1999

The New Challenge to America's Prosperity: Findings from the Innovation Index

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Chairmen's Foreword

It is no coincidence that a disproportionate share of U.S. economic and export growth over the past 10 years has been generated by a handful of industries, all closely linked to innovation and resulting technological leadership. In order to foster further growth and sustain our competitiveness, America must maintain a high rate of technological innovation. It is, therefore, incumbent upon business leaders and policymakers to understand the many forces driving innovation.

The Innovation Index, developed by Professors Michael Porter of the Harvard Business School and Scott Stern of MIT's Sloan School, offers a path-breaking method for assessing the strengths of national innovation systems. Porter and Stern use regression analysis and quantitative modeling to statistically identify those factors that are most closely linked to the innovative output of nations and their relative contributions. The resulting Index offers the first-ever objective benchmarking of how individual nations have performed relative both to themselves over time and to other nations.

The messages from the Index are straightforward. First, a handful of critical factors are highly and positively correlated with the success of a nation's innovation system, including:

- the size of the labor force dedicated to R&D and other technically oriented work
- the amount of investment directed at R&D
- the resources devoted to higher education
- the degree to which national policy encourages investment in innovation and commercialization

Second, Porter and Stern's work conclusively demonstrates that the number of innovative countries is growing globally. An increasing number of nations—both OECD countries and fast-paced emerging economies—are rapidly making the transition from technological imitators to genuine innovators. It should be remembered that only a decade ago, American confidence was shaken by strong competition from a single nation, Japan, the prototypical country that successfully moved from follower to leader. The United States is once again the world's undisputed economic power; but it is not clear that we are taking all of the necessary steps to compete in a world where more and more nations possess considerable innovative capabilities and where investments quickly flow to those locations offering the best environment to employ them.

Finally, the authors note that despite the advances of other nations, the United States is failing to invest in the "fundamentals" of its own innovation system. Although the past decade has been one of the strongest periods of U.S. macroeconomic growth since World War II, total spending on basic research is flat or heading downward, and the declining numbers of degrees granted in the physical sciences and engineering suggest that reversing this trend will involve concerted public policy changes. These observations suggest that America's current innovation leadership is increasingly rooted in past investment and that the long run basis for our future strength is being eroded—all while other nations are accelerating their own efforts.

The conclusions of this research are consistent with the views of the 150 CEOs who attended the Council's 1998 National Innovation Summit at MIT and the 120 heads of research and development (R&D) from companies and universities who participated in the Council's study, *Going Global: The New Shape of American Innovation. Going Global* traced technology trends in five sectors—health care, advanced materials, information technology, automotive, and express package transport—and assessed strengths and weaknesses in the national platform that underpins innovation in each sector.

The Innovation Index gives credence to concerns that the United States could lose its preeminence in technology unless a new national innovation agenda is developed. It should serve as a wake-up call for U.S. policymakers and legislators, and university, industry, and labor leaders alike. Now is the time to begin replenishing the resource base and developing the policies required for future economic growth through innovation.

We owe a debt of gratitude to Council Executive Committee member Professor Michael E. Porter and to Professor Scott Stern, who jointly devised the Index, conducted the analysis, and contributed substantial time and effort to this work over the past year and a half. Major contributions to the report have also been made by Council Vice President Debra van Opstal, Senior Research Associate Chad Evans, MIT Sloan School PhD candidate Jeffrey L. Furman, and Harvard Business School Research Associate Gregory C. Bond. Our thanks also go to Simon Johnson and Joshua Gans for their comments on earlier drafts and to the many council members who provided comments. The Sloan Foundation provided support for this effort, and we are grateful to Sloan Program Officer Frank Mayadas, whose enthusiasm and ideas helped shape the research program.

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Executive Summary

Despite eight consecutive years of economic expansion, the United States could lose its status as the world's preeminent innovator nation in the next decade if current national policy and investment choices continue unchanged. That is the most striking finding of the new research presented in this report. At a time when U.S. competitiveness is the envy of the world, it may seem like an alarmist message. Yet the moment of greatest apparent success can be a nation's moment of greatest vulnerability. A concerted effort is needed now to renew the foundation for long-term U.S. competitiveness and prosperity. The Innovation Index points the way.

The defining challenge for U.S. competitiveness has shifted during the past decade. From the mid-1980s through the mid-1990s, the United States properly focused its efforts on putting its financial house in order, opening global markets, and increasing industrial productivity by improving quality, cutting costs, and reducing time to market. Having met those challenges, however, there is a new challenge looming—our national capacity for innovation. At a time when innovation is becoming even more fundamental to the prosperity of advanced economies, the U.S. commitment to innovation has weakened.

Chapter 1, "Innovative Capacity and the Prosperity of Nations," describes why innovation has become so essential to America's and the world's future prosperity. No advanced economy can maintain high wages and living standards, and hold its own in global markets, by producing standard products using standard methods. In a rapidly integrating world economy where lower wage developing countries are quickly improving their skills and can access today's technology, U.S. prosperity depends on whether we can remain a moving target. We must continually improve our ability to identify and commercialize new products, services, and processes. Those must be high-value (even unique) to yield the productivity growth needed to generate profits and support high-wage jobs.

Beyond explaining why innovation has moved to the top of the competitiveness agenda, Chapter 1 also outlines why some nations are so much more innovative than others. There are three main contributors to a nation's overall innovative performance: the **common innovation infrastructure** that supports innovation in the economy as a whole (e.g., investment in basic science); the **cluster-specific conditions** that support innovation in particular groups of interconnected industries (e.g., automotive, information technology); and the strength of the **linkages** among them (e.g., the ability to connect basic research to companies and the contribution of corporate efforts to the overall pool of technology and skilled personnel).

The Innovation Index is a quantitative measure that captures these three areas. It is not a measure of near-term competitiveness, but an objective benchmark of a nation's potential to sustain productivity growth and competitiveness in the long term. The measures employed in the Index are: total R&D personnel, total R&D investment, the percentage of R&D funded by private industry, the percentage of R&D performed by the university sector, spending on higher education, the strength of intellectual property protection, openness to international competition, and, finally, a nation's per capita GDP.

The Index is calculated using statistical modeling to examine how these measures have affected innovative output across countries and over time. Innovative output is measured by international patenting, or patents filed in the United States as well as another country. The statistical analysis yields a weighting of the relative importance of the measures. This weighting is applied to each country's actual resource and policy choices to determine its Index value. The Index measures innovative capacity on a per capita basis, rather than its absolute level, highlighting that the intensity of innovative investment in a country that is more meaningful for future prosperity.

The Index allows us, for the first time, to dissect the multiple drivers of national innovative capacity. It tells us which variables matter most; it lets us evaluate historical trends in a nation's innovative performance; and it enables us to look ahead to the future impact of recent trajectories and of national policy choices. Overall, it can be used as a guide to inform government and private sector policies.

Chapter 2, "The Innovation Index," explains how the Index works and how it was constructed. It also offers the following important insights into the sources of innovative capacity:

Resource and Policy Commitments Matter. The resource and policy drivers highlighted by the Index explain a very high percentage of the variance in innovative output among OECD countries over the last quarter century.

No Single Factor Is Sufficient to Drive National Innovative Capacity. All of the drivers highlighted in the Index contribute to national innovative output. An economy cannot sustain world-class innovative performance without strength in each area. Scientific publications are not enough to support innovation unless these conditions are present.

How R&D Is Funded and Conducted Makes a Difference. National innovative capacity is reinforced by a high proportion of private funding of R&D activities, by a major role for universities in performing R&D, and by only a modest government role in actually conducting R&D.

The Status Quo Yields Diminishing Returns. If a nation's policy environment and rate of investment in innovation is constant, innovative output actually declines. This need to raise the commitment to innovation just to maintain innovative output is consistent with prior studies.

Developing New-to-the-World Technologies Is Closely Linked to Productivity Growth and Exports in Technology-Intensive Sectors. A high rate of innovative output is an important determinant of both exports and growth in productivity.

International Trends and Projections

The Index has been used to track the innovative capacity of 17 OECD economies since 1973 and eight emerging economies since 1990. It also has been used to project performance to 2005 based on the assumption that current trajectories of national resource and policy commitments continue. From this analysis flow several overarching conclusions about the development of innovative capacity outside of the United States:

OECD Innovative Capabilities Are Converging. Although the United States and Switzerland appear at the top of the Index across three decades, the relative advantage of the leader countries has declined over time. The Index projects further convergence of innovative capacity among the world's industrialized economies if current patterns continue.

Japan Gains Ground. Despite its economic slowdown in the 1990s, Japan has dramatically improved its innovative capacity since the early 1970s. Its investment in innovative capacity shows little sign of weakening even though its economic and per capita income growth have been suffering.

Scandinavia Emerges as a New International Innovation Center. Denmark and Finland have made major gains in innovative capacity since the mid-1980s, joining Sweden in establishing a region of world class innovation. By contrast, following a period of growth during the 1980s, Germany has struggled to maintain its innovative capacity after reunification while France and Italy have treaded water. Finally, at least in terms of commercializing new technologies, the United Kingdom is in danger of moving from an important innovator nation to a follower.

