Comparative Innovation in Japan and in the United States

イノベーション（革新）の
日米比較（要旨）

Arthur J. Alexander

RAND
The research described in this report was conducted in RAND's Center for U.S.-Japan Relations. The Center's research is supported by ten major U.S. and Japanese corporate sponsors. American sponsors include Boeing Commercial Aircraft, Citicorp, Motorola, United Airlines, and Xerox; Japanese sponsors are C. Itoh, IBM Japan, Kawasaki Heavy Industries, Minebea, and Toshiba.

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August 1990
The Center for U.S.-Japan Relations was established within The RAND Corporation in 1989 to analyze the changes, problems, and opportunities that have emerged as the United States and Japan have grown more interdependent, and Japan has become the principal source of world capital supply, an expanding financial center in the world economy, and an economic superpower.

The Center’s research focuses on the economic relations between the two countries in the context of political, social, cultural, and security considerations. Interdisciplinary in character and design, this research involves active collaboration between RAND and Japanese scholars, experts, and institutions. The Center’s research seeks to advance the following objectives:

- Promote informed discussion of U.S.-Japanese relations among high-level government officials and policy analysts in both countries.
- Foster increased understanding in government, business, the media, and among the larger publics of the two countries, of key issues and problems affecting U.S.-Japan relations.
- Provide “early warning” of potential conflicts and misunderstandings, and thereby forestall or alleviate them.
- Provide U.S. and Japanese policymakers in both the public and private sectors with research findings that will help formulate policies to guide the relationship between the two countries.

To advance these objectives, the Center’s research has been built around the broad theme of “U.S.-Japan Cooperation, Concerns, and Shared Leadership in the 1990s.”

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PREFACE

This study was originally planned as a first phase of research comparing innovation in the United States and Japan. The literature review, reported on here, was to be the foundation for further research. However, the results of the literature review stimulated sufficient interest that it was believed desirable to bring them to a wider audience. Therefore, the principal goals of this report are to describe and synthesize the comparative literature. At several points in the report, the author also suggests additional hypotheses stimulated by the literature review.

The author acknowledges the useful contributions of two colleagues, C. Richard Neu and James Steinberg, who reviewed an earlier draft of this report. Their comments helped to clarify the arguments and encouraged the author to fill in several blank spots in the analysis.

This study was conducted under the project entitled “Comparative Innovation in Japan and the United States” for the RAND Center for U.S.-Japan Relations.
SUMMARY

CIRCUMSTANCES AND POLICIES IN JAPAN AND THE UNITED STATES

The Japanese postwar environment was characterized by several traits that influenced the style of innovation. First, a broad national consensus existed for recovery and growth. Second, Japanese industry lagged behind the world leaders in industrial productivity, technology, and science. Third, economic and national security stability prevailed in much of the period. Fourth, the supply of resources, including energy (until 1973) and labor, never constrained the rapid growth of investment and production. And fifth, the economies of the United States and Europe provided export markets for the growing Japanese productive capacity.

Certain government policies encouraged household saving and the channeling of capital to industry. The regulation of financial markets and the insulation of domestic markets from international financial flows allowed Japanese industry to receive the large flow of funds from domestic savings at favorable interest rates. Foreign trade was controlled through financial regulation combined with explicit restrictions of selected imports to protect many industries whose productivity did not match foreign levels.

Government coordination and guidance were of mixed effectiveness: In steel, shipbuilding, and chemicals, coordination achieved cartel-like results, especially during recessions; but in many other cases, including machine tools and automobiles, it was ineffective.

One policy was important because of its omission: The Japanese government financed very little science and university research.

A large volume of capital, often available below market equilibrium rates, encouraged rapid investment, capacity expansion, and market entry. Import restrictions supplied a protective umbrella against more productive foreign suppliers. As a result, fierce competition ensued among Japanese producers, who sought competitive advantage through greater efficiency, productivity, and lower costs. Since science, technology, and new product concepts were being developed elsewhere, Japanese producers had little need to devote their energies to these activities. Instead, the domestic competitive environment stimulated a focus on production efficiency. The hallmark of postwar Japanese innovation was the transformation of production processes that were efficient at volumes much lower than in the United States and Europe.
The imperative for cost-reducing innovation carried over into R&D, which was harnessed to the crusade for greater efficiency. By reducing the development time of improved products it became economically feasible to introduce new models and products quickly, thereby permitting greater flexibility in reaction to market and technological opportunities.

Circumstances in the United States were entirely different from those in Japan. The wide destruction and disruption of the war outside the United States gave the war-strengthened U.S. industry an extended period of uncontested foreign sales and a continental domestic market.

U.S. industry's traditional attachment to science and research was particularly suited to the commercialization of many of the technologies that had been stimulated by military expenditures and demand. The 1950s witnessed the emergence of science-based industries, creating commercial opportunities and generating some powerful myths about military R&D. As the military, supported by unprecedented defense demand and funding, further developed and applied the research results of the civilian sector, military uses gradually diverged from civilian applications in a process of specialization and refinement that reduced the probability of later civilian application. However, governments all over the world interpreted the congruence of military and civilian technological requirements and applications of the middle part of the 20th century as a general phenomenon and promoted military R&D for its presumed civilian returns. By the late 20th century, with the benefit of a still hazy hindsight, the evidence appears to refute this belief.

Some studies suggest that defense may have diverted resources away from investment, thereby slightly reducing economic growth over the long run. Other findings show no discernible influence of defense expenditures on investment. Defense R&D appears to have no long-run measurable effect—positive or negative—on productivity or on the supply of scientists and engineers to the civilian sector.

U.S. industry was supported by mature capital markets and entrepreneurial venture capital firms, which together financed the growth and development of both older and newer industries.

Government policy strongly promoted science and research in government laboratories, industry, and universities. At the same time, a pervasive philosophy generally restrained government interventions in markets.

The innovation of U.S. firms tended to be devoted to wholly new products and production technologies. Cost and efficiency took second place. Because of the well-developed capital markets, firms paid the
market price of capital; their decisions were dominated by expected rates of return.

Both countries benefited mutually from their diverse circumstances and developments. Japan’s growth and transformation depended on the technology, science, and markets of the United States; and American welfare would have been diminished without the Japanese pursuit of efficiency, productivity, and product evolution. U.S. manufacturing subsequently benefited directly from adoption of Japanese production methods.

INNOVATION STYLES IN R&D

American industrial research tends to emphasize product rather than process R&D, and entirely new products and processes rather than improvements. U.S. firms emphasize the “front end” of the development cycle, and Japanese, the production phases. Consistent with these expenditure patterns, Japanese companies obtain more of their ideas for their research projects from users, whereas U.S. projects tend to flow from R&D personnel.

Innovations in Japanese R&D management appear to have been driven by a competitive evaluation that fast introduction time of new products was a profitable strategy. This behavior is consistent with other evidence that Japanese firms, compared with similar American firms, seem to be willing to devote about twice as many resources, on the margin, to reduce development times.

INNOVATION IN PRODUCTION

Japanese innovation in production management began in automobiles. By 1960, Toyota’s vehicle output per employee had already outstripped the three largest U.S. producers; and by 1980, Toyota and Nissan were four to six times more productive than the U.S. Big Three. These crude differences are narrowed somewhat when the figures are adjusted for differences in vertical integration, capacity utilization, and labor-hour differences; however, the Japanese producers remain two to three times more productive. These differences are not associated with either scale economies or capital investment: The Japanese firms achieved their high productivity at output levels well below typical U.S. volumes; investment per unit of output was less in Japan than in the United States until the early 1980s when large Japanese capital expenditures brought their figures up to the American level.
The principal explanation for variation in productivity and quality was style of management, characterized as lean, unbuffered, fragile, and high-stress. The "just-in-time" (JIT) method of parts supply and inventory control has been used as a shorthand designation to describe the entire process.

JIT was fragile or unbuffered because defects or problems stopped production. JIT's important (and unplanned) result was that it increased the feedback of information generated in the production process. The system compels attention to problems because they stop production. The constant attention and problem solving increased efficiency as production rates were continually raised with the solving of each problem and the stressing of new areas. The JIT process has been statistically associated with higher productivity, not only in Japanese automobile plants but in factories worldwide.

INNOVATION IN THE 1990s

Circumstances in Japan in the 1990s are substantially different from those of the postwar years. The growth consensus has evaporated, and competing demands have grown for savings. Financial markets are in the process of being deregulated and internationalized, so that government ability to control financial flows is a thing of the past. However, venture capital continues to be underdeveloped. International and domestic pressures no longer permit overt import restrictions, and informal barriers are under constant attack. Resource constraints are becoming more binding, with higher energy prices and tighter labor markets. Applied R&D and technology are now at world levels, but the country continues to lag in basic research, science, and graduate technical education.

The United States in the 1990s faces intense competition from foreign sources in domestic and world markets. Technology, productivity, and advanced management practices have spread throughout the world. Despite low savings rates and investment, venture capital is ten times higher in the United States than in Japan. Also, investment in science and basic research is much greater; however, the ratios of R&D to GNP, R&D per capita, and company-sponsored R&D to sales are all now higher in Japan. American scientific education remains strong and is, in fact, an important service export sector with many foreign students in American engineering departments and graduate schools.

The area of biotechnology illustrates the mix of strengths, weaknesses, and complementarities between the two countries. The Japanese government designated biotechnology as a high-priority target in 1980.
However, by 1984, they had allocated only $35 million to research, compared with U.S. funding of more than $500 million. By 1990, Japanese government spending was still only about 30 percent of the U.S. figures of ten years earlier.

By 1990, more than 500 new U.S. businesses had started up; 200 or so had gone public, and in 1986 alone they raised more than $1 billion in initial public offerings. Few, if any, Japanese firms were started. In 1982, more than 1200 doctorate level scientists and engineers worked in U.S. biogenetic engineering, while only 161 similarly trained personnel could be found in Japanese laboratories.

The biotechnology scenario may offer one partial view of the future: U.S. strengths in science, research, new products and concepts, graduate education, entrepreneurship, and venture capital; Japanese strengths in financial capital, product commercialization, applied technology, and production efficiency. At the same time, American firms are struggling to understand and copy Japanese production and product development methods; and Japanese industry, government, and academia are slowly responding to their science and education deficiencies, partly by actively participating in U.S. science and advanced education.
概要

1. 日本と米国における経済環境と政策

日本の戦後の経済環境はイノベーションの様式に影響を及ぼすいくつかの特性を備えていた。最初は新しい成長に対する国民的合意が存在していたことである。第二に日本の産業が工業の生産性、技術、および科学において世界的に先進国よりも遅れていたことである。第三は経済的安全性および国家安全保障上の安定性が維持されてきたことである。第四はエネルギー（1973年まで）および労働力をふくむ資源の供給が投資と生産の成長の中で制約されなかったことである。そして第五は米国とヨーロッパが拡大する日本の生産能力に対する輸出市場を提供したということである。

いくつかの政府の政策が家計の貯蓄を奨励し、産業への資金供給を促してきた。金融市場の規制と国内市場の国際的資金フローからの隔離が日本の産業に国内貯蓄からの大量の資金を低利で調達することを可能にした。海外貿易は資金規制および生産性が海外の水準に到達していない産業を保護するための選別的な輸入制限によってコントロールされていた。

政府の調整と誘導の効果があったともいえるなかったともいえる。鉄鋼、造船、および化学では、調整によって、とくに不況時に、カルテルに似た結果がもたらされた。しかし、工作機械および自動車をふくむ多くの産業では、効果がなかった。

一つの政策はその欠落ゆえに重要であった。日本政府は科学と大学での研究にほとんど資金を出さなかった。

しばしば市場均衡レート以下で利用可能な大量の資金が急ピッチの投資、能力拡張、および市場参入を促進した。輸入制限は生産性の高い海外供給者から保護するための傘となった。その結果、激しい競争が日本の生産者の間で起き、価格は効率を高め、生産性を高め、コストを引き下げることによって比較優位を保つようになった。科学、技術、および新製品のコンセプトは他国で開発されていたから、日本の生産者は彼等のエネルギーをそうした活動に注ぐ必要はほとんどなかった。その代わり、国内の競争環境が生産効率に焦点を合わせるように仕向けた。

戦後の日本のイノベーションの特徴は、米国やヨーロッパよりも少ない生産量でも高い効率をもたらす生産工程の転換にある。

コスト削減的イノベーションという若者はR&D（研究開発）にもあてはめられた。R&Dはいっぱいの効率向上の推進に役立てられた。製品改良のための開発期間の短縮によって、新しいモデルや製品を速やかに導入することが可能になり、市場や技術的情報に柔軟に対応することができるようになった。
出てくる傾向がある。
日本のR&D管理のイノベーションは、新製品導入までの時間を縮めることが有利な戦略であるという競争戦略の評価基準によって進められてきたように思われる。こうした行動は、日本企業は類似の米国企業に比べて約2倍の資源を開発期間の短縮に費やすことを断わないらしい。という別の証拠とも矛盾しない。

3. 生産におけるイノベーション

日本の生産管理上のイノベーションは自動車産業から始まった。1960年代にはトヨタの雇用者1人当たり自動車生産台数はすでに米国の3大メーカーを上回っていた。そして1980年代にはトヨタと日産は米国のビック・スリーより4〜6倍も生産性が高かった。これらは、図の統合度の差、能力利用度の差および労働時間の差を調整することによって若干縮まるが、それでも日本のメーカーは2〜3倍も生産性が高い。こうした格差は規模の経済や投下資本に伴うものではない。なぜなら、日本企業は典型的な米国企業の生産量をはるかに上回る生産水準においても高い生産性を達成しているからである。また、生産台数当たりの投資は、日本の大規模な投資支出が米国みなの水準に引き上げた1980年代初めまでは、米国より日本のほうが少なかった。

生産性および品質の差の主要な説明要因は、無駄がなく、衝撃を受けやすく、こわれやすく、緊張度が高いという特徴を持つ管理様式に求められてきた。部品供給および在庫管理の「ジャスト・イン・タイム(JIT)」方式という言葉が全体のプロセスを表す簡便な称名として使われている。

JITはこわれやすいか衝撃を受けやすかった。なぜなら欠陥や問題が発生した時に生産がとまってしまうからである。JITの重要な（そして計画外の）結果は生産工程で生ずる情報のフィードバックを高めたことである。このシステムは注意力を問題に向けさせた。なぜなら問題が起きれば生産がとまるからである。

個々の問題を解決し、新たな領域に目が向けられるにつれて、こうした不断の注意と問題解決が効率を向上させた。JITのプロセスは、日本自動車工場だけでなく世界の工場においても、より高い生産性をもたらした。

4. 1990年代のイノベーション

1990年代における日本の経済環境は戦後のそれとは本質的に異なる。成長へのコンセンサスが弱まり、貯蓄に対して反対する要求が強まっている。金融市場は規制緩和と国際化の途上にあり、また資金の流れをコントロールする能力は政府にはない。しかし、ベンチャーキャピタルはまだ未発達である。国際的および国内的な圧力はもはや公然の輪渡制限を許さず、非公式の監督は絶えず攻撃にさらされている。資源制約は、エネルギー価格の上昇と労働市場の逼迫によって、一段と強まりつつある。応用的なR&Dと技術は今や世界中に広まっているにも
米国の環境は日本とはまったく異なっていた。領土を含む戦争による広範な破壊と戦争は無能な米国産業に海外でも米国内でも、かなりの期間、無敵の地位を与えた。科学と研究に対する米国産業の伝統的愛着は、軍需に刺激された多くの技術を商業化するのに特に適していた。1950年代には科学基盤産業が勃興したが、それらを新たな商業機会を創造し、軍事的R&Dに関する力強い神話を作り出した。前例のない国防需要と資金手当てに支えられて、軍部がさらに拡張し、民生部門の研究結果を応用するのに失敗、専門化および洗練化の過程で軍用的利用が徐々に民間の利用から分離し、そのことが後に民生用への適用の確率を低下させた。しかし、世界各国の政府は20世紀半ばにおいて軍事用技術の利用と民生用技術の利用との調和こそが一般的な現象だと考え、民生用への見返りを想定しつつ軍事的R&Dを促進した。20世紀末においても、ぼんやりした後知恵ではあるが、実事はそうした信念と反対のようである。

