22 percent of Advantest (testers),
NEC owns 50 percent of Ando (testers), Hitachi owns Hitachi Electronic
Engineering (various products), and Toshiba owns a producer of electron beam
equipment. Several semiconductor producers, including Hitachi and
Matsushita, also produce automated bonders. In other cases, equipment
suppliers are members of the same industrial complex as one of the
semiconductor firms. One such firm, Shin-Etsu, a member of the Sumitomo
group which includes NEC, holds 80 percent of the world market for mask-
quality glass and quartz. Another Japanese firm, Hoya, controls another 10
percent of the world market and also competes in maskmaking.

Recently, Japanese firms have also begun to acquire U.S. producers of
infrastructural goods, particularly of materials. Mitsubishi and Kawasaki
Steel, for example, both with growing semiconductor operations, have both
acquired U.S. silicon producers. And even where no structural relationship
exists, Japanese equipment firms have often benefited from enduring
sponsorship from major customers, MITI, and/or NTT. Nikon and Canon, which
may soon dominate the world market for some categories of lithographic
equipment, have both benefited from such assistance, as has Advantest.
Often NTT has issued development contracts with equipment firms for
development of new capital goods to be installed and used by the firms which
manufacture NTT's semiconductors - i.e. the largest Japanese semiconductor
and electronics firms. In some cases, NTT and/or semiconductor producers
have assigned employees to work for the equipment developer for substantial
periods of time.
As a result, many Japanese equipment firms have now become roughly equal, and in some cases superior, to their American counterparts. Furthermore, nearly all Japanese production and equipment purchases occur in Japan. Relatively small, self-financed American equipment firms without long-term Japanese relationships are significantly disadvantaged in penetrating the Japanese market. U.S. firms sometimes decide that if they are to enter the Japanese market, they must do so through joint ventures rather than wholly owned subsidiaries. So as American semiconductor firms have lost memory market share, American equipment firms have lost it as well. In memory-specific areas such as memory testers, these losses have been severe; even in other areas, they have been significant.

In the United States industry, market share loss, reduced cooperation with American semiconductor producers, and diminished profitability translate relatively directly into reduced productivity, higher costs, and reduced R&D. Consequently as American firms have withdrawn from memory and other technology-driving markets, the U.S. equipment industry has lost the incentive and financial ability to advance the state of the art in lithographic density, environmental and materials purity, testable clock rates and pin counts, and production automation technology. Soon, design technology may suffer as well. The result, already visible, is a gradual loss of technical primacy culminating in abandonment of important research projects, technologies, and business areas, which are then dominated by Japanese firms.
Probably the most extreme problems directly traceable to memory market loss are in lithography and testers. In the projection aligner and stepper markets, Canon and Nikon have established strong positions; Perkin-Elmer’s market share is reportedly declining, GCA is nearly bankrupt, and other suppliers are minor by comparison. Similarly, Advantest and Ando are gaining market share in testers. Teradyne, the American market leader, is an excellent firm and has established wholly owned Japanese operations. But Teradyne is a $400 million independent with limited diversification, and it is now effectively the last supplier of technically competitive memory testers in the United States. Sentry, a subsidiary of Schlumberger and once part of Fairchild, is reportedly losing both market share and technical competitiveness.

In several emerging technologies, developments are perhaps even more alarming. Eight U.S. firms undertook major R&D efforts in electron beam etching for direct writing and/or mask making. Only two remain: IBM and Perkin Elmer. HP, Varian, GCA, Veeco, General Signal, and CDC/Microbit cancelled their efforts, writing off over $100 million in investments by mid-1985. In contrast, three Japanese firms have continuing efforts; one (JEOL) already markets a system in the United States, and the other two are closely linked to Hitachi and Toshiba respectively. Trends in R&D areas critical to future equipment and process technologies are even more alarming. Submicron lithography will be dominated by some combination of three technologies: electron beam etching, laser based direct writing, and X-ray lithography. I have already mentioned the deteriorating position of American electron beam technology. Japanese R&D efforts in optoelectronics,
semiconductor lasers, and laser systems generally are generally considered quite strong.