New Centers of Innovative Activity Are Emerging Outside of the OECD. Singapore, Taiwan, South Korea, and Israel have made substantial investments in and upgraded their innovative capacity over the past decade. Ireland has also established the infrastructure and industrial clusters consistent with strong innovative activity. In terms of national innovative capacity, all of these economies could rise to a par with second-tier OECD economies by 2005.

In contrast, several countries that have drawn much attention as potential economic powers—India, China, and Malaysia—are not yet generating a meaningful level of innovative output on an absolute or relative basis. None of these countries is investing rapidly enough across their economy to produce innovative capacity at a world-class level.

The Challenge to U.S. Leadership

The Index indicates that the United States may be living off historical assets that are not being renewed. Investment in the fundamentals of innovative capacity reached a peak in 1985 and then fell. During the first half of the 1990s, the U.S. Innovation Index remained flat. The report details the causes underlying the decline and stagnation in the U.S. Index over the past decade, revealing several critical areas where low investment and inattention have led to the relative weakening of our ability to continue innovating at the international frontier.

Chapter 3, "Charting the U.S. Innovation Agenda," explores these areas in greater detail and highlights the challenges to crafting a new national innovation strategy:

Emerging Shortages in the National Talent Pool. Despite the strength of the U.S. economy during the 1990s, there has been a serious weakening of the nation's available scientific and technical workforce. The number of R&D workers as a percentage of the total workforce has been declining since the late 1980s, at a time when the need for them is rising. Graduate school populations in engineering and the physical sciences, even in computer sciences, are also static or declining. An increasing proportion of graduates are international students, and an increasing proportion of them are returning to their home country on completion of their studies. While the training of international students has been a historical strength of American higher education, these trends suggest an emerging shortage for the American R&D labor market.

Stagnant Investment in R&D Driven by Cutbacks at the Federal Level. Current investment in R&D is lower as a percentage of national wealth than it was in the early 1980s. Despite robust growth in the health sciences, total spending on basic research has declined even more steeply as a percentage of GDP. These declines are partly the result of disinvestment by the Federal government, which has only been partially compensated for by private sector investment. Growth in R&D spending has been lower during the current expansion than in any other expansion period of the past 25 years. Private research shows clear signs of becoming much shorter term.

A Slowdown in Policy Innovation. Following a period of U.S. leadership in opening international markets and strengthening protection of intellectual property, policy momentum has stalled. Further, after a spurt of positive activity encouraging downstream commercialization (e.g., the Bayh-Dole Act or opening up Federal laboratories to partnership with industry), there have been few policies or programs designed to rejuvenate more upstream aspects of innovation. Overall, the U.S. regulatory and legal environment still inflicts substantial, unnecessary costs on industry, and is ranked poorly relative to other countries.

A Dissipating Political Consensus about the Public Role in Innovation. Many emerging nations and OECD countries are expanding their innovative capacity despite short-term macroeconomic difficulties. In contrast, the United States, while enjoying its best macroeconomic performance in a generation, is reducing public investment in the national innovation infrastructure. This erosion in part reflects restructuring after the end of the Cold War, but also an inattention to long-term fundamentals of productivity growth and competitiveness in favor of near-term efficiency and the workings of domestic and international financial markets.

Policy Implications for the United States

To remedy these deficiencies, a new national innovation strategy—supported by a broad array of public and private investments and policy choices—is needed.

First, the downward slide of federal support for R&D outside the health sciences must be reversed. But simply increasing the federal R&D budget, as desirable as this would be, is insufficient. Encouraging private R&D spending, particularly on long-term projects, and attending to the vitality of basic research at universities need to be part of the solution. Making the R&D tax credit permanent is but one example of a specific policy that would encourage higher R&D investment.

Second, the United States must rebuild its dwindling pool of scientists and engineers. This will require major changes and investments in K-12 education, together with a concerted effort to rebuild undergraduate and graduate training in technical disciplines.

Third, policies for improving intellectual property protection in areas such as copyrights must become a top priority. As a nation whose assets are increasingly knowledge based, America should be taking the lead in crafting intellectual property tools that address new forms of innovative output and new uses for it.

Fourth, historic American leadership in market-opening efforts both at home and abroad must be renewed. The United States cannot lead the world in innovation if we lack access to global markets and restrict access to ours.

Fifth, we must revisit the national regulatory environment in order to encourage innovation while maintaining high standards. In a world in which companies have many choices about where to invest, a policy framework that encourages investment in innovation is becoming ever more important.

The crux of the challenge is to rebuild the broad national consensus that created the assets upon which the nation is now drawing. That consensus, which rested for four decades on national security threats and the legacy of scientific and technical achievement during World War II, has dissolved since the end of the Cold War. It can only be restored if Americans feel a sense of urgency about the need to renew the foundations of long-term U.S. economic prosperity.

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CHAPTER 1

Innovative Capacity and the Prosperity of Nations

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Chapter 1:

Innovative Capacity and the Prosperity of Nations

Throughout the early 1990s, the competitiveness challenge facing the United States was to get our house in order. In a way that was the envy of many countries, America moved aggressively to shrink its budget deficit, strengthen its financial institutions, and streamline regulation. American companies made huge strides in improving quality, reducing costs, and shortening time to market. Restructuring eliminated nonproductive activities and made companies leaner and more focused. Commercialization speeded up markedly, and companies are doing a better job of exploiting their technology base in new products and processes. American capital markets have played a major role in driving these changes and are financing a record number of new companies and ventures.

This progress, coupled with well-known difficulties in Japan and Germany, has led many to pronounce success and conclude that there are no serious threats to U.S. economic preeminence on the horizon. As is so often the case in competition, however, the moment of greatest apparent success is often the moment of greatest vulnerability. While the United States has succeeded as perhaps no other economy in the relatively short-term process of restructuring and improving quality and efficiency (and this process must continue), there are clear signs that the foundations for longer-term progress are becoming less solid. Future prosperity depends on maintaining an environment in which the United States is able to successfully develop and commercialize new technologies, products, and processes. Yet, investment in the innovative capacity of the United States has slowed, and current rates of reinvestment and policy commitments may not be high enough to sustain future improvements in our standard of living.

Although recent calls to significantly increase the nation's federal research and development (R&D) budget are a sign that this concern is being recognized, government R&D spending is but one part of a much larger set of influences on innovative activity. Without a concerted rethinking of both government and private sector policies in light of new circumstances, there is little assurance that an increase in government spending will bear fruit. A national innovation strategy is needed, one that draws upon but differs in important respects from that which guided the United States in the post-World War II era.

These issues underpin the Innovation Index project, an effort to quantitatively assess the innovative capacity of nations, examine the performance of a wide array of nations over the last several decades, put U.S. innovation performance in both international and historical context, and develop implications for policy. While prior Council reports have examined the *competitiveness* of American firms from an international perspective, the concept of *innovative capacity* is different. It focuses not on competitiveness in the present, but on the ability to sustain it in the future.

In this chapter, we describe the reasons why innovation has become so essential to America's and the world's future prosperity and outline the elements that determine a nation's innovative capacity. This will provide the foundation for the construction and evaluation of the Innovation Index, described in Chapter 2. Chapter 3 delves more deeply into the specific challenges facing the United States, providing a richer portrait of the areas raised as challenges by the Index.

Innovation and Prosperity in a Global Economy

The prosperity of any economy depends on its productivity, or the value created by a day of work or a dollar of capital invested. Productivity sets the wages that a nation can sustain and the returns earned by holders of capital, the two major contributors to per capita national income. The central role of technological innovation in productivity improvement, long-run economic growth, and in determining a nation's standard of living is well recognized by both economists and policymakers.[1] In the absence of sustained innovation, the rate of productivity growth in labor-constrained economics will ultimately fall to zero. Over time, an even tighter link between innovative capacity and prosperity has emerged, especially for advanced nations such as the United States. The challenge for national policymakers is to foster an environment where innovation flourishes.

Productivity, contrary to popular usage, is more than just efficiency. It is equally driven by the *value* of the products and services a nation can produce, where value is measured by what customers are willing to pay for them. Italy, for example, supports high wages and profits in shoes because of the high value that consumers place on its products, not because Italian shoe manufacturers produce shoes more cheaply than others. Moreover, national productivity is an aggregate of the productivity of each of a nation's industries, not just those whose products are exported or technology-intensive. Local industries can either contribute to or detract from national productivity and play an instrumental role in influencing the productivity of more visible export industries.

Indeed, in a modern economy, it is not only *what* a nation produces but also *how* it goes about it that matters. Innovation can drive productivity improvement across all industrial sectors. In this sense, there are no "low tech" industries—only low technology companies that fail to incorporate new ideas and methods into their products and processes. Innovation opportunities are present today in virtually any industry. Although industries producing enabling technologies such as computers, software, and communications have received much attention, opportunities to apply advanced technology are present in fields as disparate as textiles, machinery, and financial services. For example, the historical success of U.S. agriculture in international markets is due in no small part to the development and application of advanced technologies specific to the agricultural sector, including farming techniques guided by computers and agricultural biotechnology.

Innovation—the transformation of knowledge into new products, processes, and services—involves more than just science and technology. It involves discerning and meeting the needs of customers. Improvements in marketing, distribution, and service are innovations that can be as important as those generated in laboratories involving new products and processes. Indeed, some of the most important innovations today occur in sales and distribution. Consider, for example, the revolution in small-package delivery that has occurred over the past 15 years—and the resulting U.S. global preeminence in this industry.