いくつかの研究では、国防支出は投資に向けられるべき資源を奪い取り、そのため長期の経済成長を僅かに低下させていることが示されている。また別の研究によれば、国防支出は投資に目を向けた影響をもたらさない。国防用のR&Dは生産性または科学者および技術者の民間部門への供給に、プラスにしろマイナスにしろ、長期的に測定できるほどの影響を与えないように思われる。

米国の産業は成熟した資本市場と企業家精神に富むベンチャーキャピタルによって支えられ、それは一体となって旧産業および新しい産業の成長と発展のための資金を供給してきた。

政府の政策は、政府研究機関、産業、大学における科学と研究を強力に促進した。それと同時に米国での支配的な哲学が政府の市場への介入を抑制した。

米国企業の技術革新は全体として新製品および生産技術に向けられた。コストと効率は二の次であった。資本市場が発達していたために、企業は資本の市場価格を払った。そのため彼等の意思決定は期待収益率に支配されていた。

日本両国は互いにそれぞれ違った環境と発展状況から恩恵を受けた。日本の成長と転換は日本の技術、科学および市場に依存していた。そしてアメリカ人の近辺を住む米国の効率、生産性および製品改良への追求なくして高まらなかったであろう。それに加えて米国の製造業は日本の生産方法を採用することによって直接の恩恵を受けてきた。

2. R&Dにおけるイノベーションの様式

米国産業の研究は、工程のR&Dよりも製品のR&Dを改良よりもまったく新しい製品あるいは新しい工程を強調する傾向がある。米国企業は開発サイクルのフロント・エンド（前部）を強調し、日本企業は生産面を強調する。こうした研究開発支出パターンに対応して、日本の会社は研究プロジェクトのアイディアの多くをユーザーから入手する一方、米国のプロジェクトはR&D従事者から
かかわらず、日本は基礎研究、科学、および大学院の技術教育では依然立ち遅れている。

1990年代の米国は、国内および世界市場において、外国との厳しい競争に直面している。技術、生産性、進んだ経営慣行は世界中に拡散してしまった。高い貯蓄率と投資にもかかわらず、米国のベンチャーキャピタルは日本の10倍も大きい。また、科学および基礎研究への投資は大きいものの、R&D対GDP比率、1人当たりR&D、企業負担のR&D対売上高比率では、今や日本のほうが上回っている。しかし、米国の科学教育は依然として強く、事実、アメリカの工学部と大学院に多くの外国人学生を受け入れることによって重要なサービス輸出部門となっている。

バイオテクノロジーの分野は両国の強さと弱さと補完関係が混在したよい例である。日本政府は1980年にバイオテクノロジーの優先度の高い分野に指定した。しかし、1984年までにわずか3500万ドルしか研究に割り当てていない。これに対し米国は5億ドル以上を投じている。1990年までの日本政府の支出は、米国の10年前の数字の約30％にとどまっている。

この分野では、1990年までに500以上の新しい米国企業が設立された。このうち約200社が株式を公開し、1986年だけで10億ドル以上を一次公募で調達した。他方、日本企業は、あったとしてもほんの僅かしか設立されなかった。1982年ににおいて200人以上の博士レベルの科学者が技術者が米国の生物工学の分野で働いているが、日本の研究所では同じ程度の訓練を受けた人の人数はわずか161人である。

バイオテクノロジーに関してのシナリオは将来に対する部分的な見方しか与えられないかもしれない。米国の強さは科学、研究、新製品とそのコンセプト、大学院教育、企業家精神、およびベンチャーキャピタルにある。他方、日本の強さは金融資本、製品の商業化、応用技術、および生産効率にある。それと同時に、米国の企業は日本の生産と製品開発の手法を理解し、真似るように躍起になっている。そして、日本の産業、政府、および学界は遅まきながら科学および教育上の欠陥に対応して、部分的ではあるが、米国の科学および高等教育に積極的に参加している。
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I. INTRODUCTION

Enormous improvements in productivity and economic welfare swept through the industrialized countries in the 19th and 20th centuries, largely as a result of innovation and technological change. A review of research on productivity notes: "Virtually all scholars of productivity growth now agree on the central role of technological advance." However, that reviewer urges caution on one point: "Differences across countries in the post World War II productivity growth rates are not correlated with inter-country R&D spending differences." The search for the sources of divergent productivity trends must, therefore, go beyond the study of R&D.

The subject of this report is innovation, which is intended to be somewhat broader in meaning than technological change. The dictionary definition of innovation, "the introduction of new things or methods," is broad enough to encompass change brought about by science, research, development, product engineering, manufacturing processes, and the organization and institutions of production. Innovation is defined here as any activity that provides users with new or improved processes or products; the result of innovation is change that generates positive economic value to its immediate beneficiaries. Users or beneficiaries may be producers or final consumers; innovations may be marketed, used directly by the innovator, or made freely available to others. This report discusses industrial behavior, to a large degree excluding such activities as education that lie mainly outside the production sphere; this exclusion is not because such activities are unimportant or because they do not accord with the basic definition of innovation offered above, but because of a need to provide some focus to an already broad study.

This report addresses several key questions: (1) What are the differences between the United States and Japan in their approaches to innovation? (2) What are the reasons for and sources of these differences? (3) How are these differences and their sources changing? (4) What are the implications for innovation in the future?

The behavior of both countries in the postwar period under review was conditioned by circumstances over which the nations had little control. Although it would be going too far to say that results were totally the accidents of history, the bounds of policy were nevertheless

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2Ibid., p. 1035.
sharply constrained by custom and circumstances. Furthermore, some policies that were initiated could not always be implemented as planned (Japanese industrial policy, for example), and those that were effective had unplanned and even undesired side effects; however, those gave rise to the driving force for innovative energies that profoundly changed Japanese productive processes.

To answer the key questions, I sought out previous studies in which comparisons could be drawn between Japan and the United States. Some studies were explicitly comparative; others included both countries as only two points in broader, multinational analyses. Many of the best comparative research efforts were carried out at U.S. business schools, perhaps because of the demands of their main client: American industry. Something was obviously occurring in Japanese manufacturing that required closer observation and better understanding. This research collected data across samples of observations and analyzed these data according to the fairly rigorous standards of the academic scientific community; although these standards were often neither as theoretically based nor as empirically rigorous as the more orthodox economics community would have demanded, there is a consistency and sensibility in the cumulative volume of results that give strength to the main findings. For this report, I reviewed approximately 50 comparative studies and made active use of about half of them.

The comparative studies were placed in a context provided by policy research, macroeconomic analyses, and productivity investigations, as well as by detailed case studies of automobile manufacturing and biotechnology.

By and large, most of the reviewed literature covers the period from 1950 to the 1980s. It describes the postwar transformation of Japan and the evolutionary change in the U.S. economy. The selection of comparative studies was opportunistic; I would have preferred more cases, for example, in electronics or computers (to note just one deficient area) but found only a few that met the criteria of data-based comparisons. The selection process also tended to favor production innovations rather than science and R&D; the apparent bias was dictated by the major innovations in postwar Japan, which were in production processes. The focus of the study was on innovation with direct economic consequences; therefore, industrial behavior was more thoroughly reviewed than pure research. The gaps in the analysis should provide ample grounds for future research.
II. POSTWAR ENVIRONMENTS IN JAPAN AND THE UNITED STATES

CIRCUMSTANCES AND POLICIES IN JAPAN

From 1945 to 1973 circumstances in Japan established the conditions under which a peculiarly Japanese approach to innovation evolved and flourished. These circumstances began to change after the rapid 1973 increase in energy prices and the subsequent transformation of the national economy.\(^1\) By the mid-1980s, and certainly in the 1990s, these conditions have been so altered and so many new circumstances have arisen that Japan is now moving on a new trajectory.

The postwar circumstances were composed of a mixture of environmental factors and policies.\(^2\) First, a broad national consensus for postwar recovery and growth explicitly favored growth over equity, thus avoiding the ideological debates over distribution that engendered serious political disagreements in Europe. Because of this consensus, there was little debate over the policies adopted by the government ministries and the legislature dominated by the Liberal Democratic Party.

Second, Japanese industry lagged behind the world leaders in industrial productivity, technology, and science, in no small part because of wartime destruction. This situation provided the opportunity to start afresh; the clear incentive was to buy, borrow, and copy technology and all the other knowledge associated with it: products, processes, designs, and market concepts. Although the investment in industrial infrastructure, equipment, and technology required enormous sacrifices in the early postwar period, it created a modern base for subsequent expansion.

A third area of considerable importance was the economic and national security stability that prevailed during much of the period. Until 1973, growth was unaffected by major downturns or the disrupting influence of war. Indeed, both the Korean and Vietnamese wars provided market opportunities for Japanese motor vehicles and aviation.

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\(^1\)One important change following the oil-price shocks was a government deficit during the mid-1970s recession; the need to finance this deficit was instrumental in breaking down the close regulation of financial markets.

\(^2\)This list of circumstances is largely taken, with modification and amendment, from Yamamura, 1986, pp. 169–171.
Finally, Japan was lucky in its resources and markets. Internally, the supply of labor never constrained the very rapid growth of investment and output; externally, supplies of materials and energy were abundant and fairly low priced (although the oil price increases after 1973 severely disrupted several important industries and adversely affected productivity growth for a decade). The growth of the United States, Europe, and the rest of the industrialized world also provided export markets for Japan’s hugely increased productive capacity.

These generally favorable circumstances, largely independent of Japanese actions, were abetted by central government policies. A major goal of the growth-oriented government was to provide as much capital as possible at the lowest possible cost to firms pushing new technology and expanding capacity. The most important policy involved the encouragement of household saving and the channeling of capital to industry. The Japanese tax system contained numerous tax breaks for saving, including an assortment of maryyu provisions, under which interest income went untaxed; in addition, capital gains on land, housing, and equities received favorable tax treatment. Unlike the situation in the United States, interest paid on housing loans and other consumer loans was not tax deductible. These financial policies, together with an official and widely accepted national norm favoring savings, were important contributors to very high Japanese savings rates.

One important influence on the Japanese saving rate was economic growth itself. Most cross-country analyses find that income growth has a highly significant effect on the private saving rate. Several hypotheses have been offered to explain this observed regularity, but empirical support has been mixed. Among the better supported hypotheses are wealth-adjustment effects and life-cycle effects. According to the wealth-adjustment hypothesis, Japanese households saved a proportion of their incomes to maintain their wealth-income ratios at previous levels; the higher the growth rate of income, the higher the required saving rate. The life-cycle hypothesis implies that, with income growth, the saving of the young will exceed the dissaving of the old, and the higher the rate of income growth, the higher will be the household saving rate. Despite the success of these two income growth hypotheses in partly explaining the high Japanese saving rate, an extensive survey of the literature concluded that “the relative importance of the various channels through which

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3 Yamamura, 1986, p. 171.
income growth may have influenced household saving has not been clarified.\textsuperscript{5}

A highly controlled and regulated financial market directed the enormous flow of savings not only to selected firms and industries, but also to industry more generally. Government budgets were largely in balance until 1973, and consumer credit was tightly restricted, thus eliminating two potentially large competitors for funds. Insulation of the domestic market from international financial flows permitted the Ministry of Finance (MOF) to control the allocation of foreign currencies and the Ministry of International Trade and Industry (MITI) to regulate the importation of goods.

The control of foreign trade through financial controls was allied with explicit restrictions of selected imports through tariffs, quotas, and other mechanisms such as the allocation of import licenses. MITI was thus able to protect several industries whose productivity did not match the levels attained by firms in the United States and elsewhere.

Government coordination and ministerial guidance of business behavior through formally unenforceable "advice" was of mixed effectiveness. In some cases, such as steel, shipbuilding, and chemicals, government coordination and targeting achieved cartel-like results, especially during periods of weak demand. Overinvestment could be avoided in good times, and excess capacity could be reduced in an orderly manner when demand fell.

It is this Japanese approach to targeting, coordination, and guidance that has been most often singled out as representative of Japanese industrial policy. However, in many cases this approach was ineffective. In several important products, industry did not support the government's strategic plans. Machine tools, automobiles, and microelectronics were cases of government advice often going unheeded. In automobiles, for example, several government agencies argued against the three major vehicle companies entering the automobile market in 1950, based on government assumptions that domestic productivity and scale of production were so low as to be uncompetitive with European and American producers.\textsuperscript{6} When the companies ignored this advice and began domestic production, MITI curtailed imports to protect the Japanese producers, which were inefficient relative to foreign producers. Imports subsequently fell from 45 percent of sales in 1951 to 9 percent by 1955, and to only 1 percent in 1960. Under this umbrella, and with access to low-cost public and private financing, eight more firms subsequently entered the motor vehicle market; these firms

\textsuperscript{5}Ibid., p. 80.
\textsuperscript{6}Cusumano, 1986, pp. 15–23.
shared an annual market in 1955 equal to less than a single day’s output of the U.S. industry. Several times in following years, MITI tried to encourage consolidation and mergers of automobile producers, but with no success.

In the automobile case, and in many other products and industries, the most important elements of government policy were the control and channeling of financial resources and the protection from foreign competition during vulnerable periods of industrial growth.

One other policy deserves mention, mainly because of its absence. Because of fairly small government budgets, tight expenditures controls by the Ministry of Finance, and minuscule defense R&D, the Japanese government funded very little science, research, or development. As a percentage of Japanese GNP, 1970 public funding of R&D was only 0.55 percent, compared with 1.48 percent in the United States. In absolute terms, the amounts were tiny—only $3.7 billion in 1970, rising to $7.6 billion in 1985. (U.S. expenditures grew from $35.6 billion to $46.0 billion in this period.) Because of the small involvement of the Japanese government in financing science and poor communications among Japanese scientists, the government promoted a research approach quite different from U.S. experience: the encouragement of cooperative industrial research. More than 80 technology research associations were established, mainly under MITI's aegis and coordination; typically these ventures brought together several companies for information exchange and mutual coordination of a small research agenda, financed partly through public funds and favorable tax policy.

CONSEQUENCES OF JAPAN’S CIRCUMSTANCES AND POLICIES

A large volume of capital was available to industry because of the government’s policies of regulated capital markets and high household savings rates. Lending by private and government financial organizations at interest rates that were often below market equilibrium rates encouraged rapid investment and capacity expansion.

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7Total U.S. production in 1955 was 8 million vehicles, but only 20,300 in Japan. On a 365-day production basis, the U.S. average production rate was 22,000 vehicles per day.
8Cusumano, 1985, p. 23.
9National Science Foundation, 1988, Tables B-2, B-4.
10Heaton, 1988, p. 33. Cooperative research will be discussed more fully in Sec. III.
11Some economists have questioned the broadly accepted view of subsidized interest rates; one of their arguments is that financial market imperfections were compensated for by government policy such that the cost of capital to a firm was not less than it would have been in a smoothly functioning market. A somewhat different argument is that the MOF policy was simply ineffective. Sakakibara, 1982; Horiuchi, 1984.
Import restrictions supplied a protective umbrella against the onslaughts of more productive foreign competitors. Domestically, however, an inefficient Japanese firm had to contend with only equally inefficient Japanese competitors. With the easy availability of capital, the benefits of protection, and the small scale of production required to meet the demands of a still-recovering domestic market, market entry was easy in many products. By 1960, for example, 11 companies were producing automobiles. Thousands of tiny manufacturing firms produced components and parts for the larger firms in automobiles, machine tools, and other manufacturing industries. These tiny firms were supported by a protected financial sector that specialized in small companies.