X-ray lithography, roughly five to ten years from large scale commercialization, shows an even more extreme decline in U.S. efforts relative to Japan's. X-ray technology, generally considered the favored technology for dimensions of 0.5 microns and below, will likely be based upon computer controlled superconducting X-ray synchrotrons costing five to ten million dollars each. Current R&D is led by Germany and Japan. German firms have already announced commercial availability of synchrotrons and X-ray steppers. In Japan, cooperative efforts between NTT, NEC, Fujitsu, and Hitachi already involve beam line experiments with one synchrotron. Several more jointly operated synchrotrons, at least one of them superconducting, are planned. In contrast, IBM is the only major U.S. IC producer regularly using its own beam line for lithography R&D (at Brookhaven). Several U.S. equipment firms, including Varian, have cancelled their X-ray lithography efforts. Announced Japanese projects appear to involve R&D budgets totalling more than a billion dollars over the next five years.

Finally, semiconductor facility engineering and construction show similar symptoms. In 1986, IBM for the first time chose a Japanese construction firm, Shimizu, as the contractor for its next major semiconductor plant in East Fishkill. An IBM executive told me that this Japanese firm spends $10 million annually in R&D specifically devoted to improving clean room construction techniques, whereas no U.S. construction firm possessed any comparable effort. In 1987, IBM reversed its decision,
apparently because IBM preferred not to provide Shimizu with details of its facility engineering and fabrication methods.

If the costs of this deterioration were confined to the U.S. equipment industry, the issue would be significant but not critical. But there is another cost. As American equipment technology and suppliers decay, the technical and competitive strength of American semiconductor production also declines. Hence the decline of the semiconductor industry perpetuates itself: decline in semiconductors leads to decline in equipment producers, which leads to decline in semiconductor producers. Such decline, if it reduces the level of technology available on the market, affects even world class and/or captive producers. Their progress becomes limited by the inadequacies of their suppliers; and no producer, including IBM, can supply itself even nearly completely.

This phenomenon, which we will encounter repeatedly and discuss further in connection with policy analysis, has an interesting implication. Every U.S. producer, in the long run, is dependent upon external suppliers and therefore, indirectly but powerfully, upon the collective vitality of its suppliers’ other major customers, i.e. its domestic competitors. Even producers able consistently to better the industry - e.g. IBM - are ultimately limited by the industry’s average technology level and therefore hostage to its health. Otherwise the domestic infrastructure will decay, resulting in dependency upon whatever Japanese firms choose to make available. Some of these Japanese firms are direct competitors, not all renowned for their compliance with intellectual property laws.
Effects of equipment sector decline upon semiconductor production

As semiconductor design and production become increasingly computerized, automated, and capital intensive, the interdependencies between semiconductor production, capital equipment, and downstream industries (particularly computer systems) continuously increase. Therefore, semiconductor production increasingly requires detailed, long range cooperation with equipment suppliers and factory automation management. Furthermore, the leverage derivable from superior capital equipment and its customization to processing requirements is significant and possibly increasing.

Indeed, some fraction of recent American decline and Japanese progress in semiconductors can be attributed to the arms-length, short-term, even adversarial relationships which have traditionally existed between American semiconductor producers and their equipment suppliers. Large, long term cooperative investments diffuse rapidly to competitors. Cooperation is rendered difficult and precarious by distrust, bargaining and coordination problems, and the financial instability of potential partners. Therefore U.S. producers tended not to develop close, enduring relationships with their suppliers. But such relationships are important to technical progress and maximum productivity, and the Japanese industry has emphasized them.

The decline of American equipment technology and suppliers will (unless reversed) eventually damage both merchant and captive semiconductor
production. To the extent that U.S. semiconductor producers continue to rely on domestic sources, they will find themselves using inferior technology and struggling against the equipment industry's short time horizons and instability. But if U.S. producers seek to obtain Japanese equipment and technology, they will labor under disadvantages relative to their Japanese competition. As I indicated earlier, some major Japanese equipment suppliers have equity relationships with large semiconductor and electronics firms such as Fujitsu, Hitachi, NEC, and Toshiba. They also have longstanding cooperative technical relationships which involve joint equipment development, NTT funded research, technology and personnel transfer, so-called "beta" (i.e. site) testing of new machinery, and in some cases permanent engineering staffs at customer sites for equipment modification, maintenance, and repair service. (Service is critical to throughput in capital intensive plants.)