1 Bush (1945) provided an early and eloquent rationale for sustained public investment in the nation's science and technology base. The centrality of innovation in economic growth has been appreciated since the seminal contributions of Schumpeter Solow (1956) and Abramovitz (1956). Rosenberg, however, was the first to identify how innovative activity of the macroeconomy was inherently the result of more microeconomic processes and their interaction with the environment and national institutions (Rosenberg, 1963; 1982). Building on such early work, Nelson (1990), among others, focuses on the elements of the national innovation system (most closely resembling our concept of the common innovation infrastructure described below) while Porter (1990; 1998) conceptualizes the critical importance and workings of clusters and their role in innovation and competitiveness. Our work also links these more microeconomic-oriented approaches to the macroeconomic approach employed by Romer (1990; 1996), who focuses on the relationship between the "ideas" sector of the economy and the overall process of productivity growth in the economy. For a more detailed discussion of the motivation for this work and its relationship to prior studies in the economics of technological change, see Stern, Porter, and Furman (1999) and Porter and Stern (1999).

History teaches us that the private sector is the engine for innovation. The transformation of knowledge and new ideas into wealth-creating technologies, products, and services is the province of firms, not governments or universities. Nonetheless, national policy and public institutions create an environment that can encourage or detract from firms' innovative activity. The U.S. pharmaceutical industry, for example, has benefited greatly from intellectual property laws that encourage investment in discovering new drugs; by contrast, patent laws in Japan and pricing laws in France historically discouraged investment in new medications, resulting in less innovative companies within these nations' borders.

A higher rate of innovation in one nation does not come at the expense of others. The ability of firms in one country to create new ideas can be enhanced by innovations created in others. Raising their rates of innovation can improve the prosperity and productivity of all nations, and collectively speed the rate of world economic growth. Indeed, as many advanced nations face the prospect of declining population growth, a stepped-up rate of innovation is needed to drive the faster productivity growth that will be required to sustain healthy economic growth rates. The Innovation Index does not aim to designate winners and losers but to measure how countries are performing relative to their potential, and suggest ways in which the innovative capacity of all nations can be nurtured.

Challenges to U.S. Innovative Leadership

Throughout the 1950s and 1960s, standards for productivity and innovation were set primarily within our own borders. The United States was internationally preeminent in science and technology, and American firms were little exposed to international competition. In fact, the only country comparable to the United States in terms of per capita innovative output was Switzerland, a comparatively small nation whose innovative efforts were focused in a modest set of industries. In the late 1990s, however, the economic landscape has changed substantially. With a host of international competitors improving their performance, U.S. productivity leadership is no longer a foregone conclusion in any area. In order to maintain international productivity and innovation leadership in this changing environment, the United States and other advanced nations must confront a complex set of challenges:

Increased Competition from Fast Followers. Advanced countries are subject to competition via imitation by firms in less innovative countries with lower wages. Countries such as Spain and New Zealand, while not at the international innovation frontier, have improved their ability to follow quickly. Moreover, an increasing number of the world's lower wage countries are positioning themselves as rapid imitators in global markets. They have moved beyond traditional exports of natural resources and simple labor-intensive goods to open their economies aggressively to international trade and investment focusing on more advanced export industries. As a result, some production traditionally based in the industrialized world has been moving elsewhere—improving technical skills and infrastructure are weakening the tradeoffs associated with locating stalled activities in lower wage economies.

More Rapid Diffusion of Intellectual Capital. Furthermore, the advantage provided by a given amount of innovation may be decreasing with the increased diffusion of intellectual capital. Not only has globalization increased the international mobility of goods and risk capital, but it has also increased the rate at which ideas and production methods become widespread. The speedy dissemination of knowledge and practices enables lower wage countries to produce goods at higher productivity levels. In general, for innovator countries to be able to maintain their competitive advantages in each stage of the value chain, they will be challenged to innovate more quickly than the increasingly rapid global diffusion of ideas and technology.

Competition for Investments by Multinationals. Recently liberalized international markets, coupled with new transportation methods and advanced communication technologies, are altering patterns of corporate investment, both in production as well as in more high-value R&D activities. Companies are able to locate investments wherever circumstances offer the greatest opportunity. As a result, the United States must compete to be the preferred location for the high value activities of both foreign and even U.S.-headquartered firms.

Emergence of Other Nations That Are Innovators. Innovator countries are those that are continuously successful at discovering, developing, and commercializing novel products, services, and processes. As a result of sustained commitments to expanding innovative capacity, the historically small set of highly innovative advanced economies is expanding. Over the past several decades, a growing number of nations in the Organization for Economic Cooperation and Development (OECD), including Germany, Japan, and some Scandinavian countries, has been developing the capacity to introduce state-of-the-art products and services, raising the standard that U.S. companies must meet. A handful of newly industrialized nations are also beginning to make the transition from imitator to innovator, among them Singapore, South Korea, Taiwan, and Israel. Despite recent economic disruptions, many of these countries are continuing to invest heavily in their innovation infrastructure and the development of clusters that can compete at the international frontier of technology. Recalling the dislocations induced by Japan's emergence as a formidable technological innovator, it is clear that U.S. readiness to compete in a world in which a variety of new countries develop the capacity to innovate at the frontier is far from assured.

A Rising Bar for Innovation. Where an increasing number of countries are able to support a sophisticated innovation infrastructure, the requirements for innovating at the frontiers of technology are themselves increasing. Our research for the Index verifies a finding that has been identified by others: as time goes by, a constant rate of investment and policy support for innovation in a country is yielding a declining payoff in terms of innovative output. An increasing commitment to innovation is necessary for an economy's national innovative capacity *to stay in the same place,* much less to improve in relative terms.

Collectively, these changes define a new competitive environment for the United States and other industrialized countries. Increasingly, the prosperity of advanced nations will depend on their rate of innovation. They will not be able to sustain their competitiveness and support high wages by producing standard products and services made with standard methods. High U.S. wages are unlikely to be justified for mobile activities requiring modest skill, capital, or technology. Indeed, much of this activity has already begun to move offshore.

Instead, the prosperity of the United States and other advanced economies will depend on whether they can remain moving targets, continually at the forefront of creating and meeting the needs of the domestic and international markets and customers. To do so requires a strong level of national innovative capacity. That capacity for innovation affects not only the measured rate of economic growth but also the prospects for sustained increases in the standard of living.

Yet the stakes riding on innovation are even higher, and go beyond the United States alone. A rapid rate of innovation is needed to drive productivity growth in the world economy, especially in the labor constrained advanced economies. Stepped-up innovation is the key to expanding the world economic pie to provide economic opportunities for advanced and developing nations alike. Advanced nations can prosper and employ citizens producing new goods and services in new ways, while developing economies can find improving employment and trade opportunities in more mature areas. Finally, innovation also holds the potential to directly address pressing social and human challenges such as health, environmental quality, safe working conditions, and greater opportunities for individuals with disabilities. As more and more nations become part of the world economy and address the basic foundations of competitiveness, the collective importance of innovation rises.

The Historical Commitment to Innovation in the United States

To many, the preeminent position of the United States as the world's innovative leader is implicit, even preordained. But the leadership of the United States in science and technology and a consensus that innovation is crucial for standard of living have their origins only in the 1940s and 1950s. The role of science and technology in World War II, coupled with technological competition with the Soviet Union during the Cold War, helped forge a strong national consensus around public and private support for the investments and institutions on which America's innovative capacity was built. The public sector played a key role in this strategy, both directly by providing public resources for science and technology and indirectly by encouraging private sector investment in innovative activities.

The Space Race, the Cold War, and the War on Disease captured the nation's attention and motivated sustained investment in scientific research and cutting-edge (often pre-commercial) technologies. The National Aeronautics and Space Administration (NASA), the National Institutes of Health (NIH), the U.S. university system, and particularly the Department of Defense became focal points of the nation's innovation strategy. In addition to being major conduits for government-funded R&D, these agencies played a crucial role in training people and acted as the early and most performance-oriented buyers for new technology.

Both public and private investments in basic research often yield spillovers beyond the specific target of the initial investment. From the public side, defense investments spurred nuclear technologies, spy satellites, precision-guided munitions, and radar. Out of these programs grew weather and communications satellites, passenger jets, supercomputing, the Internet, robotics, and sensor technologies, to name only a few. Public programs, in turn, have been the beneficiaries of further private sector advances in information technology and other fields. The recent introduction of electronic payment of benefits for social programs—simultaneously reducing fraud and administrative costs—is but one example of how the provision of government services benefits from innovation in the private economy. Over time, perhaps the greatest area of sustained interaction has been between the innovative activities of private firms focused on the life sciences and the various research programs supported by the NIH—in this area, the United States has consistently led the world.

This consensus about innovation began to dissipate in the early 1990s, with the end of the Cold War and the collapse of the Soviet Union. Defense funding, long the bedrock of basic research in the United States, began declining, particularly in the physical sciences. The improving competitiveness of the U.S. economy, coupled with the difficulties facing Japan and Germany, has caused complacency about innovation both in the public and private sectors to set in. After all, a nation with so many high-tech startups that is doing so well in information technology and biotechnology could hardly need to worry much about its capacity for innovation.