In product after product, fierce competition was engendered by the entry of many firms, often fighting over a small domestic market. Later, as Japanese industry became more efficient and competed on a global scale, the same processes continued to operate. For example, 25 Japanese companies are fighting for the facsimile machine market. According to one analysis:

The bitter competition means no easy profits for any of them . . . . With so many competitors, success today is no guarantee for tomorrow . . . . Newcomers have an edge over entrenched electronics establishments. Their small size gives them the flexibility to produce new models quickly.

A similar story is told in semiconductors:

The semiconductor industry is so competitive that the production ranking of companies could change any time, industry watchers say. Technological innovation often leads to a dramatic shift in market share and subsequent changes in the leading players. Also, new entrants have become conspicuous recently.

The fierce competition in manufacturing and electronics, in traditional industries and new products, in the 1950s to the 1980s, drove a search for efficiency as a means toward profitability. Since science, technology development, and new product concepts and innovation were occurring elsewhere in the world, Japanese manufacturers had little need to devote their scarce resources and energies to these activities; it was feasible, less

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12 More than 80 percent of Japan's 1000 companies in the machine tool industry had fewer than 20 employees. The average size of such firms was only 1.6 people. Alexander, 1990, p. 13.
13 Friedman, 1988, pp. 151–175, describes the financial support structure for small firms. This banking sector can be compared to the savings and loan industry in the United States, which is designed to support family home ownership and housing construction.
costly, and rational to license, copy, or otherwise learn from the technology developments occurring elsewhere. Instead, the domestic competitive environment stimulated a focus on production efficiency. The hallmark of Japanese innovation in much of the postwar period has been the transformation of production processes arising from the competitive demands for efficiency and productivity. Moreover, these productivity gains had to be achieved with production volumes much lower than were typical in the larger American and European markets.

The imperative for cost-reducing innovation, although focused on production, carried over into product development and R&D, which were also harnessed to the crusade for greater efficiency. Product improvement was not neglected by R&D, but much of it was aimed at incremental improvements and fast development times to meet competitive challenges.

The combination of circumstances and policies in Japan led to a dynamic production sector that transformed manufacturing, rivaling in scale and importance the earlier revolutions that have been attributed to Eli Whitney and Henry Ford. Of course, more than circumstances and policies were necessary for such a revolution. Energy, genius, and passion were also ingredients. Taiichi Ohno, the chief architect of the Toyota production system, was thus described by the Nissan director for manufacturing: "To devise and implement these techniques required a fanatic, a Taiichi Ohno. Nissan simply did not have one."\textsuperscript{16}

\textbf{CIRCUMSTANCES AND POLICIES IN THE UNITED STATES}

\textbf{Postwar Opportunities}

Circumstances in the United States following World War II had little of the transformational qualities witnessed in Japan. Having come out of the war undamaged and with its economic structure buttressed by large wartime machinery investment in selected industries, the U.S. economy was the most efficient and productive in the world. However, large sectors of the more traditional American industries were still saddled by investments made in the 1920s, having had little renewal during the depression-bound 1930s.

With a continent-wide domestic market, the newer U.S. industries were able to combine advanced machinery with well-honed manufacturing management techniques to take advantage of economies of scale in domestic and international markets. The destruction and disruption

\textsuperscript{16}Casumano, 1985, p. 319.
of the war in Europe and Asia gave the United States an extended period of uncontested foreign sales that extended even to the less well positioned traditional sectors.

Importance of Science

One of the sources of American productivity advantage was the country’s dedication to science, research, and industrial R&D, which produced not only a stream of innovations advancing productivity, but also a flow of new products. This attachment of U.S. business to science was not new; its roots were in the 19th century and de Tocqueville commented on it in the 1820s. By 1899, U.S. industry had already established, by one count, 139 industrial laboratories. This figure had increased to 813 by 1928. Along with this growth in industrial R&D was a simultaneous increase in the research activities of universities and the government, as well as a sharp expansion in the numbers of engineers and technically trained workers.

The World War II experience stimulated this historical penchant to apply science to industrial ends. Several technologies that had their origins in the civilian sector had particular value for the military, which, with its enormously expanded wartime resources, contributed to their accelerated development. Aviation, electronics, nuclear technologies, communications, computing, certain medical products, and numerous other technologies benefited from this infusion of military R&D as well as from the impetus provided by the military as a ready buyer of many advanced products. U.S. industry subsequently entered the peacetime period with the opportunity to commercialize these new technologies and products.

Defense Expenditures and R&D

The returns from the military-related developments continued to influence civilian developments for the next several decades. However, the circumstances that created the opportunities for profitable commercial spin-offs from military R&D also created myths about the universality of the phenomenon. With the benefit of a still hazy hindsight, we can now see waves of spin-on and spin-off, from civilian to military to civilian use of technology. At the present time, this phase of the cycle appears to emphasize spin-on: the creation of military benefits from civilian efforts in microelectronics, computing, materials, and

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other technologies. As military requirements, supported by unprece-
dented defense expenditures, further developed the findings of the civil-
ian sector of the 1930s to the 1950s, military uses diverged from civil-
ian applications in a process of specialization and refinement that
reduced the probability of later civilian applications.\textsuperscript{19} Unfortunately,
governments all over the world interpreted the congruence of military
and civilian requirements of the middle part of the 20th century as a
general, typical, and usual occurrence and promoted military R&D for
its presumed civilian return.

The defense R&D spin-off theory has been countered by another
argument that has gained some currency in recent years: Defense
expenditures impose a drain of economic resources, thus retarding
growth and productivity. A different version of this argument focuses
specifically on defense R&D, asserting that the best engineers and
scientists are bid away from the civilian sector to work on exotic and
technologically attractive military technology, thus starving civilian
activities of the best talent; at a minimum, it is claimed, the demands
of defense R&D will raise the salaries of technical people, thereby lead-
ing to smaller numbers employed in civilian efforts. Since U.S. expend-
itures on defense have ranged from about 5 to 8 percent of GNP,
whereas the Japanese contribution to defense has been consistently
under 1 percent, these arguments imply that defense has adversely
affected American growth and productivity.

Attempts to test these arguments empirically have produced a minor
academic industry. Unfortunately, much of this effort is ideologically
motivated, and the resulting studies offer little more than weakly sup-
ported propaganda. The handful of objective studies are often beset by
data and methods problems. However, several recent review articles
have attempted to determine the consistency of those findings that are
based on adequate methods and data.

One review concluded, "the available evidence suggests that
moderate levels of defense spending, while they do have a dampening
effect on economic growth, play a marginal role in shaping overall
economic performance... The tradeoff does not appear to be
severe."\textsuperscript{20} Defense expenditures will have their major long-term effect
on the economy when military spending crowds out civilian invest-
ment. This reduction amounts to only a few percent of annual invest-
ment, yet its cumulative effect can be substantial. Although this effect
is not consistently found across all countries and time periods, it has

\textsuperscript{19}This assertion is based on personal observation and an impressionistic review of
military technology developments of the past 75 years rather than on careful, quantita-
tive assessments.

\textsuperscript{20}Kupchan, 1988, p. 449.
been observed in the United States both before and after World War II.\textsuperscript{21} In cross-national studies, crowding out is found more often than not, although the reasons for the inconsistent results are not known.\textsuperscript{22}

Most of the tradeoffs between military expenditures and investment are found in cross-sectional studies; time series analyses of individual countries tend not to find such effects. Indeed, several time-series-based analyses of U.S. behavior find that consumption reduction rather than investment is associated with military expenditures, although many other variables could account for the relationship, including the large rise in U.S. personal income taxes since World War II. One major review of this literature concludes that “defense spending is not an important determinant of investment, . . . with little historic evidence of any consistent tradeoff between defense and investment operating either through the mechanism of the federal budget or through the private market.”\textsuperscript{23}

The essence of the argument that defense R&D diverts talent and technical resources from private endeavors is that the supply of both research personnel and funds is inelastic. Studies on the supply of engineers and scientists do not support the inelasticity argument for other than the short run of about 3–4 years.\textsuperscript{24} Neither does the evidence support the argument that the best technical people go to defense. A National Research Council survey of university placement officers found that students prize commercial positions over defense because they offered more varied challenges and greater potential for advancement.\textsuperscript{25} Moreover, a survey by the Office of Technology Assessment of electrical engineers concluded, “The military engineer is viewed as more risk averse, less creative, and less likely to be interested in advancement. In contrast, the civilian engineer is viewed as more people-oriented, more talented, better able to bring out products, and is more selective.”\textsuperscript{26}

There may be some long-term effect on growth through the channel of investment, but no observable effects—positive or negative—from defense R&D. Of course, these findings are for aggregate economic activities over a long period. The effects in the short run on individual products and industries may be substantial.

\textsuperscript{21}Chan, 1985, p. 416.
\textsuperscript{22}Faini, Annez, and Taylor, 1984.
\textsuperscript{23}Gold, 1990, p. 3.
\textsuperscript{24}Brown, 1988, p. 4.
\textsuperscript{25}Cited in Brown, 1988, p. 4.
\textsuperscript{26}Ibid.
Capital Markets

The growth of new industries in the United States was supported by a well-developed infrastructure of capital markets that was able to supply to both established companies and newcomers the investment funds needed to develop new industries on a massive scale. The creation of new products was fraught with tremendous uncertainties, only some of which were related to the well-known problems of R&D. Even greater uncertainties were related to the use and marketing of wholly new products, ranging from such component devices as electronic circuit elements to such industrial and consumer products as numerically controlled machine tools and television. These massive market and production uncertainties were often met by the U.S. venture capital market, which helped to create the thousands of new companies attempting to exploit technological and market opportunities. Needless to say, a large proportion of these ventures did not pay off, but out of the maelstrom of market experimentation arose the companies and products that have since become familiar to observers of the American industrial scene.

Government Policies

Several government policies contributed to this growth, some by commission, others by omission. One important active policy was the support of research by government agencies, both civilian and military. Whether measured by the number of Nobel Prize winners, science literature citations, patents, or technology licensing revenues, American performance in academia, government laboratories, and industry dominated world science. For several decades, in pursuing its own requirements defense R&D also contributed to an American strength in the emerging industries.

Another policy—or, one may better say, a pervasive philosophy—was the government’s promarket orientation. Although there were considerable deviations from this approach (nuclear power, for example), that philosophy generally restrained government intervention in market choices; such restraint is especially noteworthy in comparison with policies adopted in Japan and many European countries.

Results on U.S. Innovation

The effects of this set of circumstances and policies on U.S. innovation were as powerful and as pervasive as the forces operating in Japan. First, competition was less intense in the United States than in
Japan. U.S. firms did not have to be concerned with foreign competition, and the size of the U.S. internal market allowed companies in many industries to take advantage of economies of scale and to operate profitably and efficiently without having to capture the entire national market.

Second, the innovation focus tended to be devoted to new products, new markets, wholly new production technologies, and new materials. Cost and efficiency of manufacture took second place to coming up with something new. It made little commercial sense for a firm to concentrate its energies on shifting an entire cost curve downward when it was struggling to bring out a new product, or when a competitor could come up with a new product that would displace an older model.27

Third, the mature, little regulated, and well-developed financial markets meant that firms paid the market price of capital. Their decisions were dominated by expected rates of return. Of course, in many areas, these returns were expected to be high enough to warrant the investments; even in the very rapidly evolving new industries, venture capitalists could reasonably balance off the probabilities of very large gains against the likelihood of many failures. With this access to capital, the new technology startups—by proximity often associated with the major universities—became a standard feature of the American industrial scene. However, in contrast to Japan, U.S. tax policy tended to favor consumption over saving: interest, capital gains, and dividends were taxable, and interest payments on mortgages and consumption loans were deductible for tax purposes. For these and other reasons, the rate of flow of household savings into investment was substantially less than in Japan.

Thus, the patterns of development in postwar Japan and America were quite different from each other, having been conditioned by dissimilar circumstances and policies. It is no exaggeration to say that both countries benefited mutually from these diverse developments. Japan’s growth and innovation would not have been possible without the technology, science, and markets of the United States; and American welfare would have been diminished without the Japanese pursuit of efficiency, productivity, and skills in product evolution. More recently, U.S. manufacturing has been able to take advantage of the Japanese discoveries of new manufacturing and management processes.

27Moving down a cost curve through increased volume was viewed as a more profitable strategy than focusing on production efficiency and driving the whole cost structure downward; the way to increase the quantity of goods sold (thereby reducing costs) was to seize a temporary monopoly position by coming out with a new product before competitors could enter the market.
III. INNOVATION STYLES IN R&D

DIFFERENCES IN RESEARCH PROJECTS

The Japanese emphasis on production begins in R&D. As a general tendency, Japanese industrial R&D has favored projects directed toward manufacturing processes, whereas U.S. projects tend to be aimed at new products.

Professor Edwin Mansfield has conducted several studies of research projects ongoing in 1985 among 50 pairs of firms in the United States and Japan, matched by industry, products, and size. One of the sharpest intercountry differences in his samples is the percentage of R&D expenditures spent on products and processes. Mansfield finds that U.S. producers outspend their Japanese counterparts by almost two to one in product (rather than process) R&D: 68 percent vs. 36 percent. Also, U.S. firms spend almost half (47 percent) of their R&D budget on entirely new products and new processes (rather than product or process improvements), compared with only one-third (32 percent) for the Japanese firms.¹

Examination of the distribution of expenditures across R&D phases shows that U.S. firms spent 26 percent of their innovation costs, compared with 21 percent for Japanese firms, on the “front end” of the R&D process—in the stages designated as “applied research” and “preparation of product specification.”² Expenditures on preparation for production (“tooling and manufacturing equipment and facilities”) were emphasized by the Japanese firms with 44 percent of their total R&D, versus only 23 percent for the U.S. sample. However, U.S. firms devoted a much larger share of their resources to the marketing portion of innovation and commercialization: 17 percent vs. 8 percent.