American firms are unlikely to obtain similar relationships. One might suspect that Advantest, partially owned by Fujitsu, has a closer relationship to Fujitsu than it has to IBM. Reciprocally, IBM might be pardoned for feeling a certain reluctance to disclose detailed technical information to Advantest, given that IBM is also pursuing legal action against Fujitsu related to allegedly large scale theft of intellectual property. So while Japanese firms may continue to commercialize their equipment, they will tend to do so after extensive beta testing and modification conducted in conjunction with their favored customers, who will surely be Japanese. Furthermore, many American firms have limited understanding of Japanese business practices, little experience with the
Japanese industry, limited ability to scan and assess Japanese technical practice and product offerings, and few employees who speak Japanese. For at least the time required to learn, they will suffer accordingly. Finally, Japanese firms usually have less extensive service networks in the United States than in Japan.

For all these reasons, Americans will wait longer for their equipment, obtain less throughput from it, pay higher prices, and receive less technical support and service - even if Japanese firms do not engage in strategic technology hoarding. But furthermore, they probably do. I have been told independently by several U.S. firms, both merchants and captives, of cases in which Japanese firms refused to sell advanced equipment, or made purchases difficult and expensive.

If continued, this process will have two consequences. First, American semiconductor producers will fall further behind Japan in process technology and manufacturing. Most significant, perhaps, is the potential damage to technically strong and/or critically important captive producers such as IBM, AT&T, DEC, HP, and GM/Hughes. The dependence of these firms upon the Japanese equipment sector is significant and increasing. So, therefore, is the advantage to be gained by Japanese firms from withholding technology. And second, U.S. producers will shift their production facilities and/or purchasing to Japan in the hope of gaining improved access to technology.

We do not yet know precisely how severe these effects will be. On the currently available evidence, it appears that they could eventually become
extremely serious. But more important, probably, is the process which will translate Japanese superiority in semiconductor technology into competitive advantage in larger downstream industries. Developments in systems markets exemplify this development, but other sectors will be affected as well.

Semiconductors and Downstream Industries

Semiconductor components are a rising fraction of virtually all mechanical or assembled goods - cars, weapons, computers, machine tools, washing machines, telephones, consumer electronics. The semiconductor content of computers, industrial and medical electronics, telecommunications equipment, and military electronics typically ranges from 3 to 10 percent, and is increasing rapidly. For example, IBM now (1987) consumes roughly $4 billion in semiconductors annually, yielding a content level of approximately 6% for its computer business. Dataquest's estimates for various U.S. industries are as follows:


<table>
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<th>Category</th>
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<tr>
<td>Data Processing Equipment</td>
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<td>6.6%</td>
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<tr>
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<td>7.0</td>
</tr>
<tr>
<td>Industrial Electronics</td>
<td>4.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Military Electronics</td>
<td>3.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Automotive Electronics*</td>
<td>9.3</td>
<td>10.1</td>
</tr>
</tbody>
</table>

*Electronic content, not entire automobiles. (Dataquest, 1986.)

There is wide agreement within these industries that semiconductor technology is becoming important to competitiveness in final markets. With the advent of VLSI, many systems previously based upon analog or low-
integration technologies are being digitized and converted to LSI and VLSI logic. Concomitantly, semiconductor technology continues to progress. The importance of microelectronics to competitive advantage in downstream industries is therefore increasing rapidly. Within ten years, consumer electronics will be nearly entirely digitized; new high definition television sets will probably contain more logic gates than were used in 1970 mainframe computers. New personal workstations such as the PC RT, Microvax 2, or Sun 3 already contain more logic, and processing power, than 1970 mainframes.

In some cases, the components involved are essentially commodities. This is true, for example, of memories and of the microcontrollers used in goods such as answering machines. However, this is not necessarily reassuring. First, their contribution to cost can be substantial; semiconductor memory is a significant and growing fraction of the cost of personal computers, VCRs, and other mass-produced goods. Second, custom digital design is becoming more important every year. This is a consequence of the increasing attractiveness of VLSI logic, often in the form of advanced microprocessors or application specific circuits such as gate arrays. While low end, mature products such as inexpensive telephones may always use circuits which are mature commodities relative to the state of the art, the importance of advanced VLSI to novel or high end markets appears to be increasing. This is certainly true of the computer, networking, telecommunications, automotive, industrial, and consumer markets. (It appears to be less true of defense markets as a consequence of the currently long delays involved in the design, qualification, and
production of weapons systems, at least in the United States.)