A strong case can be made, however, that today's innovative achievements are an inherited outcome of yesterday's seed corn. The challenges outlined above—more nations that are innovators, greater competition from imitators, and the increased effort required for innovation—suggest that this is an opportune moment to reexamine U.S. innovative capacity. A new understanding of national innovative capacity and its role in prosperity can aid in forming a new national consensus.

Sources of National Innovative Capacity

Why are some nations so much more innovative than others? This is not the same as asking why some countries publish more scientific papers than others, nor is it the same as asking why some countries are able to achieve higher scores on standardized tests in math, science, or engineering. Instead, the answer requires identifying those factors that influence the ability of a nation's firms to identify economically valuable new products, services, and processes and develop them commercially.

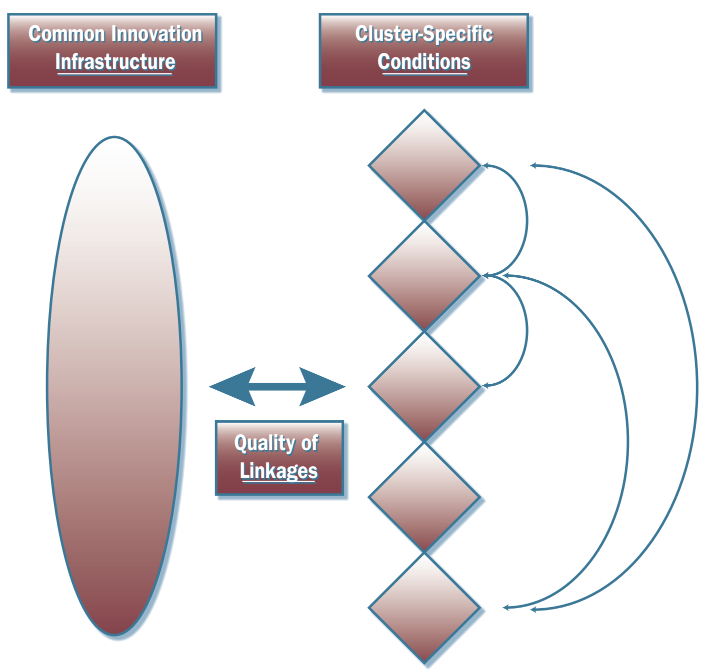
History is replete with examples in which scientific or conceptual advances have been identified in one country but commercially developed in another. The powerful nineteenth-century German chemical industry, for example, was very much dependent on the discoveries of a British chemist. In more recent times, it was Japanese companies that built upon the initial invention of the video cassette recorder (VCR) in 1956 by Ampex (a U.S. company) and turned the VCR into an overwhelming commercial success. History also offers numerous examples in which national industries developed and maintained innovation and international competitive advantage for decades, such as the American computer and German automobile industries. In each of these cases, innovative and competitive success was supported by a wide range of supporting circumstances. The continued success of the German chemical industry, for example, has been underpinned in large part by a highly developed university system that encourages innovative research partnerships with industry.

These cases highlight an important aspect of our approach, suggesting that the sources of national innovative capacity can be divided into two broad categories: a *common* pool of institutions, resource commitments, and supporting innovation as well as the *particular* capacities of groups of interconnected industries. National innovative performance is the result of the interplay between the common innovation infrastructure that benefits many fields and the specific circumstances in particular fields, whether they be automotive products, advanced materials, or health care.

Figure 1-1 illustrates our framework. The left-hand side represents the cross-cutting factors that support innovation throughout many if not all industries: investments in basic research; investment in education; a network of universities conducting research and training scientists, engineers, and others in advanced problem-solving; and policies that affect the incentives for innovation in any industry. The diamonds on the right side signify the innovative environment in groups of linked industries which we term clusters.[2] Clusters are geographically proximate groups of interconnected companies, industries, and associated institutions in a particular field, linked by commonalities and complementarities. We focus on clusters (e.g., information technology) rather than individual industries (e.g., printers) because there are powerful spillovers and externalities that connect the competitiveness and rate of innovation of clusters as a whole. Dotted lines connecting some cluster diamonds to others indicate that spillovers occur across clusters as well. For example, innovation in automotive products draws to some extent on national innovative capacity in the information technology and advanced material clusters. Because of the importance of proximity, the focus of innovation in clusters is often at the *regional* level in larger countries such as the United States.

Finally, there is also an important reciprocal interaction between the common innovation infrastructure and the cluster-specific circumstances that completes the framework. Each cluster in the nation draws on the common innovation infrastructure, but its investments and choices also *contribute* in some respects to the development of that common innovation infrastructure. Biotechnology firms draw on technology and people from university science departments and medical schools, but typically support them through grants and contract research. The internal research and clinical testing of biotechnology firms advance the knowledge base in these institutions. Often through trade associations, biotechnology firms also participate in specialized training activities that boost the nation's stock of skilled talent.

Figure 1-1. Elements of National Innovative Capacity

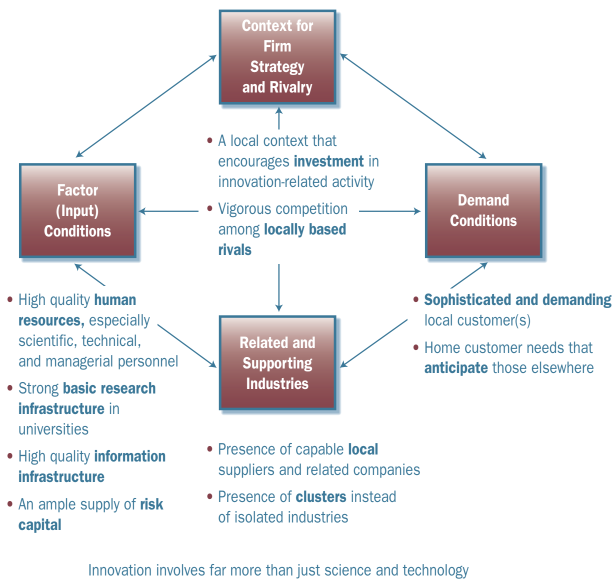


2 For a discussion, see Porter (1998).

Cluster-Specific Conditions

At the root of innovation at the national level are the circumstances that support innovation at the cluster level. Innovation starts with conditions that allow individual firms to improve products and processes. Innovation and productivity growth at the cluster level are driven by the interaction of the four determinants identified in Figure 1-2.[3]

Figure 1-2. The National Environment for Innovation



The four determinants Innovation involves far more than just science and technology are the presence of high-quality and specialized inputs, a context that encourages investment and intense local rivalry, pressure and insight gleaned from sophisticated home demand, and the presence of a cluster of related and supporting industries. In driving innovation, a subset of cluster circumstances takes on particular significance. In the area of inputs, these include high-quality human resources, such as specifically trained, expert scientific, technical, and managerial staff; frontier research relevant to industry issues; and an effective system for communicating best practices and transferring knowledge. In the context for firm strategy and rivalry, the norms, rules, incentives, and pressures that encourage innovation-oriented forms of investment and competition are important. Intense local rivalry and consistent pressure from high-quality international competitors will stimulate innovation by raising the bar for competitiveness and encouraging the inflow of ideas.[4]

Even with high-quality inputs and vigorous competition, however, innovative activity will suffer unless local demand conditions also provide early insights into existing and future needs and press firms to improve. By raising the bar through their choices, demanding customers drive domestic commercialization activities toward best-

3 This environment has been analyzed in the framework introduced in Porter (1990). The framework, often referred to as the "diamond" because of its graphical representation, encompasses a wide array of individual elements, some of which have been identified in previous literature, while others have received little attention.
4 See Sakakibara and Porter (1998).

in-the-world technologies and create a strong market pull for innovation. The presence of a technologically sophisticated workforce in a country contributes to creating demanding customers. So, too, does a regulatory environment that stimulates and facilitates innovation rather than discourages it.

Even with other favorable circumstances for innovation, innovation is made more difficult if firms are isolated or if innovative capability is absent in related fields. Innovation tends to be facilitated by the presence of a cluster, particularly where the cluster is concentrated geographically. Firms within a cluster are often able to more clearly and rapidly perceive new buyer needs than can isolated competitors. Silicon Valley and Austin-based computer companies, for example, plug into customer needs and trends quickly and effectively, with an ease nearly impossible to match elsewhere. Moreover, firms within a cluster can often commercialize innovations more rapidly and efficiently through their ability to easily source needed components, machinery, and services. Smaller entrepreneurial firms draw even more heavily on the environment for innovation in a cluster than do large firms, which only raise the importance of innovative capacity in the new economy.

Reinforcing these other innovation advantages is the sheer pressure—competitive pressure, peer pressure, and constant comparison—occurring in geographically concentrated clusters. Indeed, in some countries, such as Italy, different geographic regions enjoy remarkably different circumstances in terms of both their innovative capacity and realized level of innovation. Therefore, it is often appropriate to investigate innovative capacity at the *regional* level. Data limitations make this impractical in this study, though it is an agenda for future research.