Many observers have characterized Japanese industrial R&D as low risk and short term, especially when compared with U.S. practice. This seemed to have been especially true in the 1970s.³ Mansfield attempted to test this characterization by detailed questions to his 50 matched pairs of companies concerning the percentage of their R&D expenditures on projects with less than a 50 percent estimated chance of success, and on projects expected to last longer than five years. Mansfield’s data indicate no difference in 1985 between the companies’

¹Mansfield, 1988a, Table 4, p. 1771.
²Ibid., Table 2, p. 1770.
R&D expenditures in the two countries in their devotion to such long-term or riskier projects.\footnote{Mansfield, 1988b, Table 2, p. 226.}

The sources of ideas for R&D projects are distinctly different in the two countries and are consistent with the above-noted emphases. Of the sources of projects in Japan, 30 percent come from ultimate users: internal production organizations and customers. The U.S. proportion is only 18 percent. However, U.S. firms are more influenced by their R&D organizations, with 58 percent of the projects emanating from them, rather than 47 percent in Japan. In the electrical equipment industry, this U.S. tendency is found in exaggerated proportions: 90 percent of the R&D project ideas came from R&D personnel (47 percent in Japan), and a bare 2 percent flowed from production and customers (32 percent in Japan).\footnote{Ibid., Table 3, p. 227.}

The American focus on the front end of the R&D process is illustrated by a study of electronics manufacturing carried out by the U.S. National Research Council (N.R.C.).\footnote{N.R.C., 1988.} A questionnaire was distributed to a worldwide panel of experts specializing in electronics R&D and applications in industry, universities, government research laboratories, and other organizations;\footnote{Sixty questionnaires were distributed, and N.R.C. received 26 responses; most were from the electronics industry, but universities and government laboratories responded as well. The report made no assessment of possible biases in the responses. However, since most of these experts were actively involved in company R&D, they were presumably aware of the capabilities of their competitors.} among the questions asked was the relative lead or lag in years of U.S. producers in 11 “critical” technologies (out of an original list of 30) as applied to six R&D functions. The R&D functions spanned the creative process from the conception of a new product to its support once it was marketed: requirements, design, fabrication, assembly, test, and support. In every case, the country with the most advanced capabilities, relative to the United States, was Japan. For analytical purposes, I selected all those technology applications where the U.S. lead or lag exceeded two years.\footnote{Ibid., Fig. 3-1, p. 26. There were 11 critical technologies and six R&D functions, so the maximum number of cells was 66; however, since not every technology is relevant to every function, only 30 were technically relevant possibilities.} This selection method has the advantage of emphasizing substantial differences in technological competency and in eliminating cases where experts’ judgments showed considerable dispersion. Table 1, which displays these leads and lags, shows that the U.S. strength is in technologies applied to the conceptual development of products (requirements) and to product design. Japanese strengths are devoted to production: fabrication,
Table 1

SUBSTANTIAL U.S. AND JAPANESE LEADS IN ELECTRONICS PRODUCTION TECHNOLOGY

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Design</th>
<th>Automation</th>
<th>Computing</th>
<th>Artificial Intelligence</th>
<th>Databases</th>
<th>Process Control</th>
<th>Robotics</th>
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<tbody>
<tr>
<td>Requirements</td>
<td>U.S.</td>
<td>U.S.</td>
<td>U.S.</td>
<td>U.S.</td>
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<td>Japan</td>
<td>Japan</td>
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<tr>
<td>Design</td>
<td>U.S.</td>
<td>U.S.</td>
<td>U.S.</td>
<td>U.S.</td>
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<td>Japan</td>
<td>Japan</td>
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<tr>
<td>Fabrication</td>
<td></td>
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<tr>
<td>Test</td>
<td>U.S.</td>
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<td>U.S.</td>
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<td>Japan</td>
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<tr>
<td>Support</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: N.R.C., 1988, Fig. 3-1, p. 26.

assembly, and test. The United States is strong again in the final stages of test and support.

Although these research results showing a Japanese R&D focus on production and U.S. emphasis on product development are consistent and striking, some behavior overlaps. Firms in both countries devote considerable effort across the board. One should not conclude that Japanese companies cannot or will not develop new products, or that U.S. industry ignores costs and productivity. The central conclusion from this evidence is that because of very powerful and different forces operating in each country, the main emphases in innovation are dissimilar, but considerable overlap is still apparent.

DIFFERENCES IN AUTOMOBILE DEVELOPMENTS

The distinct set of forces in each country have also affected the speed, efficiency, and management of the R&D process itself. A driving force in many Japanese markets was the necessity to be profitable with considerably smaller production runs than were typical in the United States. For smaller production runs to be efficient and profitable, "setup costs" or fixed costs must be reduced as much as possible. This principle played a major role in the development of the Japanese production system; it also led to remarkable innovations in the product development process itself. Chronic shortages of engineers in postwar Japan reinforced the search for methods to reduce engineering inputs
in R&D. Moreover, lower development costs also made for shorter product development cycles and greater flexibility in reacting to technological opportunities and to competitive pressures. These forces generated outstanding results in both R&D and production in automobiles and other products. Japanese R&D management innovations allowed the automobile companies to market new models faster and more efficiently than producers in other countries.

One major study examined 29 automobile development projects in the United States, Japan, and Europe.\(^9\) The cases covered the period from 1980 to 1987. The average Japanese project required only one-third as many engineering hours as a typical American project (1.155 million hours versus 3.478 million hours).\(^10\) The length of time per project was also considerably smaller in Japan: 42.6 months rather than 61.9 months. (Average European experience was similar to the U.S. figures.) These raw figures may hide as much as they disclose about relative performance. Japanese automobiles are generally smaller than American, relations with suppliers are different, and the amount of change from model to model also varies. Clark et al. attempted to standardize their raw figures by taking account of such variables as the proportion of parts that are common with other existing models, the ratio of parts carried over from previous models, the ratio of unique parts developed for the project model, the ratio of parts developed entirely by parts suppliers, the number of parts where the auto manufacturers do the basic engineering but suppliers perform detailed engineering, and the number of so-called “detail-controlled parts”: those developed entirely from basic to detailed engineering.

The Japanese projects had fewer common parts and more unique parts, which should increase the engineering tasks; but they also had considerably more design participation by suppliers, and many fewer detail-controlled parts, which would reduce the engineering effort (see Table 2). Adjustments to the data were made on the basis of extended analyses and discussions with automotive engineers in the examined projects. The adjusted data describe how many engineering hours would have been required to develop the entire vehicle in-house with no carry-over or common parts. This standardization for the origin of parts slightly reduced the Japanese advantage; the estimated hours are 2.701 million for Japanese projects, 4.892 million hours for American, and 6.426 million for European.\(^11\) These adjustments however, did not include the effects of body size, number of body types, or quality (as

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\(^9\)Clark et al., 1987.
\(^10\)Ibid., Table 1, p. 741.
\(^11\)Ibid., Table 2, p. 744.
Table 2

SELECTED DATA ON AUTOMOTIVE PROJECTS, BY REGION

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total</th>
<th>Japan</th>
<th>United States</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of projects</td>
<td>29</td>
<td>12</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Engineering hours (thousands)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>2,577</td>
<td>1,155</td>
<td>3,478</td>
<td>3,836</td>
</tr>
<tr>
<td>Minimum</td>
<td>426</td>
<td>426</td>
<td>1,041</td>
<td>700</td>
</tr>
<tr>
<td>Maximum</td>
<td>7,000</td>
<td>2,000</td>
<td>7,003</td>
<td>6,545</td>
</tr>
<tr>
<td>Lead time (months)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>54.2</td>
<td>42.6</td>
<td>61.9</td>
<td>62.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>35.0</td>
<td>35.0</td>
<td>50.2</td>
<td>46.0</td>
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<tr>
<td>Maximum</td>
<td>97.0</td>
<td>51.0</td>
<td>77.0</td>
<td>97.0</td>
</tr>
<tr>
<td>Average price (1987 dollars)</td>
<td>13,591</td>
<td>9,238</td>
<td>18,193</td>
<td>19,729</td>
</tr>
<tr>
<td>Body size (percent of projects)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Micro-mini</td>
<td>10</td>
<td>25</td>
<td>0</td>
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<tr>
<td>Small</td>
<td>56</td>
<td>67</td>
<td>17</td>
<td>64</td>
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<tr>
<td>Medium to large</td>
<td>34</td>
<td>8</td>
<td>83</td>
<td>36</td>
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<tr>
<td>Average number of body types</td>
<td>2.1</td>
<td>2.3</td>
<td>1.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Project scope indicators (average)</td>
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<td></td>
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<tr>
<td>Ratio of common parts (percent)</td>
<td>19</td>
<td>12</td>
<td>29</td>
<td>21</td>
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<tr>
<td>Ratio of carryover parts (percent)</td>
<td>10</td>
<td>7</td>
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<td>14</td>
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<tr>
<td>Ratio of unique parts (percent)</td>
<td>74</td>
<td>82</td>
<td>62</td>
<td>71</td>
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<tr>
<td>Share in parts procurement costs</td>
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<tr>
<td>Supplier proprietary parts (percent)</td>
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<td>7</td>
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<td>Black box parts</td>
<td>44</td>
<td>62</td>
<td>16</td>
<td>39</td>
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<tr>
<td>Detail-controlled parts</td>
<td>49</td>
<td>30</td>
<td>81</td>
<td>54</td>
</tr>
</tbody>
</table>

SOURCE: Clark et al., 1987, Table 1, p. 741.

Regression equations were estimated with the adjusted engineering hours as dependent variable and body size, number of body types, price, and a Japanese dummy variable as independent variables. The point estimate of the dummy variable suggests that the U.S. and European companies use about 2.6 million more engineering hours than Japanese to complete a standardized project, or about twice as many engineering resources.\(^{12}\) Equations with the same independent variables were used to estimate a Japanese effect on lead time. Holding body size, body types, price, and percent of in-house

\(^{12}\)Ibid., Table 3, pp. 746–747.
designed parts constant, Japanese projects continued to have a time advantage of 12 to 13 months. Much of the unadjusted Japanese lead time advantage appeared to be a result of supplier participation, which itself was largely a Japanese phenomenon—the variable explained little of the variation within region.13

DIFFERENCES IN PROJECT ORGANIZATION AND MANAGEMENT

Additional analysis of the automobile developments suggested that project organization and management style were strongly associated with the standardized Japanese time and cost advantage. The authors defined three types of management structure. (1) “Functional structure,” which used to be common in the United States and remains so in Europe, is organized according to specialized departments (e.g., body engineering, controls); coordination is by hierarchy, rules, and procedures. (2) “Lightweight project manager” projects organize work into functional departments, but a fairly low-status project manager coordinates activities through lower-level liaison people; most U.S. projects, some European, and a few Japanese projects used such an approach. (3) “Heavyweight project management” places great authority in the manager, who has direct responsibility for all aspects of the project and holds high status within the company; four projects, all Japanese, used heavyweight project management.

Project team size was closely related to the style of management. Heavyweight teams had an average of 333 engineers, lightweight projects used 573, and functional projects had over 1400 engineering members. Project type variables were included in the engineering hours and lead time equations described above; recall that the dependent variables were adjusted for standard engineering tasks and that the independent variables accounted for product size and complexity. Inclusion of the project management variables reduced the size of the Japanese advantage in engineering from 2.6 million to 1.4 million hours, and in development time from 12.5 to 9.7 months. The project type variables, therefore, had very important effects, even after the raw data were adjusted and other project characteristics were included. But the Japanese dummy variable also continued to show a substantial and competitively important advantage in project efficiency and lead time, after the in-house and external assignments of parts responsibility.

13Ibid.
carryover across different automobile models, and automobile size and complexity were taken into account.

Two other features of project management appear to account for at least part of the residual differences among projects. Mansfield and others have shown that overlapping project phases can save time and resources but only if mistakes and pursuit of poor alternatives do not lead to additional correction work downstream. For an overlapping strategy to work, intense communications are required so that upstream and downstream activities are constantly informed about each other's activities. The Japanese projects were found to have high degrees of overlap among activities and also high levels of the required information flows across activities. U.S. projects had medium overlap and low information flows. European projects were low in both dimensions; each project phase occurred in strict sequence upon conclusion of the previous phase. In some U.S. projects, however, severe mismatch created disastrous consequences for project performance; a high degree of overlap was not supported by the necessary information flows, so that surprises, confusion, and delays often disrupted later project phases.

The study of automobile development projects is important in our understanding of innovation differences because its sample size, cross-national selection, and standardization by product type (but with variability across project organization) permit statistical analyses not possible in other studies. The findings here, however, support those discovered in more limited case studies. For example, research on five innovative and successful Japanese product developments listed “overlapping development phases” as one of six intrafirm factors that contributed to speedy and flexible development efforts. In addition to “overlapping phases,” the next item on their list of factors associated with successful innovation projects is “multilearning,” which they describe as an “almost fanatical devotion to learning—both within organizational membership and with outside members of the interorganizational network. . . . Learning manifests itself across multiple levels and across multiple functions.” This description of multilearning uses many of the same concepts and words as the notion of “intense communications flows across activities” described in the automobile development study.

The authors of the work on innovative development, however, also list some limitations to the kind of project organization they describe.

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14Ibid., Table 9, p. 759.
15Ibid., p. 760.
16Imai et al., 1986; also published in a shorter version in Takeuchi and Nonaka, 1986.
17Imai et al., 1985, pp. 353-354.
For example, an extraordinary effort is required of all project members and it is possible that the organization is not applicable to very large or breakthrough projects. In the first case, extensive communications in face-to-face interactions may be limited by the sheer size of the project. In the second, the scale of the uncertainties may constrain the efficiency of overlapping phases. Nevertheless, for a wide range of R&D projects, the organizational methods described in these studies appear to contribute to lower costs, shorter lead times, and greater flexibility.

EFFICIENCY IN THE USE OF INTERNAL AND EXTERNAL TECHNOLOGY

Japanese automobile firms, on the average, appear to have attained an advantage in the cost and time dimensions of R&D. Mansfield attempted to determine whether such efficiencies extended to other industries and products. To do this, he surveyed and interviewed chief executives in 50 Japanese and 75 American firms in six industries, all of which performed R&D in both the United States and Japan. "Each firm provided its estimate of the average ratio of American to Japanese innovation time and the average ratio of American to Japanese innovation cost for new products and processes in 1985."18 The survey indicated close agreement on relative costs: When the estimates were averaged across each industry, by Japanese and American respondents, all of the Japanese industry estimates and five of the six American industry estimates judged that U.S. costs were higher than Japanese. Across all industries, the Japanese believed that U.S. costs were 23 percent greater, whereas the U.S. executives, on average, claimed that U.S. costs were 10 percent greater. Mansfield obtained similar results for the time of innovation. Japanese executives believed that U.S. projects took 18 percent longer, and their American counterparts placed the U.S. disadvantage at about 6 percent.

The Japanese efficiency advantage seems to depend on the source of the innovation. The traditional strengths of U.S. firms in pursuing new products and new technologies have been matched by the organizational innovations of many Japanese firms in becoming more efficient in this kind of R&D. Japanese firms' real strengths, however, appear to lie in their ability to copy and adapt technology developed by others, rather than developing it internally. To test this common view, Mansfield compared 30 pairs of Japanese and U.S. firms, matched according to industry and size of firm. For roughly comparable

18Mansfield, 1988c, p. 1158.
projects undertaken from 1975 to 1985, he collected data on the time and money devoted to the development and commercialization of new products. The time and cost of projects based on technologies developed within the firm were not significantly different across the two countries. American firms were also about as efficient at using technology developed externally to the firm as in developing and commercializing their own innovations. Japanese firms, however, were significantly more effective in using external technology than in producing it internally. In Japan, firms spent about 25 percent less time and 50 percent less money in carrying out projects based on external than on internal technologies. That is, Japanese firms have proven to be effective imitator, to be skilled at modifying a product and reducing its costs.

TIME AND COST TRADEOFFS

Many studies on R&D demonstrate a tradeoff between time and costs: Innovation time can often be reduced by measures that increase project costs. Mansfield's data suggest that Japanese firms seem to be willing to devote about twice as many resources to reduce development time as U.S. firms. This behavior is consistent with Japanese firms' belief that profits from innovation decrease rapidly because of project delays. The Japanese firms' attachment to overlapping R&D phases is one of the methods for achieving faster development speeds and appears to be related to the competitive requirements of the Japanese market.

A JAPANESE APPROACH TO R&D: RESEARCH COOPERATIVES

Several circumstances and policies of the Japanese research environment encouraged the government to promote research cooperatives: the low mobility of industrial researchers, the weak links between university laboratories and industry, the small amount of government funding of generic research in either industry or universities, and the official willingness to accept the possible anticompetitive results of collaboration among otherwise competitive firms. Reacting to these circumstances, MITI pursued an active policy that promoted collaborative associations among firms.