In some sectors, advanced semiconductor technology is already critical to comparative advantage in final markets. The most important of such sectors are computers and telecommunications systems. Certain specialized areas within defense electronics, such as those requiring GaAs devices, also require very advanced devices for rather different reasons such as combined speed and radiation hardness requirements. When the merchant semiconductor industry began its decline, American semiconductor consumers therefore had some combination of five choices: continued dependence upon decreasingly competitive merchant technology; increased dependence upon Japan; extremely expensive development of internal capacity; formation of stable, long term relationships with semiconductor producers; or vertical integration through friendly mergers and acquisitions.

With the exception of a few captive producers who have expanded (GM, DEC, IBM), American industry has increased its dependence upon Japan. This course permits American firms to avoid the direct disadvantage of inferior merchant technology and/or higher merchant prices. But it does not generally meet the need for closer integration between semiconductor and downstream operations, and it renders American firms highly dependent upon the Japanese firms who, in many cases, are their direct competitors in final markets. Once again, the potential and actual benefits of technology denial, and/or the exercise of technical leverage in order to obtain increased control, are rapidly increasing as a result.
Analysis of semiconductor dependencies

The implications of Japanese semiconductor dependency are dependent upon three variables. These are (a) the degree of Japanese market power, coordination, and technical control in various semiconductor product areas; (b) the degree to which the Japanese controlled technology is critical to competitive advantage and/or national security in downstream industry; and finally (c) the degree to which Japanese semiconductor producers (and/or their parent organizations) are or will become competitors in the downstream industry. By all of these criteria the computer, telecommunications, and industrial automation industries are the immediate candidates for Japanese strategic action. The defense electronics industry is also potentially involved, though not yet in a large way as a consequence of Japan's postwar political commitment to refrain from weapons exports.

Semiconductor markets and computer markets

Bipolar LSI circuits

Three Japanese firms dominate production of Japanese mainframe computers and supercomputers - Fujitsu, NEC, and Hitachi. They also control over two thirds of the Japanese telecommunications equipment market, and are three of the four largest Japanese semiconductor producers. They also control over 80 percent of the world market for ECL RAMs critical to the performance of mainframe cache memories, disk cache controllers, and supercomputer memories. In these product areas, and particularly in supercomputers, the importance of high speed memory to system performance is
increasing substantially. Cray and ETA Systems purchase bipolar memory from their direct Japanese competitors in supercomputer markets. Only IBM among American firms produces substantial quantities of high speed bipolar memory internally.

The CPUs of all minicomputers and mainframes are based upon bipolar custom and semicustom logic, primarily gate arrays. Mainframe and supercomputer CPUs typically use ECL gate arrays. Aside from IBM's captive production, only two U.S. firms - Motorola and Fairchild - remain even nearly competitive in this business, and American users are unanimous in their opinion that U.S. technology is deteriorating relative to that of four Japanese firms - Toshiba and the three mainframe and supercomputer firms listed above. Excluding U.S. captive production (the vast majority of which is accounted for by IBM), Japanese firms shipped 31 percent of all bipolar gate arrays produced in 1985, worldwide. (The world total was $623 million, again excluding U.S. captive production.) These shipments were divided between internal consumption by the computer systems divisions of these firms and open market sales. Most U.S. minicomputer, mainframe, and supercomputer firms now purchase at least some of their CPU arrays from these Japanese companies. In 1987, Unisys decided to use Hitachi bipolar components in its future mainframe systems. (In addition Amdahl, which is 49 percent owned by Fujitsu, uses Fujitsu components.) The performance of these arrays is critical to system price and performance.

Equally important, however, is the fact that American users sometimes cannot purchase the most advanced technology available because the Japanese
firms in question prefer not to sell it. There are already strong indications that the relatively low world market share of Japanese firms, and particularly of Fujitsu and NEC, reflects not the level of their technical capacities but the fact that they are now using their best technology in their own machines for significant periods of time before they commercialize it.

CMOS technology

As circuit density and speed increase, CMOS technology becomes increasingly favored relative to bipolar devices. One U.S. supercomputer, the ETA-10, is already being designed using VLSI CMOS gate arrays cooled by liquid nitrogen. It is generally agreed that five to ten years from now, CMOS (either room temperature or cooled) will become a favored technology even for extremely high speed CPUs which now use ECL arrays. The question therefore arises as to Japanese versus U.S. CMOS technology levels and R&D efforts. The answer is that Japan clearly leads the U.S. industry in CMOS processing, and its lead appears to be increasing. Indeed this processing advantage may already be contributing to increased Japanese dependency in another critical product area, CMOS ASICs.