Common Innovation Infrastructure

Although it is ultimately the behavior of individual firms and clusters of firms that accounts for the innovative performance of a national economy, some of the conditions that support innovation activity cut across the entire economy. Some important dimensions of this *common innovation infrastructure,* which is the result of both public and private investments, are shown in Figure 1-3.[5]

Figure 1-3. The Common Innovation Infrastructure

- Investment in basic research
- Tax policies affecting corporate R&D and investment spending
- Supply of risk capital
- Aggregate level of education in the population
- Pool of talent in science and technology
- Information and communication infrastructure
- Protection of intellectual property
- Openness to international trade and investment
- Overall sophistication of demand

5 See Rosenberg and Birdzell (1987), Nelson (1993).

The common innovation infrastructure forms a part of every cluster's innovation environment. A pillar of this infrastructure is basic research, which advances fundamental understanding and is at the root of much new commercial technology. Government funding is the mainstay of virtually every nation's investment in truly frontier research. Sustained support for research, particularly university-based research, also tends to augment the pool of scientists and engineers because research funding often includes stipends and assistantships that attract young talent.

The set of technically trained personnel and the aggregate level of education in the population constitute another important cross-cutting element of national innovative capacity. Certainly, the ability of firms to develop specialized expertise in designing innovative products and processes depends critically on the availability of suitably talented technical employees. While technological work is performed by only a small subgroup of the labor force, innovative personnel are not necessarily technical staff. Innovation arises in numerous domains, including marketing, service, and management. The ability of a nation to develop individuals with such abilities depends on whether the educational system provides a high-quality cognitive skill base from which all firms can draw.

Support for research and education alone, while necessary to support innovation, is not sufficient. High scores in international math exams may increase the potential to develop engineers but do not ensure innovative success. Even the quality of science in a country, as measured by the number of important publications, is only a weak predictor of national success in commercial innovation.[6] Other cross-cutting institutions that enhance the strength of the common innovation infrastructure upon which clusters can draw are a strong information infrastructure and an accessible supply of risk capital. The recent changes wrought by the Internet are ample demonstration that information availability and the infrastructure to disseminate it can drive innovation across a wide array of industries in the economy.

Risk capital is a vital lubricant to innovation, especially for the translation of innovations into commercial products and services. There is a tendency in the United States to equate risk equity with venture capital, but the institutional structure for providing risk capital can take different forms in different nations. In Japan, for example, most risk capital comes from large corporations. As any nation seeks to improve its supply of risk capital, it should build on its unique institutional strengths. Any innovation strategy for the United States should build upon and reinforce the vibrant venture finance community that has developed over the past quarter century.

A set of important national policies constitute another element of the common innovation infrastructure. It is well understood that the incentive to innovate disappears when firms cannot reap returns on their investments. As a consequence, policies that protect intellectual property are essential for creating a pro-innovation environment. Particular policies associated with innovation, such as patent and copyright laws, are more important in some industries than others. However, one can distinguish countries with respect to the overall environment ensuring the appropriability of returns to innovative investments. Other policies—such as the extent of R&D tax credits, an antitrust environment that encourages competition, and low taxation of capital gains—affect incentives for innovation across the economy. Policies toward the openness of the economy to international competition are also an essential component of the national innovative environment; open borders encourage upgrading through increased competition and the inflow of ideas.

6 See Stern, Porter, and Furman (1999).

A further aspect of the common innovation infrastructure is the overall sophistication of a country's consumers. The drive for innovative products is derived in great measure from the nature of demand in the domestic economy. In the United States, for example, the Federal government has acted as a demanding and early customer for many important technologies, just as well-educated Americans have been demanding consumers across a wide variety of markets. In this case, it is not so much the size of the home market in a nation that matters but its character.

Finally, a nation's common innovation infrastructure also depends on its level of overall technological development. This harder-to-measure condition is the result of the accumulated array of learning and investments over time in the economy.

The Quality of Linkages

By themselves, the common innovation infrastructure and cluster-specific conditions are powerful determinants of a country's capacity to innovate at the international frontier. However, the strength of the interaction between the two also matters. Are there effective institutions in place to migrate basic science into established or nascent clusters? Do the strongest clusters provide sustained support back to the common institutions? While evaluating the strength of these interactions is difficult, it represents a key element of a successful national innovation strategy.

Renewing National Innovative Capacity

The foundations of innovative capacity, then, are broad and touch on myriad aspects of a nation, its institutions, and its policies. The elements of national innovative capacity are subtle, and the consequences of disinvestment are slow (but sure) to materialize. To create an Index of innovative capacity, our challenge will be to find a way to capture these in ways that can be quantified and compared across countries. Our detailed approach to the construction and evaluation of the national Innovation Index is the subject of the next chapter.

Raymond V. Gilmartin
Chairman, President and CEO
Merck & Co., Inc.

1999

The Five Enabling Conditions for Pharmaceutical Innovation

Nowhere has innovation been pursued as successfully as in the United States during the twentieth century. And within the United States, I would argue, nowhere has the pace of innovation been as rapid as in the research-based pharmaceutical industry.

The U.S. pharmaceutical industry leads the world—scientifically, medically, and competitively. We are the No. 1 global innovator, having discovered more new drugs by far than any other country. Over time, these medicines have made tremendously important contributions to the health and wellbeing of men, women, and children worldwide.

In this century, for example, life expectancy for a child at birth in the United States has increased by more than 75 percent. A baby born in 1900 had an expected life span of 40 to 45 years. Today, life expectancy is in the mid-70s, and edging upward every year.

In the past 50 years, researchers from U.S. pharmaceutical companies have discovered and developed break-through treatments for asthma, heart disease, osteoporosis, HIV/AIDS, stroke, ulcers, and glaucoma. And, thanks to the efforts of researchers in the U.S. pharmaceutical industry, parents can immunize their children against illnesses that previously were common causes of death among infants, including polio, rubella, *Haemophilus influenzae* type b, and whooping cough.

The success of the U.S. pharmaceutical industry in discovering breakthrough medicines is even more remarkable when you consider the fact that only one out of 5,000 new compounds that our researchers test will ever make it to market. Getting it there will take 10 to 15 years of laboratory and clinical trials and regulatory reviews, at an average cost of $500 million. That means if a researcher discovers a new compound today, a 5-year-old child will go through grade school, high school, and three years of college before the drug gets to your medicine chest.

Why has the U.S. pharmaceutical industry been so successful? Because we have invested in innovation through breakthrough research. The U.S. pharmaceutical industry leads the world in its commitment to research, measured by the percentage of overall sales reinvested in research and development. Overall, U.S. industry invests under 4 percent of its revenues in R&D. In contrast, America's research-based pharmaceutical industry invests about 19 percent of its revenue in R&D, and this percentage has increased steadily for many years.

But while the U.S. pharmaceutical industry is committed to investing in R&D, it is not enough to ensure future innovation. To sustain innovation, we need policies worldwide that support and encourage our ability and freedom to take the risk to innovate. The U.S. pharmaceutical industry has identified five enabling conditions necessary for the discovery and development of important new medicines. It is little coincidence that these conditions are similar to the factors Michael Porter and Scott Stern use in their study to predict a nation's long-term ability to sustain innovation. They are:

- A free market for pharmaceuticals based on competition and choice,
- Continued government support of basic biomedical research,
- Effective intellectual property protection,
- Efficient and effective regulatory and drug approval systems, and
- A global business environment conducive to free trade.

America is unique in that we have nurtured all five enabling conditions of innovation—at least so far. While other countries have done some things well, they have fallen short in other areas by restricting market access or imposing price controls. Although the United States remains the global leader in pharmaceutical innovation, we must not become complacent or forget what has led to our present success. If we do, our leadership position—as well as the future health of Americans—will be at risk.

As we stand at the dawn of a new millennium, our researchers are working on new medicines that could prove to be better than we could ever begin to imagine. With the emergence of new technologies and advances in biomedicine, researchers today have the tools to unlock the mysteries of disease. They are working on better treatments and even possible cures for a host of life-threatening diseases that have plagued society for centuries—diseases such as cancer, diabetes, and depression.

But the U.S. pharmaceutical industry will only be able to make these diseases distant memories in the twenty-first century if we, as a nation, continue to support the factors necessary for innovation.

1999

CHAPTER 2

Innovation Index

1999

THE NEW CHALLENGE

Chapter 2:

Innovation Index

The central objective of the Index is to create a quantitative benchmark of national innovative capacity which highlights the resource commitments and policy choices that most affect innovative output in the long run. Our focus is neither on scientific progress nor competitiveness per se, but rather on the subtler concept of national innovative capacity—the ability of a country to produce a stream of commercially relevant innovations. This capacity is dependent in part on the technological base of the economy, but also reflects investments, policies, and circumstances in a wide variety of other areas. National innovative capacity is not the exclusive result of government policy, but is shaped by the accumulated outcome of the interaction between many public and private choices. While competitiveness in the short term can be improved by cost cutting and deficit reduction, national innovative capacity is a lynchpin of national industrial competitiveness over the long run.

Improvements in national innovative capacity are not a zero sum game. If many nations improve innovative capacity, all will enjoy more rapid growth in productivity and with it an improved standard of living. Improving innovativeness in one country can also benefit other countries through the diffusion of knowledge and products. Much of the world has benefited since World War II from the scientific and technological leadership of the United States. So, too, does the United States benefit from ideas and technologies developed elsewhere. Our goal with the Index is to understand how innovative capacity can be enhanced in any country by drawing on the experience of a broad array of advanced countries over the last two decades.