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18Ibid., p. 1160.
19Ibid., Tables 3 and 4, p. 1161.
20Ibid., pp. 1163–1164.
The associations usually did not actually perform research, which was almost always conducted in the member firms' own facilities by their own personnel. Only a small fraction of the members' R&D was performed in this cooperative context, and the government funds themselves were quite modest. A company official in one such venture commented, "Government funding is typically so small as to be insignificant to our overall research portfolio."\(^{22}\) In 1980, for example, total funding of six major MITI projects in semiconductors and computers came to approximately $88 million;\(^{23}\) the number of project participants numbered from five to over 100 (in the case of one software automation project).

The very-large-scale integration (VLSI) project of the late 1970s and early 1980s was perhaps the best known and most successful cooperative research venture, but in many ways it was highly atypical. Five participants received generous government funding to perform intensive research in a single facility with clear technical goals: development of 1-micron device technology, submicron process technology, and 64K-bit dynamic memories. The typical projects were different in all major respects from the VLSI collaboration; they received less support, involved more participants, had broader and more research-oriented goals, and were performed at the sites of the participants.\(^{24}\)

The VLSI project was one of a series of collaborative ventures promoted by MITI to challenge the U.S. computer industry, particularly IBM. Earlier projects included the "large-scale project system" in 1966–1972 to develop a super-capacity computer, and the integrated circuit development promotion in 1972–1974. The VLSI project was to develop a domestic computer to compete with the IBM models to follow the 370 series.\(^{25}\) Despite the earlier collaborative projects, the technology of integrated circuits was moving so fast that Japanese computer firms faced great difficulties in breaking into the market. In mid-1975, MITI and Nippon Telegraph and Telephone (NTT) agreed to unite parts of their separate R&D programs and to support developments in the components industry.\(^{26}\)

A particular focus of the VLSI project was production technology. Between one-third and one-half of the funds were used to purchase

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\(^{22}\)Quoted by Heston, 1988, p. 35.

\(^{23}\)These figures are calculated from Yamamura, 1986, Table 8.1, p. 194.

\(^{24}\)Heston, 1988, p. 37.

\(^{25}\)Wakasugi, 1988, pp. 15–17.

\(^{26}\)Stow, 1989, p. 252.
advanced U.S. equipment, much of which was dismantled and analyzed in an attempt to design Japanese versions with superior performance.\textsuperscript{27}

The focus on production was consistent with the general Japanese approach to innovation, in which cost reduction was of central concern. The VLSI project provided an organizational framework such that the device and component firms could work toward a production system that could be constantly improved and refined; because all of the participants in the project possessed a common technology base, this strategy created an incentive for semiconductor producers to seek competitive cost advantage by working closely with their equipment suppliers. Thus, by concentrating on production and costs, and by sharing the fruits of the research among the five participants, the firms were driven even more to find ways to improve their competitive positions.

The actual value of the government contribution to the VLSI project over its lifetime from 1976 to 1981 has been open to some debate. The subsidy granted through actual contracts was about 30 billion yen, or roughly $132 million.\textsuperscript{28} NTT also invested $350 million independently of MITI's VLSI project.\textsuperscript{29} Finan and LaMond count up at least $500 million in direct government subsidies and soft loans.\textsuperscript{30} The companies also contributed 40 billion yen ($176 million) to the collaborative VLSI project.\textsuperscript{31} At a minimum, the government's 30 billion yen direct subsidy was a substantial contribution to R&D at a critical juncture for Japanese manufacturers. The quick introduction of the 64K Dynamic random access memory (DRAM) moved the Japanese industry into its first large-scale volume production of integrated circuits. One Japanese academic analyst suspects that "if there had been no subsidy, the joint R&D system would not have materialized and, as a consequence, the technological progress regarding VLSI would not have been generated."\textsuperscript{32}

Despite the success of the VLSI project, its analysts warn that this model of R&D management is not one that can be expected to be universally efficient and successful; certain crucial elements of this particular project may not always be present. First, the production technologies at the heart of the VLSI project were applicable throughout

\textsuperscript{27}Ibid.
\textsuperscript{28}Yamamura, 1986, Table 8.1, p. 194; Waka sugi, 1988, Table 7, p. 16.
\textsuperscript{29}Finan and LaMond, 1985, p. 171.
\textsuperscript{30}Ibid. The subsidy value of a soft loan should be calculated on the basis of the difference between the lower subsidized interest rate and the market rate of comparably risky loans. Finan and LaMond seem to have simply added the face value of the loans rather than the value of the subsidy.
\textsuperscript{31}Yamamura, 1986, p. 196.
\textsuperscript{32}Wakasugi, 1988, p. 20.
semiconductor production processes. Second, the coming together in a single laboratory of the five companies stimulated efficient interfirm transfer of the common technologies. Third, the R&D goals were clearly defined in advance, a time limit was established, and a fixed amount of funds was allocated. These conditions established clear and tight constraints on the participants and helped to focus their efforts. Wakasugi believes that these reasons for success were unique to the project and that “they cannot be a basis for arguing that R&D activities by the technology research cooperative approach are generally rational.” To test the validity of this evaluation more broadly, it would be necessary to assess the relative success or failure of a broad sample of collaborative projects and to relate the measure of success to the project characteristics. Wakasugi’s evaluation is based on an informal application of this method.

33This commonality of technology and the efficiency of transfer was difficult to achieve; initially, researchers from each firm pursued their own ideas in separate rooms within the common research facility. This situation persisted for more than a year before a MITI research director was gradually able to persuade the participants to work together in greater collaboration. Yamamura, 1986, p. 196.

34Wakasugi, 1988, p. 20.
IV. INNOVATION IN PRODUCTION

Innovations in production have had notable effects on the economic and political relations between the United States and Japan. Even more than in science, R&D, and the development of new products, the dramatic advances in production efficiency pioneered in Japan have led to profound changes in relative efficiencies and economic power.

INNOVATION IN AUTOMOBILE PRODUCTION

Despite sharply lower production rates, crude measures of productivity (annual output of vehicles per employee) were higher in Toyota by 1960 than in the American automobile companies. Table 3 shows that the second ranking Japanese company, Nissan, had higher crude productivity levels than both General Motors and Chrysler, despite production rates that were barely 3 percent of those of General Motors. By 1980, the Japanese companies had improved by 400 percent, whereas the United States experienced about 20 percent increases in two companies and a 30 percent decline in the third.

These crude figures, though dramatic, hide important differences among the companies: levels of vertical integration, capacity utilization, and labor hours per employee, to name just three. Vertical integration is substantially lower in many Japanese producers than in their U.S. counterparts as a greater responsibility for production is

Table 3
ANNUAL VEHICLE OUTPUT PER EMPLOYEE

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>G.M.</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Ford</td>
<td>14</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Chrysler</td>
<td>11</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Nissan</td>
<td>12</td>
<td>30</td>
<td>47</td>
</tr>
<tr>
<td>Toyota</td>
<td>15</td>
<td>38</td>
<td>61</td>
</tr>
</tbody>
</table>

SOURCE: Cusumano, 1985, Table 44, p. 187.
placed on suppliers. In 1979, the rate of integration stood at 29 percent and 26 percent for Toyota and Nissan, and 43, 36, and 32 percent for G.M., Ford, and Chrysler.¹ Productivity measures based on output per company employee could therefore vary by up to 65 percent from vertical integration differences alone.

Capacity utilization rates were also significantly different, with Toyota typically operating at full capacity and Nissan in the 82 to 97 percent range. U.S. factory utilization rates were more variable, falling as low as 60 percent in 1982. Also, since Japanese workers put in about 10 percent more hours per year than the U.S. automobile labor force, these differences in labor utilization distort crude productivity measures.

Table 4 corrects for vertical integration, capacity utilization, and employee hours distortions. By 1965, Toyota was already 50 percent more productive than the average U.S. company, and Nissan had about the same productivity as the American companies. By 1983, both Japanese companies were about twice as productive as the American Big Three, Nissan productivity having grown by more than 2.5 times from 1965 to 1983 and Toyota by more than 80 percent; the U.S. companies had managed a bare 20 percent gain over the same period.

Even the adjusted labor productivity figures reported in Table 4, as dramatic as they are, do not tell the full story. Labor is only one of the inputs into the production process; other input factors such as capital need to be included in estimates of total input factor productivity.

Table 4

<table>
<thead>
<tr>
<th></th>
<th>U.S. Big 3</th>
<th>Nissan</th>
<th>Toyota</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>4.7</td>
<td>4.8</td>
<td>6.9</td>
</tr>
<tr>
<td>1970</td>
<td>4.6</td>
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<tr>
<td>1975</td>
<td>5.3</td>
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<td>1979</td>
<td>5.5</td>
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</tr>
<tr>
<td>1983</td>
<td>5.7</td>
<td>11.0</td>
<td>12.7</td>
</tr>
</tbody>
</table>

SOURCE: Cusumano, 1985, Table 49, p. 299.

¹Cusumano, 1985, Table 46, p. 190. Vertical integration is defined as the ratio of value added (minus profits) to sales (minus profits).
to obtain a more complete measure of productivity differences and change. Cusumano did not calculate total input factor productivities but did provide measures of fixed assets per vehicle, adjusted for vertical integration and capacity utilization, as shown in Table 5.

According to these figures, the American manufacturers used more capital per unit output until 1983, so that capital intensities could not account for the large differences in adjusted labor productivity. However, substantial capital deepening occurred in the 1980s; the 75 percent growth in capital-output ratio at Nissan and the 170 percent increase at Toyota may have been associated with those companies’ growth in labor productivity from the late 1970s. These figures indicate that an explanation of the improvements in Japanese automobile industry labor productivity relative to that in the United States has to go beyond factor inputs.

One additional point must be considered in an evaluation of the productivity gains of the Japanese companies: scale economies. A widely used study in the automobile industry estimates that most economies of scale are exhausted at annual production rates of 200,000 vehicles in an integrated company, with no gains to be expected after one million vehicles. Both Nissan and Toyota had passed the 200,000 mark by 1962; until then, reductions in manufacturing costs per unit output had largely followed industry experience. Yet both companies continued to achieve remarkable productivity gains, even after reaching the million vehicle level. According to Cusumano, "much of the 2-fold productivity differential [over the U.S. companies] stemmed from the techniques Nissan and Toyota developed, prior to 1970, to manage their techno-

Table 5

<table>
<thead>
<tr>
<th>FY</th>
<th>U.S. Big 3</th>
<th>Nissan</th>
<th>Toyota</th>
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</tr>
<tr>
<td>1975</td>
<td>8,055</td>
<td>6,405</td>
<td>5,270</td>
</tr>
<tr>
<td>1979</td>
<td>7,165</td>
<td>6,165</td>
<td>7,705</td>
</tr>
<tr>
<td>1983</td>
<td>10,450</td>
<td>10,796</td>
<td>11,853</td>
</tr>
</tbody>
</table>

SOURCE: Cusumano, 1985, Table 57, p. 212.

2Quoted by Cusumano, 1985, p. 215.
logical, capital, and labor resources to raise worker output and lower costs far beyond the levels expected or achieved outside of Japan."³

Before considering more closely the sources of these productivity changes, we will turn to another study of the automobile industry, one that looks at a specific, standardized manufacturing function, automobile assembly.⁴ John Krafcik, a former automobile engineer at the joint General Motors-Toyota NUMMI plant in California, wanted to estimate better productivity measures than those calculated by Cusumano and others, and at the same time to analyze the effects of management methods on such output measures as productivity and product quality across a wide range of management styles. Cusumano’s results (described above) were based on aggregate company performance. Krafcik sought plant level data for similar operations—automobile assembly—standardized to account for differences in such variables as automobile size and number of models produced.

Krafcik’s sample included 38 final assembly plants in 13 countries, representing 15 major companies, and comprising roughly 25 percent of world automotive assembly capacity.⁵ Krafcik adjusted total employee hours by defining a list of “standard” operations based on the most common set of plant activities in the sample of plants. If a plant performed nonstandard activities, the people associated with them were removed from the productivity calculations.⁶ He also made adjustments for absenteeism and actual working hours. On the output side, a standard vehicle was defined to adjust for product size, number of welds, and equipment content. Quality measures were based on a J. D. Power and Associates questionnaire to new car buyers in the United States on problems experienced in 12 different areas. However, since not all defects are related to assembly, he purged the raw data of nonassembly defects.⁷

The results of this analysis are shown in Figs. 1 and 2. Several points should be noted in the productivity estimates of Fig. 1: most notably, the sharp differences between the average productivity levels of American-owned plants, Japanese, and European plants. The average domestically owned plant in North America is almost 40 percent less productive than the average Japanese plant, and the European level is almost 90 percent worse than the Japanese figures. Second, there is a wide dispersion of results. Japanese productivity experience

³Ibid., p. 217.
⁴Krafcik, 1988a.
⁵Ibid., p. 13.
⁶Ibid., pp. 55–56.
⁷Ibid., p. 73. Since not all models were sold in the United States, only 24 plants appear in the quality sample.
Fig. 1—Productivity levels in world automobile assembly plants
Fig. 2—Quality levels in world automobile assembly plants
in North America is as good as it is in Japan, and the best domestically owned American plant is equal to average Japanese productivity. Similar results are true for Europe, although their overall showing is generally inferior.

The quality levels (shown in Fig. 2) also vary widely, but there is considerably less overlap than in productivity: The best American and European values are worse than the average Japanese experience, although the detailed data show that at least one Japanese transplant in the United States produces at the same quality level as its mother plant in Japan.

Several variables were used to investigate alternative explanations for the wide productivity and quality differences among plants. A robotics index, designed to measure the use of high technology hardware, was completely uncorrelated with plant productivity. Since the number of models and body types was expected to increase the complexity of plant operation and reduce the possibilities of scale economies, a model mix complexity index was constructed. Contrary to expectations, the Japanese plants accommodated a more complex mix of platforms and body types than their North American or European competitors.

Conventional manufacturing analysis asserts that productivity and quality are negatively related: As factories devote more resources to obtain higher quality output, costs will increase and productivity will decline as a consequence. However, a plot of productivity versus quality (Fig. 3) shows just the opposite for the cross section of assembly plants: Productivity and quality are positively related (the correlation coefficient is 0.60). “Those plants producing high-quality products do so with substantially less effort than low-quality plants.”

INNOVATION IN JAPANESE PRODUCTION:
JUST-IN-TIME

High levels of productivity and quality in the Japanese automobile industry are not associated with capital, high technology, complexity of product mix, or scale effects; neither are productivity and quality negatively related to each other. The explanation for high productivity rests in the management of the production process. Elements of this management approach arose in several Japanese companies in the postwar period, but the system in its most complete form evolved in Toyota under the driving pressure of its manufacturing director Taiichi

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8Ibid., p. 107.
9Kreftik, 1988b, Fig. 23, p. 95 (emphasis in original).
Ochno. It was then adopted by the other automobile companies and their suppliers and later diffused throughout Japanese industry. In the 1980s, this approach began to spread around the world as it was adapted to many kinds of products and production processes.

The Japanese production process has been given different labels by analysts: lean, unbuffered, fragile, and high-stress. The “just-in-time” (JIT) method of parts supply has been used as a shorthand designation to describe the entire process; although the Toyota approach encompasses many other interrelated elements, JIT is a convenient tag.