MOS ASICs are a rapidly growing market already critical to a wide variety of electronic systems including personal computers, logic boards in various control systems, and telecommunications equipment. Japanese firms hold 40 percent of the world market in MOS ASICs, and have recently entered the American market in CMOS gate arrays with extraordinary aggressiveness. Japanese firms may capture one third of the American CMOS ASIC market this
year (1987). Aside from IBM, AT&T, and HP, no major U.S. consumer has competitive ASIC capabilities. There is some evidence that even these large captive producers are losing technical competitiveness relative to the Japanese. The potential dependency issues arising from Japanese control of CMOS ASIC markets are quite large. ASIC customers must disclose their designs to ASIC vendors and thereby expose themselves to industrial espionage; and ASICs are increasingly important to an extremely wide array of consumer, industrial, computer, and military products.

Further evidence of Japanese superiority in CMOS processing, and of its strategic risks to U.S. firms, is found in the microprocessor market. NEC and Hitachi are producing Intel and Motorola compatible microprocessors respectively. Both Japanese firms reverse engineered the American devices in CMOS, resulting in higher performance and lower power consumption. Hitachi used its bargaining leverage to obtain cross licensing agreements with Motorola, while Intel sued NEC for copyright infringement of its microcode. (More recently, in 1986 Motorola signed a joint venture agreement with Toshiba involving an exchange of Toshiba’s CMOS process technology for Motorola’s 68000 family microprocessor architecture.) Intel now holds less than half of the worldwide Intel-compatible microprocessor market. It is possible that within four years, significant dependency issues will therefore arise in 16 and 32 bit CMOS microprocessors.

Finally, there is increasing consensus that high speed computers, signal processing equipment, communications satellites, various consumer products, and a variety of military systems will soon employ gallium
arsenide circuits in significant quantities. Cray Research, for example, has announced that its Cray-3 machine will employ a GaAs central processing unit. Although commercial markets for GaAs remain embryonic, evaluations of Japanese R&D by IBM, the CIA, and others indicate that Japan possesses a significant lead in GaAs and optoelectronics relative to most U.S. computer systems and defense electronics firms, and an overwhelming lead in consumer applications such as high definition television. Consequently the large scale employment of GaAs will almost surely give rise almost immediately to significant American technical inferiority in final goods and/or dependence upon Japanese devices.

The next question, therefore, is whether the United States can maintain its current competitive position in these large downstream sectors even if it depends upon Japan for its most advanced semiconductors and semiconductor capital equipment. The answer is no. If American semiconductor technology and production deteriorate, American industries become dependent upon open market Japanese technology. The gradual but inevitable result would be deterioration in the productivity and international competitiveness of these downstream industries. This in turn could lead to reduced demand, R&D, and technical progress in their infrastructural industries, leading to further difficulties in sectors such as construction, robotics, advanced materials, and software.

Computer Markets and Computer Users

Analogously, deterioration within the U.S. computer industry is likely
to result in differential damage to the productivity of U.S. computer users. Many U.S. computer users, including much of the software industry, are effectively locked into their U.S. vendors for substantial periods of time as a consequence of complementary investments in personnel, software, supplies, long term contracts, service networks, and procedures. Switching costs are substantial. Hence for the same reason that U.S. market share in computer systems would probably decline more gradually (relative to the rate of decline in technological competitiveness) than has that of the merchant semiconductor industry, consumers of those U.S. systems would suffer more. Since the U.S. computer industry holds over 90% of the U.S. installed base but less than 40% of the Japanese installed base, a disproportionate share of adversely affected users will be American.

Hence, several further questions arise. The first is whether decline, and particularly the decline already facing the merchant semiconductor industry, has political and/or military consequences beyond the direct economic damage.
APPENDIX THREE
DATA SOURCES AND METHODOLOGY

As anyone who has tried knows, obtaining accurate and detailed information about the semiconductor and computer industries is not an easy task. Relative to other industrial sectors, at least three major problems differentially complicate the life of an analyst of microelectronics and information systems industries. First, much information is considered confidential, as a consequence of the industries' dependence upon proprietary technology, much of it not effectively protected by intellectual property law. Second, the standard sources for industry information (for example, the Census of Manufactures and other government statistical series) are of very little use, both because they do not contain much of the necessary information, and because they are frequently inaccurate. The Census of Manufactures, for example, lists total U.S. captive semiconductor production as roughly $1 billion for the year 1980, when IBM's production alone was nearly twice that size, and total U.S. captive production was probably $3 billion.