We use the framework of the previous chapter to identify those influences that affect national innovative capacity, measure them across countries, and determine how to weight different influences relative to each other. National innovative capacity results from the strength of the common innovation infrastructure, the specific conditions supporting innovation in the nation's clusters, and the strength of positive interactions between common infrastructure and the cluster-specific conditions. The Index measures the contributions of each of these areas using a small number of indicators flowing from this framework. For the common infrastructure elements, we can measure some of the most important ones directly, such as the strength of intellectual property protection and the public investment in higher education. To ascertain the degree to which conditions in clusters contribute to national innovative capacity, we must employ intermediate measures of the aggregate cluster innovation environment. Similarly, we use an intermediate measure to gauge the strength of interactions. These measures are far from perfect, and cannot capture the full range and subtlety of how national innovative capacity is nurtured and maintained. However, our framework allows us to identify and employ a judicious set of contributors to national innovative capacity which can be measured consistently and accurately.[7]

7 As discussed in Chapter 1, our framework builds on research from both economics as well as technology policy (including seminal contributions by, among others, Schumpeter, 1943; Bush, 1945; Solow, 1956; Porter, 1990; Romer, 1990; and Nelson, 1993).

The Index uses statistical modeling to distinguish the relative importance of these contributors to national innovative capacity. We employ regression analysis across a set of 17 OECD countries over a 25-year period from the 1970s through the mid-1990s to link these contributors to an internationally comparable and revealing measure of national innovative output—per capita "international" patenting. This analysis provides a consistent and comparable way to assign relative weights to the different influences on national innovative capacity.

The Index thus provides one metric with which to evaluate national innovative capacity in an international context. The analysis reveals new insights about how a wide range of nations has performed historically. It also provides a way to put the recent progress of newly industrializing nations such as Korea, Taiwan, or Israel in perspective, and offers guidance about the likely consequences for nations that maintain recent trajectories of investment and policy choices. It also highlights a set of emerging challenges for the United States.

Distilling Measures of Innovative Capacity

The theoretical framework in the previous chapter suggests that the Index should include measures reflecting the common innovation infrastructure, the innovation environment in clusters, and the quality of linkages between these two areas. The Index includes the best available measures of the strength of each area. No single influence alone, whether it be the quality of scientists or the strength of international property laws, ensures a healthy stream of innovative output. When several of these influences improve concurrently, however, national innovative capacity will tend to rise.

Along some dimensions, particularly those which capture the strength of the common innovation infrastructure, direct measures are available and are included in the analysis. More subtle and multi-faceted concepts, such as the cluster-specific innovation environment, cannot be quantified directly from available and internationally comparable data. We address this challenge by employing an intermediate measure which does not capture the underlying drivers of national innovative capacity in a particular area but measures an outcome associated with the strength of those specific drivers. The quality of the innovation environment within clusters is inherently difficult to measure, for example, as it involves such areas as the supply of specialized talent and the degree of domestic customer sophistication in particular fields. However, the amount of collective R&D activity funded by a nation's clusters provides an indicator of these more fundamental circumstances.

With the distinction between direct and indirect indicators in mind, we review the specific variables used in the calculation of the Index and how each relates to national innovative capacity.

The Quality of the Common Innovation Infrastructure

Aggregate Personnel Employed in Research and Development. A critical determinant of the underlying innovative capacity of an economy is the overall supply of scientific and technically trained individuals available. Both private and public entities engage the skills of these individuals, whose continuing learning builds on their formal training. An intermediate measure of the more fundamental process by which individuals choose to invest in scientific and technical skills, the level of personnel employed in R&D-related activities in a nation reflects the baseline level of human resources which can be utilized for purposes of innovation across the economy.

Aggregate Expenditures on Research and Development. In addition to human resources, a strong national innovation infrastructure includes the availability of funding for innovation-related investments. While the determinants of investment in an individual cluster will be a function of relevant technological and commercialization opportunities, the aggregate level of such investments by both business, non-profit, and public institutions reflects the overall availability of R&D-directed capital. It is crucial to note that while specific forms of financing (e.g., venture capital) are often cited as being the most efficient form of providing capital for innovation, countries have developed a variety of institutions for delivering a high *level* of R&D capital, including investment by large corporations and cooperative R&D (Japan), interlocking cooperative funds centered around small- and medium-sized companies (Northern Italy), and the American venture capital model. Aggregate R&D expenditure is also an intermediate measure reflecting more fundamental drivers of investment, not the least of which are national R&D tax policy and the existence of regulations facilitating capital market institutions such as venture financing.

Openness to International Trade and Investment. The degree of openness to international trade and investment is a critical element in the national innovation infrastructure. Policies encouraging the flow of goods, services, and ideas from one nation to another have the dual effect of increasing competitive pressures on domestic firms and enhancing the flow of ideas from abroad. Greater competitive pressures from abroad require firms across a broad range of a nation's clusters to step up investment in innovative activities. The direct and indirect exchange of knowledge with foreign companies also supports technological change, while inbound foreign investment contributes to R&D funding. Although tariffs and other trade and investment impediments can benefit some industries in the short run, openness to international trade and investment constitutes a cross-cutting contributor to national innovative capacity in the long run.

Strength of Protection for Intellectual Property. Of the policies affecting national innovative capacity, perhaps the most basic is the provision of appropriate rewards for innovation by private inventors. We measure the extent to which a nation's policies protect intellectual property rights through patents, copyrights, and the like. Intellectual property protection contributes to national innovative capacity in two ways. First, strict defense of intellectual property encourages domestically based firms to invest in innovative activities and signals the attractiveness of the country as a site in which to locate innovative activity. Second, obtaining the benefits of such protection requires public disclosure of information describing the innovation. In this way, intellectual property protection encourages the diffusion of knowledge throughout the economy. While a cross-cutting measure, the impact of legal intellectual property protection is more salient for some clusters than for others. For example, while the pharmaceutical industry has long depended upon strong patent protection throughout most of the OECD, emerging areas such as software are still developing appropriate and effective intellectual property institutions.

Share of Gross Domestic Product Spent on Secondary and Tertiary Education. The availability of high quality workers, with both technical and non-technical backgrounds, is an additional and basic element of a nation's common innovation infrastructure. Investment in higher education creates a base of highly skilled personnel upon which firms and other institutions across the economy can draw; in both formal R&D activities and more informal problem-solving, skilled workers are better able to recognize, choose, and execute innovation-oriented strategies in the pursuit of competitive advantage. The intensity of national investment in higher education is therefore a crucial determinant of national innovative capacity. By sustaining investment in higher education, a country can slowly but surely upgrade the ability of its workforce to innovate and to commercialize new technologies at the international frontier.

Gross Domestic Product per Capita. Beyond direct investments and policy choices, a nation's common innovation infrastructure is affected by the general level of domestic customer sophistication and the overall accumulated level of domestic technological knowledge. These are measured in the Index by gross domestic product (GDP) per capita adjusted for purchasing power parity. The level of wealth achieved by an economy both reflects the technological stock upon which innovators draw and influences the degree to which sophisticated domestic customers exert pressure on firms to upgrade the quality of their product offerings. It is important to note that GDP per capita ultimately depends on the accumulated history of public and private choices, investments, and outcomes rather than short-term economic policies.

Cluster-specific Innovation Environment

Percentage of R&D Expenditures Funded by Private Industry. The degree to which a nation's clusters contribute to innovative capacity depends, in large part, on whether the environment of individual clusters encourages firms to commercialize new products and processes. While there is no measure of this which is comparable across clusters, time, and countries, the extent of R&D funding by private firms is a reflection of whether cluster-specific conditions are conducive to R&D investment. Across clusters, the more favorable the innovation environment, the higher national private R&D spending will be. Controlling for total R&D expenditures, then, the percentage of total R&D expenditures funded by private industry is an intermediate measure of the cumulative innovative activity of a nation's clusters and an observable manifestation of the more fundamental conditions affecting innovation in those clusters.

The Quality of Linkages

Percentage of R&D Performed by Universities. National innovative capacity is reinforced by strong linkages between clusters and the common innovation infrastructure. While these linkages take different forms in different national contexts, one commonality across countries is the leading role that universities play in mediating the relationship between private industry and elements of the innovation infrastructure. A strong university sector provides an important conduit through which basic, fundamental research results serve to catalyze the emergence of innovation-oriented domestic clusters. Conversely, by placing pressure on universities to conduct relevant research and produce high-quality students with specific technical skills, private funding and involvement in the university sector serve to foster a key reverse linkage from the clusters to the common innovation infrastructure.

Controlling for the overall level of R&D investment, then, the percentage of R&D performed by universities is an indicator of the strength of linkages. It measures the degree to which innovative activity, whether funded by companies, government or other institutions, is centered in institutions which are suited to encouraging interplay between the different entities that contribute to national innovative capacity. It is important to note, however, that we cannot capture in the Index the full range and diversity of institutions (e.g., research cooperatives in Japan and elsewhere) which have arisen across countries to contribute to such linkages.