As described in earlier sections, the Japanese automobile management problem was to produce efficiently at low volume, a requirement imposed by a rising number of competitors for a very limited market. Ohno's approach to this problem emphasized flexibility; the fullest use possible of equipment, workers, and supplies; and the reduction of in-plant personnel, factory and warehouse space, and in-process and
finished goods inventories. JIT, in the narrow parts supply sense, accomplished many of these goals. JIT accepted the Henry Ford goal of minimizing the elapsed time between beginning and ending production. But, whereas Ford achieved this through high-volume, standardized products, Toyota found ways to do it in lot sizes of a few hundred parts; when carried as far as possible, lot sizes of a single piece were possible.

As assembly line production based on Ford’s approach established its dominance over other methods in the first half of the 20th century, it gradually evolved and developed rococo variants. In many cases, management focused on the simple goal of keeping the line moving. But to accomplish this, they embellished the original concept by designing a highly buffered system with stocks of parts and assemblies in warehouses and on the shop floor to provide insurance against disruptions anywhere in the process; this approach was also extended to people, as specialists were added to the payroll (and to overhead) to expedite production, order supplies, inspect output, and manage warehouses.

The problem with a buffered system is that it absorbs information. A quality problem, a missed delivery, an inefficient worker, or a poorly planned equipment layout does not stop the system; another part is in the bin, a shelf full is in the warehouse, another worker takes up the slack. Over time, the buffered system can hide the sources of inefficiencies and deficiencies; productivity may be low and quality poor, but finding the cause can be extraordinarily difficult. Moreover, if competitors are producing according to the same system, their costs and quality will have suffered in the same way, thereby generating little pressure for improvement.

The drive to reduce inventories is one of the chief elements of the JIT approach. Lower inventories both minimize financial carrying costs and produce several other planned and unintentional consequences. Warehouse and storage space is drastically reduced in JIT plants; the need for bins, conveying devices, fork lifts, and stock specialists is lower; equipment can be placed closer together, which enhances direct personal relations among manufacturing operations and eliminates much of the need for in-plant transportation; and throughput time is reduced as work in process moves quickly through sequential operations rather than spending time in storage.

A second element of JIT is the “pull” system of scheduling and moving parts. Instead of the customary practice of building parts for stock, with each successive operation withdrawing stored parts, the pull system initiates an operation only when an operator moves back to the previous station to retrieve work in process, just at the necessary time
and in the amount needed for immediate processing.\textsuperscript{10} The pull system was gradually extended to virtually all operations, including marketing—production only began with an order for a finished product; such an approach is possible only if the throughput time is less than the desired period from order receipt to product shipment.

To facilitate the pull system, Toyota engineers introduced the so-called \textit{kanban}, or ticket; an operation was authorized only by receipt of a \textit{kanban} from the next station. This ticket would proceed backward as each operation required a part or batch of parts, finally arriving at the raw materials or purchased part station. This system was a key element in reducing inventories.

Toyota later extended the pull system to suppliers; to do this, the company established tight supplier relationships so that eventually they delivered parts directly to assembly lines, fully integrating them into the in-house parts supply system.

Batch size, or economic order quantity, is typically determined by an optimizing calculation that balances setup costs against inventory costs (interest charges, warehousing expense, and breakage and loss). The greater the setup costs for a batch of parts, the larger will be the economic production quantity. Customarily, setup costs were treated as fixed, and batch size was the result of simple calculations. However, with the goal of reducing inventories, Ohno set to work on reducing setup costs. The examples of this effort are legendary: For example, stamping press changeover time for body part dies was reduced from several hours to 15 minutes by 1962; by 1971, this time was further lowered to 3 minutes.\textsuperscript{11} U.S. automobile manufacturers took as long as a half day or more to change dies and consequently produced in batches of 10 to 30 days’ supply. Toyota changed dies three times a day and produced no more than a single day’s usage.\textsuperscript{12}

Other techniques used in the full JIT system included multiple machine operation by individual workers, worker inspection of output, mixed loading of assembly lines, component production for different automobile models, and line-stop buttons on assembly lines that gave workers authority to halt production if defects or other problems arose.\textsuperscript{13}

The combination of the line-stop system, the \textit{kanban} parts pull approach, and the minimal inventories produced a most important and unplanned result. They increased the feedback of information

\textsuperscript{10}Cusumano, 1988, pp. 34–35, provides a convenient historical treatment of the evolution of the JIT system at Toyota.

\textsuperscript{11}Ibid., p. 35.

\textsuperscript{12}Cusumano, 1985, p. 285.

\textsuperscript{13}Parker and Slaughter, 1988, p. 42.
generated in the production process. A defect, an inability to keep up, a missing part, a slow delivery, or an ineffective worker immediately made itself known. The source of a problem was easier to spot because it showed up immediately, and engineers, managers, and shop workers could address it directly. Indeed, the system compels attention to problems because they stop production. The lean, unbuffered, fragile system demands the energy and creativity of its participants.

This constant attention and problem solving has also earned the Toyota production process the designation of a "high-stress" process. Not only was quality improved by the feedback of information, but efficiency increased as production was speeded up with the steady progress in addressing problems. As each problem was dealt with, a faster flow of parts and assembly would stress new areas.\(^{14}\)

For a standard American or European assembly line, it was considered a cardinal sin to stop the line—thus, the building of buffers. In the Japanese factory, it was recognized (after 20 years of fanatical devotion to the JIT approach) that a stopped line or a problem generated information on which improvements could be based. Instead of the information being absorbed by a well-protected production process, the Japanese factory forced the information to the surface in such a manner that it could not be ignored; employees at all levels could then devote their detailed knowledge to dealing with it.

As is apparent from the above description, the individual worker is a key element in the JIT system. The typical employee is called upon to tend several different machines or operations, inspect output, constantly evaluate the ongoing production process and stop the line if necessary, contribute to solving problems, and supply a steady stream of suggestions for improving the product or production process. Japanese firms tend to give production workers broad exposure to different manufacturing methods by moving them at regular intervals to new positions. After several years, workers would have gained wide knowledge of plant operations and the relationships among them. They are also called on to make creative contributions to improving the product or the process.\(^{15}\) It is not an exaggeration to state that in a well-run JIT operation, the worker is paid to accept and promote the goals of the company, and to contribute not only physical labor and manual dexterity, but also emotional commitment and intellectual energy.

\(^{14}\)Ibid.

\(^{15}\)In one copier plant I visited, each four-person team of assembly line workers was expected to make at least 100 suggestions per month on improving the product or the assembly process. Productivity in this plant had been increasing 30 percent per year for more than 20 years.
In an attempt to determine if management approach was statistically related to productivity and quality in the 38 auto assembly plants described above, Krafck estimated regression equations with productivity and quality as dependent variables; the independent variables included a management style index, space use, model mix, product age, and production scale variables.\textsuperscript{16} The management style index was based on abstracted models of management tasks in "fragile" and "robust" systems. Management in a fragile system must tend to the skills and motivation of the work force, develop the logistics of a JIT inventory system, and create a "supportive, non-adversarial environment" in which workers actively contribute to the success and improvement of the process.\textsuperscript{17} Production management in a robust system revolves around the establishment and maintenance of various safety nets to keep the system running if something goes wrong. To quantify management style, Krafck collected data on four areas to produce a single index: (1) percentage of floor space dedicated to postprocess repair, (2) evidence of worker awareness and participation in the control of the production process, (3) the degree to which employee interactions were required in all facets of operations, and (4) the average level of unscheduled absenteeism.\textsuperscript{18} The management index had the highest statistical significance in both the productivity and quality equations, producing the greatest effect of all the variables.

**THE DIFFUSION OF JIT**

The dominance of the Toyota production system was clearly recognized by the other Japanese automobile producers. Although most of them were already motivated by similar circumstances to adopt many of the same practices, none had gone as far as Taichi Ohno; by the 1970s the process was diffusing throughout the industry. As word of the success of JIT spread, other Japanese companies studied and adopted it; some were pushed in this direction by the auto companies who demanded high quality, low costs, and just-in-time deliveries from their suppliers, while others were driven by their own competitive situations in a search for efficiency.

Eventually, of course, as demonstrated by Krafck's sample of U.S. auto plants, the process spread out of Japan to other countries in many different products. For example, the Spanish subsidiary of the accounting and management firm Price Waterhouse made arrangements with

\textsuperscript{16}Krafck, 1988a, pp. 80-81.

\textsuperscript{17}Ibid., pp. 22-24.

\textsuperscript{18}Ibid., pp. 22-32.
Kawasaki Heavy Industry (KHI) to learn the JIT system from KHI in order to teach the system to Price Waterhouse clients in Spain. Spanish customers were said to have been particularly receptive to new techniques that would improve productivity because their approaching entry into the European Common Market was about to confront them with more efficient competitors. When the English Price Waterhouse subsidiary heard of the Spanish results, it too came to KHI for lessons. Eventually the Price Waterhouse Manufacturing Management Consulting Group in the United States entered into a licensing and teaming agreement with KHI to market and provide implementation support services for what had come to be known as the Kawasaki Production System.\textsuperscript{19} JIT had itself become a marketable service.

JIT is now a frequent subject of the manufacturing press with how-to-do-it features, surveys, and anecdotes. As an example of the latter, an industrial journal recently featured the American experience of Jacobs Vehicle Equipment Company ("Jake Brake"), which implemented JIT in early 1988. The company reduced its floor space by half, using the freed space as a basketball court for employees. Moreover, in a year and a half, Jake Brake had evolved from a company with a reputation for chronically late deliveries to one with an 80 percent on-time record. Its overall productivity was up 50 percent.\textsuperscript{20}

Research on productivity based on worldwide samples of production plants "clearly linked throughput time reduction and several other linchpins of JIT manufacturing to factory productivity gains."\textsuperscript{21} The research studies involved a cross section of 265 U.S. plants in diverse industries, panel data on 26 U.S. plants over a five-year period, and an international sample of 128 plants in 30 countries.\textsuperscript{22} Although statistical results vary somewhat in detail from one sample to another, they were consistent overall. The only variable always related to productivity gains were those associated with JIT, "specifically throughput time reduction, improved quality, lower inventories, and participative management techniques."\textsuperscript{23} Just as interesting is the list of variables not related to productivity. Plants with high productivity improvements were not distinguishable by their investment in high tech equipment.

\textsuperscript{19}Jamrog, 1988, p. 22.
\textsuperscript{21}Schmenner, 1988b, p. 12.
\textsuperscript{22}The statistical results are reported in Schmenner, 1988a.
\textsuperscript{23}Schmenner, 1988b, p. 13.
In addition, younger plants did no better than older ones, and smaller plants no better than bigger ones. Similarly, there was no distinction between union and nonunion, sunbelt and frostbelt, Asian and non-Asian, and Northern European and Southern European plants. Moreover, the type of industry does not seem to affect the results: process and nonprocess industries do about the same. It appears that management, rather than geography, size, union status, age, or industry holds the key to a factory's productivity gain.\textsuperscript{24}

Although the gains from JIT are clear and transferable, the actual adoption of the process can be extraordinarily difficult, as it often requires a transformation of corporate culture, affecting both management and labor. A British study of the worldwide automobile industry had expected that by the early 1980s the Japanese success would be rapidly copied and the productivity gap quickly closed. However, in 1986, the researchers were having to revise these views:

Despite the significant changes, the process of changing established concepts and practices in the social organization of production is proving to be a difficult and painful process. Although the new best practice can be observed where it exists, diffusing this knowledge through highly structured and complex organizations takes considerably longer than investing in new equipment. Even where islands of best practice are established within a firm, it appears to take many years for them to make an impact on the rest of the company. . . . In many cases there is room for considerable increases in productivity through a reorganization of the production process without expensive retooling. \textit{The most successful example of this seems to be in cases where the competitive pressures for survival were intense enough to break down the social resistance to change}.\textsuperscript{25}

Thousands of companies in the United States and elsewhere are making progress in adopting the JIT approach and adapting it to local conditions. The Japanese companies, though, are continuing to seek out even better ways of manufacturing. For example, Honda Motor Company's plant in Ontario, Canada, is using the facility as a pilot project to see if plants with a low annual assembly capability of 80,000 vehicles can be made profitable. At present, scale economies dictate capacities of 200,000 vehicles, but Honda's strategy is to triple its productivity in Ontario so that "the company can expand on a global basis in the next decade, making cars in the areas [in which] they are sold."\textsuperscript{26}

\textsuperscript{24}Ibid.

\textsuperscript{25}Jones, 1986, pp. 9–10 (emphasis added).

EXTENDING JIT TO HIGH TECH ACTIVITIES

Innovation in production management has not required new investment and high technology. But where technology is appropriately integrated in a JIT framework, the payoff appears to be substantial. The flexible manufacturing system (FMS) is a case in point. FMS joins together several computer-controlled machining centers and other machine tools through a network of conveyors. The entire system is under supervisory control of a central computer that identifies each arriving pallet containing a piece to be worked on and controls the scheduling and movement of the workpiece (whose identity can change from pallet to pallet) through the system. Tool supply, automated inspection, and machine loading and balancing are coordinated and directed from the FMS computer. The advantages of FMS include flexibility, increased machine utilization, reduced number of machines, reduced lead times, more consistent product quality, reduced setup costs, and reduced inventory of tools through standardization.\textsuperscript{27}

Since this list of advantages is similar to the goals and advantages of JIT, it is reasonable to expect an especially good fit between FMS and JIT; however, even in a traditional production operation, FMS should also deliver the same qualitative returns. A study of 35 FMSs in the United States and 60 in Japan (more than half the installed systems in both countries) showed something quite different. Although the kinds of products they made were comparable across the two countries in size, complexity, metal-cutting times, precision, and number of tools per part, great disparities were evident in efficiency and flexibility.\textsuperscript{28}

The American systems produced only ten parts per system compared with 93 on the Japanese machines (see Table 6). The U.S. penchant for long production runs was revealed by high annual volumes per part (consistent with the few types of parts); the U.S. machines turned out an average 1727 of each part and the Japanese only 258. Japanese flexibility was also demonstrated by their introduction of new parts over the course of the year: 22 versus 1. Flexibility was not achieved at the cost of productivity: 18 Japanese systems went unattended (none in the United States), utilization was 84 percent (52 percent in the United States), and metal-cutting time per day averaged 20.2 hours (8.3 hours).

By and large, the U.S. companies' investment in expensive FMS is being wasted. Inappropriately used, high-cost equipment actually increases the productivity gap. A stand-alone FMS designed for flexibil-

\textsuperscript{27}Jaikumar, 1989, pp. 119-120.

\textsuperscript{28}Jaikumar, 1986, p. 69.
Table 6
COMPARISON OF FLEXIBLE MANUFACTURING SYSTEMS
IN THE UNITED STATES AND JAPAN

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems development time (years)</td>
<td>2.5 to 3</td>
<td>1.25 to 1.75</td>
</tr>
<tr>
<td>Number of machines per system</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Types of parts produced per system</td>
<td>10</td>
<td>93</td>
</tr>
<tr>
<td>Annual volume per part</td>
<td>1727</td>
<td>258</td>
</tr>
<tr>
<td>Number of parts produced per day</td>
<td>88</td>
<td>120</td>
</tr>
<tr>
<td>Number of new parts introduced per year</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Number of systems with unattended operations</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Utilization rate (two shifts)</td>
<td>62%</td>
<td>84%</td>
</tr>
<tr>
<td>Average metal-cutting time per day (hours)</td>
<td>8.3</td>
<td>20.2</td>
</tr>
</tbody>
</table>

SOURCE: Jaikumar, 1986, Exhibit 1, p. 70.

ity but surrounded by a traditional production process forms “at best, a small oasis in a desert of mediocrity.”