And third, the relevant industries are volatile, fragmented, and internationalized, all of which characteristics render the collection of accurate, internationally comparable data very difficult. In price-performance terms, semiconductor and computer technologies change between 25% and 45% annually; production is divided between the United States, Europe, Japan, and other Asian nations; and producers, particularly in the United States, rise and fall rapidly. And the largest and stablest firm,
IBM, is also by far the most secretive. For example, IBM is the largest semiconductor producer in the world, but it has never released any information about the size of its semiconductor R&D or production efforts.

As a consequence of these difficulties, studies of semiconductor and computer industry dynamics have tended to be either inaccurate (which several have indeed been), quite limited in scope, and/or highly dependent upon nonstandard data sources. Hopefully the present study falls into the third category. The information sources for this work have consisted of: the extant industry studies, most of which do not address issues of international competition or U.S. competitiveness; governmental and other public statistical sources where they are reasonably accurate (such as for product trade data); market research firms which collect industry statistics through private means; and personal visits and interviews, which often provide valuable information not otherwise obtainable. In addition, my own personal experience - as an IBM employee, as a consultant to many firms, and as an advisor to government studies of policy issues related to these industries - has proven extremely valuable.

1. Existing industry studies. The most detailed semiconductor industry studies of the traditional structure / conduct / performance sort are those conducted by the Federal Trade Commission in 1979 and by Charles River Associates in 1980. The recent (still unpublished) study of semiconductor industry economics conducted by government economists in connection with the National Security Council study of the semiconductor industry is also of this type. In the computer industry, the best
traditional studies are those conducted by government consultants and IBM consultants respectively during the 13-year IBM antitrust case. Other major studies are those of Tilton (semiconductor technology diffusion); Malerba (European performance); Flamm (government R&D policy in computers); Dorfman (innovation and market structure in U.S. semiconductors and computers); Borrus, Millstein, and Zysman (international competition in semiconductors); Okimoto, Sugano, and Weinstein (comparative structure of Japanese & U.S. semiconductor industries); and the United Nations (multinational semiconductor firms).

2. Public statistics. Government and public statistics do cover aggregate trade flows (products, license revenues, capital flows), technical education, employment, and aggregate market size. They do not, however, accurately report industry-level, firm-level, or intrafirm data, nor do they generally provide useful information concerning strategic variables or technology. Corporate annual reports generally do not provide highly precise information either. Louisa Koch's October 1987 report, "Data on the Electronics Industry in the U.S. and Japan," is probably the single best statistical picture available for the U.S. and Japanese semiconductor and computer industries, and draws upon most of the public statistical sources.

3. Market research reports. Several market research firms, for example Dataquest Corp. (for semiconductors and computers), ICE Corp. (semiconductors), VLSI Research Inc. (semiconductor capital equipment), Venture Economics (venture capital and new firms), and IDC (computers), collect detailed statistical information which is frequently the best
available, and usually far better than public sources. This information is collected from firms themselves and from their customers, suppliers, and contractors. The information is then aggregated and resold, usually for extremely high prices (Dataquest charges $15,000 per year per industry service). In addition, the research units of financial institutions such as investment banks collect useful information. I have been able, through various means, to obtain large quantities of market research data and equity research, some of which is used in this study. Dataquest in particular has been extremely patient and cooperative.

4. Personal interviews and visits. Over the last seven years, I have interviewed over five hundred people in relevant industries, and a considerable number of industry analysts, academic researchers, and government officials not only in the United States but in Japan and Europe as well. I have visited perhaps twenty semiconductor and computer factories in the United States and Japan. The ground rules for these interviews and visits have varied from complete openness to the requirement that the interview's existence never even be disclosed. In addition to explicit personal interviews, I have also participated in many meetings of industry executives, investment bankers, etc. at which participants discussed their companies or industries. In the majority of cases, I have checked material with at least two sources before using it in this essay, unless I have been able to confirm it personally.

By using and collating data from all of these sources, I believe that I have been able to arrive at an unusually detailed, comprehensive, and
accurate picture of the technological and competitive dynamics of these industries. The level of industrial interest in my results, and the general agreement by readers as to facts (if not always theories or explanations) would seem to validate the general accuracy of the results.