Other Measures

In developing the Index, we also examined a variety of other aspects of the innovation environment, such as measures of access to capital and the strength of national antitrust policy. While both of these factors are clearly important to the strength of innovative capacity in the United States, the available measures of them proved not to be statistically significant. This does not mean that these factors are unimportant. Our model indirectly includes these areas by measuring R&D spending funded by the private sector, the outcome of vigorous rivalry and spending by venture-backed companies. The results, then, suggest that their impact is difficult to isolate quantitatively given the other measures included in the model. In forming policy recommendations based on the Index, it is important to include antitrust and risk capital. Unique institutional advantages such as the venture capital system are vital in building up our national commitment to competition.

As well, the failure of these other measures to attain statistical significance may well be due to the fact that they are likely reflected in other included intermediate measures, such as R&D expenditures and the supply of R&D personnel. For example, if a strong antitrust policy fosters innovation by stimulating rivalry, this should be reflected in higher levels of R&D spending, an attribute captured in our analysis. As discussed below, the extremely high proportion of variance explained by the model highlights the difficulties of separating out distinct but related attributes of a nation's innovation environment.

Designing the Index

We sought to combine the measures discussed above to create an overall Index to gauge national innovative capacity.[8] The easiest way to create such an Index would be to simply accept each of the measures as valid and calculate a sum across all measures for each country, weighting them equally. Such an approach would yield an aggregate indicator comparing national resource commitments and policy choices across time and across countries. However, the Innovation Index goes beyond this approach and incorporates two additional features which increase the confidence we can attach to the findings and to the Index's relevance for guiding policy.

First, rather than simply assuming that individual measures are important and weighting them equally, we directly assess the influence of each measure on innovativeness through statistical analysis. We regress the measures included in the Index as a proxy for national innovative output—the level of international patenting. Measures which historically have been more important in determining high rates of innovative output across all countries are weighted more strongly than those which have a weaker (though still important) impact on innovative capacity.

Second, the Index is calculated on a per capita basis to measure innovation intensity rather than its absolute level. The underlying motivations for the Index—increasing standards of living and productivity at the national level—are inherently tied to a per capita evaluation. We are interested in innovative output *relative* to the human and other resource base of a country, because this will determine a nation's sustainable rate of improvement in Wages and productivity. Indeed, while the United States will almost certainly remain an important center for innovation simply by dint of its size, the Index provides evidence as to how the innovative capacity of the United States has evolved over time relative to other industrialized economies. The per capita measure also facilitates comparison across countries, and small innovative countries can achieve high rankings.

8 It is important to note that comparisons of the resource and policy commitments across countries are employed to understand the causes of innovative capacity rather than to suggest that one nation's gain comes at the expense of others.

Measuring Innovative Output

In order to obtain the weights for the Index, we benchmark national innovative capacity in terms of an observable measure of innovative output. While there is no available measure that is ideal, we employ the number of "*international*" patents issued to a country as the best available measure of a national innovative output. An international patent is one which is filed in both the home country as well as abroad. In this study, we examine the number of patents that are approved in both the country of the inventor as well as by the United States Patent and Trademark Office, incorporating a lag between the discovery of a new idea and date a patent is issued.[9]

Three important factors drive our decision to use international patents. First, patenting over countries and time is highly likely to reflect actual changes in inventive outputs rather than spurious influences, especially in measuring innovativeness at the world frontier. Patenting captures a sense of the degree to which a national economy is developing and commercializing "new to the world" technologies—a necessary prerequisite for building international competitiveness on the basis of quality and innovation. In short, international patenting is "the only observable manifestation of inventive activity with a well-grounded claim for universality."[10] By requiring that a patent is granted by the U.S. Patent and Trademark Office in an economy which is highly advanced technologically, we can be confident that a common standard has been applied and the invention is near the world technological frontier.

Second, while international patenting is not a perfect measure, other measures suffer from greater conceptual or data limitations. Copyrights, for example, are potentially important indicators of innovative activity, particularly in industries such as software. However, copyrights vary greatly in their definitions and importance across countries and over time, and prove not to be very useful for international comparisons of aggregate innovative activity. The number of scientific journal articles, while a precise and standardized measure of innovative output across countries, is an indicator of more basic activity that is closer to scientific exploration than to commercial significance. We also believe that the intensity of patenting is correlated with other manifestations of innovative activity.

It is important to keep in mind that the Index itself is not the number of international patents, but rather the sum of the measures described earlier (such as national R&D employment, weighed by their demonstrated influence on international patenting. Therefore, the Index *reflects the actual resource and policy commitments of a country* and not simply a country's propensity to patent or its involvement in patent-intensive industries. The choice of patents as a measure, then, only modestly influences differences in the weights used in the Index calculation. The Index captures R&D personnel and funding even in those sectors which do not rely heavily on patenting. Even though areas such as software are much less patent-intensive than, say, the life sciences, the employment of software engineers and R&D expenditures in software *is* part of the Index.

A final consideration in selecting international patents as our measure of innovative output is their connection with commercial significance. Obtaining a patent in a foreign country is a costly undertaking, which is only worthwhile for an organization that anticipates a commercial return in excess of the substantial costs. This insight is confirmed in a suggestive way by examining the relationship between international patenting and more general international economic data. As discussed further in the Technical Appendix, international patenting is strongly

9 For the United States, we utilize the number of patents granted to establishments (non-individuals) both in the United States as well as in one other country. To account for the fact that U.S. patenting abroad may follow a different pattern than foreign patenting in the United States, we include a dummy variable for the United States in the analysis. This dummy variable turns out to be both small in impact and insignificant.
10 Trajtenberg (1990) provides a thorough discussion of the role of patents in understanding innovative activity, stretching back to their use by Schmookler (1966) and noting their ever-increasing use by scholars in recent years (e.g., Griliches, 1984; 1990; 1994). Our use of international patents also has precedent in prior work comparing international inventive activity (see Dosi, Pavitt, and Soete, 1990; Eaton and Kortum, 1996).

correlated with alternative measures of innovative output such as the number of scientific journal articles and also with outcome measures such as a country's market share in high-technology industries. After controlling for the level of international patenting, however, more upstream measures (i.e., scientific journal articles) do not have a significant relationship with outcome measures (success in international markets). In other words, international patenting seems to encompass alternative measures of innovative output and is also closely associated with patterns of success in innovation-driven international competition.

Calculating the Index

The Index is calculated and evaluated in four stages, summarized in **Figure 2-1.** The first stage consists of creating the database of variables relating to national innovative capacity for our sample of 17 OECD countries from 1973 to 1993. This database is used to perform a time series/cross sectional regression analysis determining the significant influences on per capita international patenting and the weights associated with each influence on innovative capacity.

Figure 2-1. **Calculating the Innovation Index**

Stage I
- Create a database for 17 OECD countries from 1973 to 1993
- Employ a time series/cross sectional regression analysis to determine the significant influences on innovative output three years ahead and the weight associated with each influence

Stage II
- Calculate the Innovation Index for each country for each year, including 1994 and 1995, using the weights from Stage I
- Evaluate the differences in the Index among countries and changes in the Index over time

Stage III
- Project the Innovation Index into the future for each country, given the recent trajectory of its policy and resource commitments
- Evaluate projected shifts in the Index among countries and the influence of various policy areas

Stage IV
- Expand the sample to include recent data for eight emerging economies
- Calculate the current and projected Innovation Index for each emerging country
- Identify countries which are on the path to becoming significant innovation centers

In the second stage of the analysis, the weights derived in the first stage are used to calculate a value for the Index for each country in each year given its actual resource and policy choices.[11] It is in this sense that we refer to national

11 One important difference between Stage I and II is that we extend the data set to include the most recent data for 1994 and 1995. While the patenting variables for these years were not yet available for inclusion in the regression equation, the data on actual resource commitments and policy choices in these years can be used to calculate the value of the Index.

innovative capacity: the extent of countries' current and accumulated resource and policy commitments. The Index calculation allows us to explore differences in this capacity across countries and in individual countries over time.

The Index, interpreted literally, is *the expected number of international patents per million persons given a country's current configuration of national policies and resource commitments.* It is important *not* to interpret the Innovation Index as a tool to predict the exact number of international patents that will be granted to a country in any particular year. Instead, the Index provides an indication of the relative capability of the economy to produce innovative outputs based on the historical relationship between the elements of national innovative capacity present in a country and the outputs of the innovative process. While the analysis here focuses on national innovative capacity, the methodology could be extended to the regional level. For example, if data were available, it would be illuminating to divide Italy into its northern and southern regions. This would reveal differences in innovative capacity between the advanced North and the less technologically sophisticated South.[12]

The third stage of the analysis uses additional statistical modeling to provide a projection of national innovative capacity into the future, based on recent historical trends in investment and policy choices. This is a projection rather than a "forecast" in the sense of being predictive. The recent trajectories of countries' resource commitments and policy choices are extrapolated into the future, and then the weights developed in the first stage are used to project national innovative capacity in the future. Hence this exercise provides insight into the potential implications of "staying the course." Clearly, the innovative capacities that will actually be realized in the future depend on both the public and private policy decisions made in the interim. Our methodology is meant to establish a baseline for comparative analysis and provide a context for current policy debates.