There are many explanations for the failure of U.S. manufacturers to make good use of FMS, but manpower use is one of the largest contributors. Software development is critical to this information-intensive manufacturing process, and workers’ technological literacy is essential. In the Japanese companies, more than 40 percent of the work force was made up of college-educated engineers, and all had been trained on computer numerical controlled (CNC) machines. Among the U.S. companies, only 8 percent were engineers, and fewer than 25 percent had CNC training. Also, skill upgrading training was three times longer in Japan. The use of FMS is growing in Japan, with high returns to the users. In the United States, by contrast, FMSs are being withdrawn from many operations because of inadequate returns, high complexity, and insufficient use.

The different styles of innovation in the United States and Japan, especially the Japanese emphasis on production efficiency and quality, are not confined to automobiles or to what can broadly be called the metal-bending manufacturing sector. Similar traits are observed

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29Ibid., p. 72.
30Ibid., p. 70.
31Ibid., p. 72. All of the Japanese systems studied met the firms’ return on investment criterion of a three-year payback, which under reasonable assumptions implies a 26 percent rate of return.
elsewhere, especially in electronics. In the production of memory chips, several hundred dies (on which the memory circuits are printed) are produced from a single wafer. The production process requires an extended sequence of complex operations, in the course of which the wafers and dies are tested for defects. The final cost per memory chip is compounded from the cumulative yields and costs of the separate operations. Table 7 exhibits 1983 manufacturing cost comparisons of 64K DRAMS. In the first stage of memory chip production, the costs

Table 7

COST COMPARISON FOR U.S. AND JAPANESE 64K DRAM

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components of Whole Wafer Cost ($ per wafer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>$32</td>
<td>$49</td>
</tr>
<tr>
<td>Capital (depreciation)</td>
<td>29</td>
<td>37</td>
</tr>
<tr>
<td>Labor</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>$85</td>
<td>$106</td>
</tr>
</tbody>
</table>

Components of DRAM Cost

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wafer</td>
<td>$85</td>
<td>$106</td>
</tr>
<tr>
<td>Wafer process yield</td>
<td>80%</td>
<td>95%</td>
</tr>
<tr>
<td>Yielded whole wafer cost</td>
<td>$106</td>
<td>$112</td>
</tr>
<tr>
<td>Die size (mil²)</td>
<td>35,100</td>
<td>38,600</td>
</tr>
<tr>
<td>Total die/wafer</td>
<td>313</td>
<td>289</td>
</tr>
<tr>
<td>Wafer probe cost</td>
<td>$14</td>
<td>$12</td>
</tr>
<tr>
<td>Tested wafer cost</td>
<td>$120</td>
<td>$124</td>
</tr>
<tr>
<td>Probe yield</td>
<td>40%</td>
<td>52%</td>
</tr>
<tr>
<td>Good die</td>
<td>125</td>
<td>146</td>
</tr>
<tr>
<td>Cost per good die</td>
<td>$0.96</td>
<td>$0.85</td>
</tr>
<tr>
<td>Assembly cost</td>
<td>$0.20</td>
<td>$0.40</td>
</tr>
<tr>
<td>Assembly yield</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td>Yielded assembly cost</td>
<td>$1.40</td>
<td>$1.32</td>
</tr>
<tr>
<td>Final test cost</td>
<td>$0.20</td>
<td>$0.20</td>
</tr>
<tr>
<td>Final test yield</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>Factory cost per good die</td>
<td>$2.00</td>
<td>$1.90</td>
</tr>
<tr>
<td>Cumulative yield</td>
<td>23%</td>
<td>38%</td>
</tr>
<tr>
<td>Number of good die</td>
<td>72</td>
<td>106</td>
</tr>
<tr>
<td>Gross margin</td>
<td>45%</td>
<td>40%</td>
</tr>
<tr>
<td>Final selling price</td>
<td>$3.64</td>
<td>$3.17</td>
</tr>
<tr>
<td>Total revenue</td>
<td>$262</td>
<td>$336</td>
</tr>
</tbody>
</table>

SOURCE: Finan and LaMond, 1985, Table 3-5.
per wafer were 25 percent higher in Japan. However, these higher costs were partly an investment in higher yields in later production phases: For example, the higher Japanese material cost arose, in part, from stricter purity standards; and the capital cost component was higher because of an emphasis on automation.\textsuperscript{32}

The cumulative yield in Japan of 38 percent is 65 percent greater than the U.S. yield, which more than compensated for the higher Japanese wafer cost and fewer dies per wafer. (The Japanese companies accepted a larger die and consequent reduction in available dies per wafer because of the requirements for greater automation.) With the cost structures and yields shown in Table 7, Japanese semiconductor producers would enjoy a 13 percent selling price advantage. As Finan and LaMond point out, though, these costs are fairly close to each other, and for a standard device like a 64K DRAM, the final selling price would probably be identical; if forced to sell at the lower price, the U.S. gross margin would fall from a preferred 45 percent to a competitive 37 percent.\textsuperscript{33} In any event, exchange rate variations could easily swamp these cost differences. However, an important difference would still persist: For comparable plant capacities and utilization rates, Japanese producers would obtain 50 percent greater revenues than U.S. companies because of their higher yields. Put another way, U.S. companies would have to make a 40 percent greater investment in capacity to generate the same revenues.

As in manufacturing more generally, Japanese integrated circuit producers have established a comparable reputation for reliability. One example is the 16K DRAM in 1980, when Japanese failure rates were 75 percent less than those experienced by U.S. producers.\textsuperscript{34} However, another feature observed earlier also occurred here: U.S. producers were able to match and even surpass these levels once they made quality a serious objective. Hewlett-Packard, in particular, reduced its failure rate by 96 percent in just four years (see Table 8).

The particular circumstances and policies influencing U.S. and Japanese approaches to innovation have now spilled over onto a global market. Each country now faces the competition of the other, and of the broader world. Although each is more comfortable doing the things it is accustomed to doing, the nature of global competition and new circumstances and policies demand moving into different, challenging, and often uncomfortable areas that confront both national and corporate cultures. Both countries have demonstrated adaptability and

\textsuperscript{32}Finan and LaMond, 1985, p. 155.
\textsuperscript{33}Ibid., p. 157.
\textsuperscript{34}Ibid., p. 168.
the good sense to copy best practice; such adaptability is encouraged by the countless numbers of competitive challenges facing each company.

CULTURE OR COMPETITION

Many people have questioned whether the truly revolutionary nature of the organizational and managerial innovations in Japan, in both development and production, flowed out of features of Japanese culture (and are therefore difficult to transfer to other cultures) or whether they arose as a creative but otherwise random development, having little to do with either culture or economics. The use of worker teams, intense communications among project participants, and nonadversarial worker-management relations are particularly congenial to Japanese culture. However, such an explanation would ignore the very different (and American) approach to management in prewar Japan, the bitter labor-management strife in many companies over much of the postwar period, and the extremely hierarchical (even dictatorial) style of management found in most of the higher echelons of Japanese organizations. There is an alternative hypothesis.

Consider the U.S. automobile in its early days. Between 1903 and 1926, 181 companies produced automobiles in the U.S. market. At that time, the concept of the automobile was an open issue. Technology was unsettled: Would the powerplant be steam, electric, or an internal combustion engine? Would steering be by a wheel, tiller, or handlebars? How many wheels were adequate—two, three, four, or more? Would
the frame be lightweight and flexible like a bicycle or a horse-drawn buggy, rigid like a wagon, or massively based on iron and steel like a locomotive?

The use of automobiles was just as ambiguous as the technology. Would it be used by the rich, by farmers, by commerce and industry? Would there be a road system, a rail system, or would the vehicles move cross-country like tractors? Would they be used for moving people or goods, for business or pleasure, for long or short distances?

Similarly, many methods of production were being evaluated. Some producers turned out automobiles one by one, like locomotives. Others developed batch production systems drawing on bicycle experience.

Each of the almost 200 companies entering this business believed that it had the correct answers to all of these questions. Of course, most of them failed; 20 percent lasted three years or less, and half survived for less than six years. Of the top ten automobile producers in 1903, only two remained in those ranks six years later. But each of these ventures was an experiment—in technology, use, production, and marketing. The large number of trials, combined with the growth of demand and the sheer intensity of the competition, produced a feedback that was rapid and demanded attention. Out of the turmoil of multiple uncertainties and market experimentation, the modern automobile was born and with it the creation of a production system that came to dominate manufacturing for almost a century.

The analytical question is whether the revolution brought about by Henry Ford arose from his personal genius, the nature of the U.S. economy, or the American cultural character. The full flowering of the automobile and of mass production techniques probably depended on all these contributions and more. I hypothesize that the essential quality was the nature of market experimentation embedded in a competitive framework. The sheer number of trials increased the probability of coming up with a winner, of identifying genius. The competitive situation provided the incentive to play the game with skill and passion; competition established a method for picking the winners and the requirement to respond to feedback.

This pattern doesn't just describe the automobile industry in the United States in 1900 or in Japan in 1960; similar patterns have been observed in aircraft, electronics, computers, and facsimile machines. Innovation in all of these products embodied much more than technology; it included concepts of product use, manufacturing methods, and R&D strategies. Moreover, the results were unpredictable; analysts are

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36Ibid., pp. 109-139.
just as handicapped in forecasting outcomes as were the hundreds of entrepreneurs in automobiles in 1903 or in biotechnology in 1990. However, to the degree that the hypothesis outlined here accurately depicts a major source of innovative behavior, analysts may be in a better position to specify the conditions that promote industrial innovation: the support of competition and the ability to respond to its demands.
V. U.S. AND JAPANESE INNOVATION
IN THE 1990s

THE SITUATION IN JAPAN

Growth Consensus

The circumstances that prevailed for several postwar decades are now evaporating. In Japan, the social consensus favoring growth and growth-stimulating policies no longer has the same hold on the population as it once did. Growth has become politicized. Environmental concerns and a nascent consumerism now challenge the traditional growth ethic. The demand for investment in social infrastructure is competing with private investment on the political agenda. The Liberal Democratic Party can no longer count on unopposed approval of its policies; its 1989 loss of the majority in the upper house of the Diet is one concrete example of political splintering. Moreover, the feasibility of implementing pro-growth policies is problematic; for one thing, domestic savings rates are falling. The lower savings rate of a growing proportion of retired people pulls down the overall rate of saving. Slower economic growth and financial deregulation also contribute to lower savings. By the end of the century, Japan’s savings is projected to be at about the rate of West Germany’s; although Japan will be far from a pauper country, it will not be able to support the volume of domestic and foreign investment that was seen in the past.

Financial Markets

Japanese financial markets have been gradually deregulated and internationalized since the early 1980s. Except for a few remaining restrictions (especially in the retail household sector), Japanese finances are now part of the world markets. The government’s ability to control financial flows and channel investments to favored industries is generally a thing of the past. However, some parts of the financial sector are still fairly immature, especially the venture capital market.

Venture capital in Japan is small in comparison with that in the United States: $2.1 billion versus $30 billion in 1988. The number of venture capitalists are few, and most of these are associated with the


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large banks and securities companies; only six out of 86 are independent.\(^2\) One reason for the weakness in venture capital is that Japanese investors seem to prefer larger companies in proven fields. Also impeding the growth of startups is that until the mid-1980s regulations required a long wait before an initial public offering on the over-the-counter market. In the United States, 42 percent of listed firms are under ten years old; in Japan, such companies account for less than 1 percent of the listings.\(^3\) In fact, even the largest and boldest of the independent venture capital firms has only invested in 25 Japanese companies out of the 200 in its portfolio, the rest being mainly American startups, many in Japan.\(^4\)

As in other areas with structural or other impediments to efficient operations, the Japanese government has stepped into the venture capital arena. Since 1985, MITI has contributed about $250 million to the Japan Key Technology Center, a state agency that invests in research consortia. The government’s expectation was that by providing venture funds to research collaboratives that come up with their own proposals, the companies would shoulder more of the burden of technology development.\(^5\) According to the views of MITI officials, this represents a radical departure from earlier policies where the government itself would often identify the new technologies and provide a certain comfort to companies that would have shied away from unbacked new technologies.\(^6\)

**Protectionist Policies**

In the early postwar decades, the Japanese government could protect inefficient domestic industry through the imposition of import restrictions. This policy is no longer permitted by the international community and is confronting opposition by domestic interests. Japan’s international trading partners are demanding the removal of formal barriers (which has been done in most areas) as well as indirect trade impediments caused by domestic regulation and customary business practices. Consumers and business users of domestic products are now seeking lower prices and greater efficiency from removal of the costly protection of domestic enterprises in finance, communications, transportation, distribution, agriculture, construction, and other protected areas. Deregula-

\(^3\)Japan Economic Journal, August 12, 1989.
\(^6\)Ibid.
tion and the removal of industry protection schemes in all of these areas have been pushed by new political combinations that include domestic business users of high-priced, protected services and products; by domestic producers with new products and services to sell who have been prohibited from entering into protected and regulated markets; and by politicians who see great potential gains from these new constituencies. Domestic consumers have been a less potent, but growing, source of pressure; and international pressures have helped to break down barriers in finance, communication, agriculture, and distribution.

**Resource Constraints**

Resource constraints are becoming more binding. Whereas Japan had ample supply of labor and energy for many decades, it now faces higher relative costs in both of these critical areas. Energy costs have been rising since the 1970s; the nation’s adjustment to the shift in the relative price of energy caused a ten-year decline in productivity growth.7

Japanese birth cohorts have been steadily falling, and in the next ten years the cohort size entering the labor market will be the smallest since the early 1930s. With a booming economy and smaller labor force, pressures for higher real wage rates are increasing and labor costs are beginning to creep up. Over the next several years, the share of national income flowing to labor may end its long-term decline and begin rising—at the expense of the share going to profits. Firms would then be forced to obtain a greater share of their financing from the market instead of from retained earnings, internal cash flows, and bank loans. The increasing marketization of corporate finance will confront managers with the market rate of interest more sharply than when they relied on their own funds. This process, plus higher interest rates because of reduced savings and the internationalization of the flow of funds, may restrain the freewheeling investment strategies in equipment, R&D, and human capital that were so characteristic of past behavior.

**Technology and R&D**

A large proportion of Japanese postwar productivity growth can be attributed to a convergence phenomenon whereby countries’ total factor productivity growth rates are related to their initial distance from the technological leaders. When other factor inputs are accounted for, Japan’s growth from productivity “catch-up” came to an end by the

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7Jorgenson, 1988, p. 218; the contribution of productivity growth (or technical change) to economic growth was estimated to have fallen from 2 percent per year from 1960 to 1973, to 0.1 percent in the years 1973–1978, largely because of oil price increases.
1970s. Among the various alternative explanations for the pervasive effects of productivity convergence is the international public goods nature of technological progress: The discoveries and successful practices in the leading countries are adopted without the necessity of making the initial investments and absorbing the false starts and unsuccessful ventures. Japan itself is now among the productivity leaders. Not only the opportunities for gains from catch-up declined, but others are now profiting from Japanese methods, perhaps not from the results of leading-edge science, but from industrial applications of R&D and management innovations.

Japan is no longer lagging in most applied technologies. Its production capabilities are at world levels and the direction of movement is toward leadership in several areas. For example, in a comparison of 20 technologies with military application (an area of long-time U.S. strength), the United States had a lead in 11, Japan led in five, and essential parity existed in four. However, in the 15 technologies with a U.S. lead or parity, Japan was improving its relative position in six of these and was expected to become equal or draw ahead within a few years.

Research performed by Japanese companies is strong, and its growth is impressive; in 1988, the growth rate over the previous year was more than 11 percent, and the company share of total national R&D had risen to about 70 percent, up from 55 percent in 1970. Basic research, though, in the nation as a whole remained a low priority area with 13 percent of total expenditures, despite government exhortations on the necessity of supporting basic research; the growth rate of basic research was only 3 percent in 1988 compared with 10 percent growth of expenditures on development. The relative weakness of Japanese science compared with that in the United States is indicated by the amount of basic research performed by Japanese universities in 1985, which was only 36 percent of the U.S. figure; company-sponsored basic research was 34 percent of the amount in U.S. industry. Furthermore, much of what is defined as basic research in Japanese industry may be misclassified. A vice-president of the U.S. Bell Laboratories touring Japanese corporate labs noted: "Japan's corporations are not doing basic research of real significance... Their success rate is 90-95 percent; what we call basic research at Bell Labs has a success rate of 30-35 percent."

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8 Dowrick and Nguyen, 1988, pp. 1026-1027.
9 Vogel, 1989, Table 15, p. 35.
11 National Science Foundation, 1988, Table B-6, p. 53. International comparisons were made with purchasing power parities.
Japan's laboratories face lags in many basic research areas. One measure of this overall tendency is that Japanese scientists have been awarded only five Nobel Prizes in science since 1901, and two of the recent awards were for work done outside of Japan. A Japanese government survey of international comparisons of basic research levels supports this broad view; in the 20 reviewed areas, Japanese research achieved parity with the United States only in materials based on crystal structure.\(^\text{13}\) Another survey conducted by the leading business newspaper of more than 300 scholars of the Science Council of Japan concluded that Japan leads the United States in only two of 47 major basic research technologies, robotics and ferromagnetic materials.\(^\text{14}\)

The relative weakness of Japanese science has been attributed to poor funding and to rigid, hierarchical, conservative research organization and management, especially in universities. Widespread concern over the state of science has emerged in recent years as Japanese policymakers see Japan as having reached a stage of development where it must base more of its economic developments on its own research foundations.\(^\text{15}\) Reform of university research is under discussion, and MITI and other government agencies are urging that universities and industry form new partnerships with each other and push creativity into new areas. But many of the government efforts are enmeshed in interagency turf battles that are combined with a general decline in the high level of consensus and consistency that characterized Japanese science and technology in the past.\(^\text{16}\) In the meantime, many firms are reorganizing their R&D and creating new laboratories, especially overseas.\(^\text{17}\)

**THE SITUATION IN THE UNITED STATES**

**The Competitive Situation**

Unlike the situation in the first decades after World War II, the United States today faces intense competition from both developed and developing countries. High productivity levels and advanced technologies have spread throughout the industrial world. Countries with the lowest productivity in the past (among them, Japan) have tended to show the greatest gains. Total factor productivity convergence has been operating

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\(^\text{13}\)Report on Science and Technology Agency White Paper on Science and Technology," *Science and Technology in Japan*, April 1986, Fig. 5, p. 31.


\(^\text{15}\)Lynn, 1986, p. 297.

\(^\text{16}\)Ibid., p. 298.

\(^\text{17}\)Japan Economic Journal, December 24, 1988, p. 4.
for all except the poorest non-OECD countries, at a rate similar to the convergence observed within the OECD group.¹⁸ In the past, Europe, Japan, and the other Asian newly industrializing countries were the chief competitors of the United States. In the future, the breadth of competition is certain to expand. The large continental American markets are no longer locked up by American producers. Not only does the United States compete in a global market, so also do its suppliers and customers.

Science, R&D, and Investment

The United States outspends Japan in science and R&D in industry, government, and higher education, even when the military-sponsored effort is eliminated from the comparison. However, several important ratios suggest that trends favor Japan: the ratios of R&D to GNP, R&D per capita, and company-sponsored industrial R&D to sales are all higher in Japan.

R&D is one form of investment in innovation and productivity improvements; it is highly complementary to capital investment in equipment, mainly because new capital is the primary means of embodying technical change.¹⁹ Human capital investment is also complementary to both R&D and equipment investment in productivity growth.²⁰ The United States produces five times the number of doctorate level specialists in the natural sciences and engineering as Japan, and ten times the number of first degree specialists in science. However, the number of graduating engineers at the first degree level is now about equal in the two countries.²¹ Education at the high school level is a different story, with accumulating evidence that Japanese students outperform Americans in both quality and, increasingly, in the numbers of students completing high school. However, the relationship between high school level education and innovation is not clear, although hypotheses abound on such matters as the flexibility of workers and their ability to handle complex tasks.

The complementarities among R&D, capital investment, and educational attainments are important because increases of any one raise the marginal product of the others. Nelson suggests that forces leading to the growth of one are likely to stimulate an increase in the others.²²

¹⁸Dowrick and Nguyen, 1989, p. 1021.
²⁰Ibid.
Several studies of the determinants of the structure of trade have concluded that R&D has been an important factor in the comparative advantage of U.S. industries. A study of U.S. and Japanese trade structure based on 168 industries from 1967 to 1983 indicated that R&D “is highly significant statistically and shows the continued comparative advantage of the United States in R&D intensive products.”

Over this period, Japan moved from a position of comparative advantage in unskilled, labor-intensive manufactured goods and a disadvantage in human-capital-intensive products to a new position of comparative advantage in human capital; its position in regard to physical capital was roughly the same over the years. Until the mid-1970s, Japan was also at a comparative disadvantage in R&D-intensive industries, but this shifted sharply by 1975. Among high tech products (those with a ratio of R&D to sales greater than 3.5 percent), the importance of R&D to both countries has increased monotonically over the years, but its absolute importance to the United States has been and remains greater than for Japan.

Although the United States has been weaker than Japan in equipment investment, the situation in venture capital and the financing of new firms is quite different. As suggested above, the financial structure for the support of new products, new firms, and even wholly new industries is well developed and oriented toward risky investments. The venture capital market is characterized by hundreds of participants with access to capital from such sources as individuals, pension funds, and insurance; the actual investment volume exceeds that in Japan by an order of magnitude.

In summary, the situation in the United States with respect to R&D and investment is complex. Science is strong, government contributions to nonmilitary R&D are large, and university research is among the best in the world. Industrial R&D is also strong, but the trend relative to Japan is declining. Overall investment is weak, but venture capital has been the engine driving many important innovations. Education is mixed, with world-class education at the college and graduate levels, but with a poorer distribution of educational investments at the lower grades. This mix of strengths and weaknesses creates a kaleidoscopic array of implications for future innovation.

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24Ibid., p. 182.
25Ibid., p. 185.
BIOTECHNOLOGY: ONE MIRROR FOR THE FUTURE?

Among the technologies and industries of the 21st century, biotechnology offers one facet of the future mosaic. A consensus has been reached at the highest government levels in Japan that biotechnology is of substantial importance to the future of the Japanese economy.26 Biotechnology is an element of a broader Japanese government strategy that emphasizes knowledge-intensive industries and is driven by certain environmental features of the late 20th century Japanese landscape noted earlier: rising labor costs, higher energy and raw materials prices, and the transformed structure of comparative advantage in which Japan’s strength now lies in human capital and R&D. Many in the Japanese government have stated their belief that the government, working through various agencies and policies, can and ought to affect the development of biotechnology in Japan.

Circumstances in Japan now constrain the actions of government agencies and severely restrict their ability to achieve their desired goals. Deregulated capital markets reduce the government’s ability to channel private funds to chosen firms and projects, while tight budgets restrict the scale of government largesse. International and domestic objections to protection eliminate the possibility of barring foreign competition until a domestic industry develops its capacity to challenge world markets. Moreover, an immature venture capital market and small numbers of doctorate level biological scientists retard the creation of new firms, not to speak of the reluctance of both new graduates and established scientists and engineers to move into new companies. Despite the targeting of biotechnology, it has been difficult for the Japanese government to make major overt steps to aid the industry mainly because of domestic political pressure.27 “The subtler and less financially onerous steps that the Japanese government has taken to guide biotechnology . . . can be seen as limited compensation for the absence of a number of market processes and institutions, found in the United States, particularly beneficial to the development of high-technology industries.”28

As of 1984, the implementation of programs to back up the government’s rhetoric of industrial targeting of biotechnology was woefully inadequate, especially in comparison with activities in the United States. The Japanese government allocated roughly $35 million to biotechnology in 1984, versus the U.S. government’s 1982–1983 commitment of $522 million (on an annual basis). U.S. federal funds were more

27Ibid., p. 101.
28Ibid.
than double the high estimates of biotechnology R&D from the combined governments of West Germany, Great Britain, France, and Japan. Moreover, a large proportion of the Japanese funds went to energy research; aid to the structurally depressed chemical, pulp and paper, and textile industries; and to the traditionally strong area of fermentation. By 1990, the budget for all biological and health-related research totaled 73 billion yen or about $363 million at purchasing power parity conversion. This figure included all of the disease and therapy research of the Ministry of Health and Welfare. A narrower definition places the 1990 biotechnology contribution at 31.5 billion yen, or about $158 million, still only about 30 percent of the U.S. expenditures in 1982–1983.

In addition to the U.S. government’s direct R&D expenditures, in 1981 the Small Business Administration had already granted $7 million in subsidized loans to 22 new biotechnology firms. As of late 1984, no Japanese firm had received any funding from comparable Japanese government agencies.

Between 1977 and 1983, 111 new American firms were formed with the explicit intention of exploiting biotechnology, and 108 established firms entered the field. Equity markets raised $1.5 billion for small U.S. firms (those with less than $5 million net worth). The market value of the equity of the largest biotechnology firms had reached $3.5 billion by 1984.

Established firms had also invested $400 million through mid-1983 in new biotechnology companies, and four large established chemical and pharmaceutical companies had biotech R&D expenditures of over $300 million in the single year of 1982. The four largest firms active in biotechnology spent $468 million in R&D in 1985.

The Japanese industrial scene was quite different. No new firms had entered the industry by 1985, the four largest established firms in the field spent less than $100 million, and total estimated private R&D was about $400 million, 15 percent less than the expenditures of just the top four U.S. firms. While the Japanese industry is being developed by established firms, the important role in the United States is played by new startups.

In 1982, more than 1200 doctorate level scientists and engineers were working in U.S. biogenetic engineering, while only 161 similarly

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\[29\] Ibid., p. 107.
\[31\] *Japan Economic Institute*, February 9, 1990.
\[32\] Saxonhouse, 1986, p. 117.
\[33\] Ibid., p. 120.
\[34\] Ibid., p. 121.
trained personnel could be found in Japanese industrial laboratories. A 1986 assessment noted that Japan was having difficulty training a sufficient number of biotechnology researchers, "and institutional barriers have so far made it difficult for Japanese firms to receive as much assistance from Japanese universities as their American counterparts. Indeed, nearly two-thirds of the Japanese biotechnology firms have indicated that they plan to send researchers abroad for training."

By 1990, more than 500 new U.S. biotechnology companies had entered into business, and 200 or so had gone public. These companies raised $1.2 billion in initial public offerings in 1986, but the figures dropped from this high point to $741 million and then $317 million in 1987 and 1988. Many of these startups and their venture capital backers have been selling the new firms to larger companies after having demonstrated the product potential of their creations. Many of the buyers are foreign, including Japanese companies. The combination of American scientific and entrepreneurial skills and Japanese capital is helping to speed up the development of new technology and quicken the application of existing technology to an array of new products.

Collaboration is not unwelcomed by either U.S. interests or Japanese participants. In fact, small U.S. biotechnology companies are frequent visitors to Japan, scouting out partners, licensees, and financial backers for their research. U.S. universities too are benefiting from Japanese attention. The University of California at Los Angeles has established a joint medical research program with Hitachi, and the Japanese cosmetics company Shiseido contributed more than $80 million to the Massachusetts Institute of Technology for biological research. Many Japanese companies are sending employees to U.S. graduate schools for the training they cannot find in Japan.

This biotechnology scenario may be one vision of the future: U.S. strengths in science, research, new products and concepts, graduate education, entrepreneurship, and venture capital combined with Japanese strengths in financial capital, production, and cost minimization. As the technology-constrained and productivity-disadvantaged Japanese industry of the postwar period compensated by innovations in production and R&D management, Japanese companies today are compensating for their scientific deficiencies by tapping U.S. capabilities in a variety of imaginative ways. But this vision is only one possible facet.

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36Lynn, 1986, p. 300.
of the picture. The cash-rich Japanese capital market is unlikely to last out the century. American firms are struggling to understand and copy the Japanese production and product development process. The Japanese government, industry, and academic world are responding (slowly) to their science and graduate education deficiencies. Moreover, we still have fundamental questions about the sources of innovation.

CONCLUSIONS AND QUESTIONS ABOUT INNOVATION

In large part, the innovation styles of Japan and the United States were the unplanned results of postwar policies and circumstances. The restructuring of the Japanese economy led to an explosion of innovation in production, which carried over into R&D. Developments in the United States were more evolutionary, building on habitual strengths and on the technologies coming out of the war effort.

More recently, a partial convergence between the two countries is underway. High productivity methods are being diffused. U.S. scientific results are international public goods. The innovative, entrepreneurial activities in the United States are open to exploitation by a worldwide community through investment, acquisition, joint ventures, technology transfer agreements, licensing, and any of a score of other methods. Financial, product, and marketing arrangements are being integrated into global markets.

Yet differences remain among countries, and innovation will continue to be affected by national characteristics. Resource mobility differences of labor and capital, within and between countries, will affect the transferability of technology, science, and methods. Government involvement in science, education, and the promotion or restriction of cooperative and other business arrangements in R&D will influence the availability of trained personnel, the flow of scientific knowledge, and the ways in which the people and the science are used. Other government policies in such obvious areas as taxes will influence private decisions; but less obvious policies—such as those that affect housing markets, pensions, stock offerings, trade protection, antitrust, and deregulation—will influence labor and capital mobility and competition. Differences in all these areas are likely to persist into the next decade.

Finally, we are left with some puzzles related to capital and competition. Through the beginning of the 1980s, the evidence suggests that
capital was cheaper in Japan than in the United States. On an anecdotal level, a rich set of experiences indicates that many decisions on R&D investment and innovation were made in Japan as if capital costs were of little concern. If true, capital cost differentials could account for much of the difference in results observed in the two countries, in particular, the fierce competition among companies entering into and expanding capacity in new areas.

Much of the evidence cited in this survey suggests that competitive forces played a crucial role in Japanese innovation behavior and in the differences between the United States and Japan. However, the relationship of competition to innovation raises questions having to do with industry structure. Why did Japanese companies compete so actively under the protection from foreign trade? U.S. experience is consistent with that from other countries: Protection more often leads to complacency and higher prices than it does to competition and innovation. Why, for example, was the U.S. machine tool industry less productive than the Japanese? This was an industry with scores of main-line companies and thousands of parts and component suppliers, also, barriers to entry were low. Yet the U.S. industry showed little of the dynamism revealed by the Japanese machine tool industry. Were there problems of access to capital for investment and R&D? Or does the competitive push for innovation depend on more than numbers of participants and the threat of market entry?

Any study on innovation would be amiss if it ended with tidy solutions. The questions and genuine puzzles on the roles of capital and competition suggest that there is considerable research left to be done on this subject.

 Nachbar, 1990. This review of studies on the comparative cost of capital in the United States and Japan shows that serious theoretical problems afflict most of the existing research. However, the weight of the evidence, though imperfect, suggests that, in an aggregate sense, capital was probably cheaper in Japan until the deregulation of domestic and international financial markets in the 1980s.

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