Finally, the fourth stage expands the sample of countries to include recent data for eight rapidly emerging economies. Calculating the Index for these economies provides insight into the probability that these countries will emerge as centers of innovation and potential differences among them in terms of their innovation environment. Special caution is warranted in interpreting these results, however. Fewer years of data are available, and the data are not as comparable across countries. Perhaps most important, the trajectory of innovative capacity is also at its greatest uncertainty in the emergent stage of development that characterizes these countries.

Stage I: Statistical Findings on Innovative Capacity

The regression analysis reveals a strong and consistent relationship between each measure of the strength of national innovative capacity and per capita international patenting.[13] This result is interesting in its own right: while countries differ in the institutions and mechanisms used to influence and conduct innovative activity, there is a clear relationship between a small set of measures of the innovation environment and a key measure of innovative output which holds across all the countries. Overall, the measures of the strength of national innovative capacity explain more than 99 percent of the variation in international patenting, highlighting the strong relationship between the measures and observed innovative output. As discussed further in the Technical appendix and in Stern, Porter, and Furman (1999), these results are robust to a variety of alternative specifications. For example, the qualitative results are the same for a smaller data sample composed solely of those observations after 1985. Hence, the determinants of innovative output appear to have been quite consistent over time.

12 The Council is currently undertaking a project to examine innovative activity at the regional and cluster levels.
13 The Technical Appendix reviews the statistical methodology and findings in full detail. We focus here only on the implications of the analysis for the calculation of the *Index*. Table A-4 reports the regression used in calculating the Index.

Further, each of the measures identified above proves to be both statistically significant and quantitatively important in explaining innovative output at the national level. One of the strongest influences turns out to be the relative size of the R&D workforce—the pool of available technical talent. For example, a 20 percent increase in the size of the R&D workforce in a country would lead to a change in the predicted value of the Index of nearly 18 percent, almost a "one-to-one" relationship. Both the level of R&D expenditures and the proportion of funding from industry also play decisive roles in determining the level of innovative output. The results suggest that increasing the percentage of total R&D expenditure funded by private industry by 10 percentage points (e.g., by shifting industry's share from 50 percent to 60 percent of total expenditures) increases the level of innovative capacity by more than 15 percent. Although the magnitude of their effects is somewhat smaller, the other measures, including the strength of intellectual property, openness to international trade and investment, and the extent of public funds devoted to education, are of substantial importance as well.

Our suggestive but imperfect measure of the strength of linkages—the share of R&D performed by universities—also turns out to be a significant but modest contributor to international patenting performance. GDP per capita is a strong statistical determinant of international patenting as well, reflecting the importance for innovative capacity of a strong accumulated knowledge pool and a sophisticated and demanding domestic customer base. Finally, working in the opposite direction is a "raising the bar" effect. The productivity of international patenting (i.e., the number of patents produced for a given level of innovative resources) is declining over time, a result consistent with prior studies. Taken together, the statistical analysis confirms the notion that no single factor is determinative in creating a favorable innovation environment, and that concurrent progress is necessary in a variety of areas to substantially upgrade a nation's innovative capacity.

Stage II: The Innovative Performance of OECD Countries

The second stage of the analysis employed the weights derived from Stage I to calculate the Index across time for the 17 OECD countries in the sample.[14] Over the three decades examined, countries fall into three relatively stable groups in terms of innovative capacity (see **Figures 2-2** and **2-3**). The United States and Switzerland consistently appear at the top of the Index, and were joined there in the 1980s by Japan, Sweden, and the former West Germany. These countries constitute the innovator group. A second group of countries, including the remaining Scandinavian countries, constitute a middle group. The third group, including Italy, New Zealand and Spain, lag behind the rest of the OECD over the full sample. There are quite substantial differences across the groups in terms of the value of the Index. Predicted per capita innovative capacity for the top group is more than 5 times the level of capacity attributed to countries in the lowest tier.

An important finding from the analysis is that the relative advantage of leader countries has been declining over time. As can be seen in **Figure 2-3,** not only has the top tier expanded to include Japan, Germany, and Sweden, but some middle tier countries, such as Denmark and Finland, have made major gains in innovative capacity. Moreover, this convergence seems to be built on fundamentals rather than transient changes. Consider the case of

14 Table A-5 provides the value of the Index for all countries for all years. 15 For all years prior to 1990, only data for West Germany are used. From 1990 onwards, the results include the new Federal states. As a consequence, the drop-off in 1990 reflects the inclusion of the less innovation-intensive population of East Germany which has slowly been integrated over the 1990s.

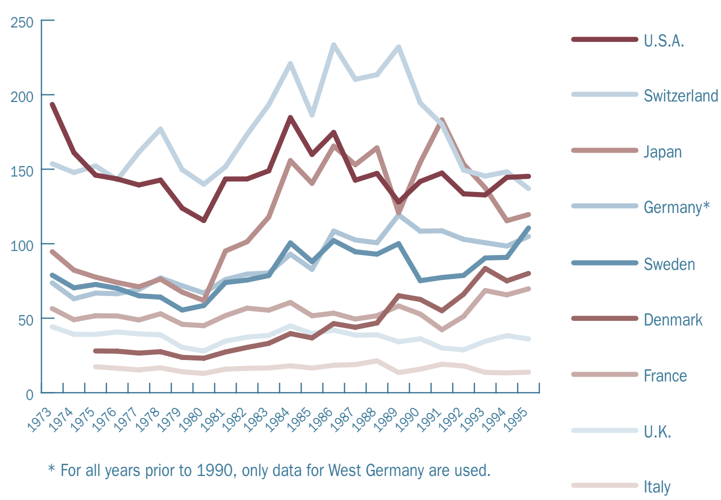
Germany, where innovative capacity grew strongly throughout the 1980s.[15] Despite a drop-off resulting from reunification with the East beginning in 1990, Germany maintained a relatively high level of innovative capacity throughout the 1990s. Indeed, looking across the OECD, there seems to have been a slow but steady closing of the gap between the innovation leaders and nations with historically lower levels of innovative capacity.

Figure 2-2. Innovation Index: Selected Years

1980	1986	1993	1995
Switzerland	Switzerland	Switzerland	U.S.A.
U.S.A.	U.S.A.	Japan	Switzerland
Germany*	Japan	U.S.A.	Japan
Japan	Germany*	Germany*	Sweden
Sweden	Sweden	Sweden	Germany*
Canada	Canada	Denmark	Finland
France	Finland	France	Denmark
Netherlands	Netherlands	Canada	France
Finland	Norway	Finland	Canada
U.K.	France	Australia	Norway
Norway	Denmark	Netherlands	Netherlands
Denmark	U.K.	Norway	Australia
Austria	Australia	U.K.	Austria
Australia	Austria	Austria	U.K.
Italy	Italy	New Zealand	New Zealand
New Zealand	New Zealand	Italy	Italy
Spain	Spain	Spain	Spain

*For 1980 and 1986, rankings are for West Germany only.

Figure 2-3. Historical Innovation Index Selected Countries, 1973-1995



* For all years prior to 1990, only data for West Germany are used.

It is important to note, however, that some important countries, most notably France, Italy, the Netherlands, and Canada have at best remained constant in their innovative capacity. Finally, the United Kingdom has seen an alarming fall off in its innovative capacity. Compared to other economies that have been able to achieve relatively strong improvement, then, these countries have eroded their relative innovative capacity over the past quarter century by neglecting investments in common innovation infrastructure and in supportive cluster innovation environments.

Stage III: Projecting the Index into the Future

The third stage of the analysis projects national innovative capacity into the future by extrapolating recent trends in resource commitments and policy choices over 10 years and applying the Index formula. Here, we project the future based on recent trends rather than predicting expected outcomes. While movement across groups has been uncommon to date, recent trends in resource and policy commitments suggest that this might change in the future.

The base case analysis reveals two broad findings (See Figures 2-4 and 2-5). First, the elite group of innovator countries is projected to further expand to include several Northern European economies. As a consequence of favorable shifts in regulatory policy and rates of investment in education and R&D, the Scandinavian countries as a group are projected to establish themselves as leading innovation centers. Second, the difference between the top tier and the middle group is projected to continue to narrow. Third, despite macroeconomic difficulties, Japan has sustained

Figure 2-4. Projected Innovation Index: Selected Years, 1995-2005

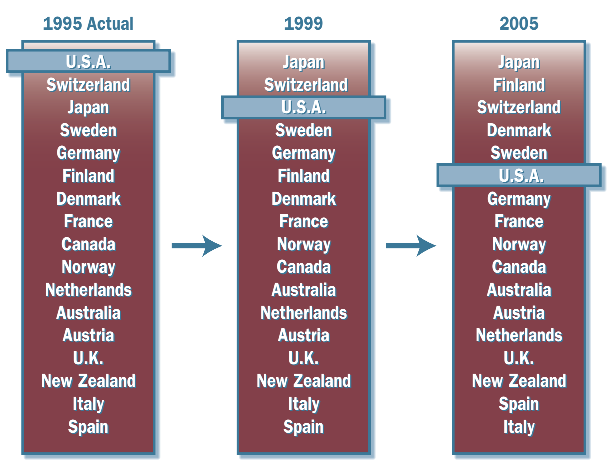
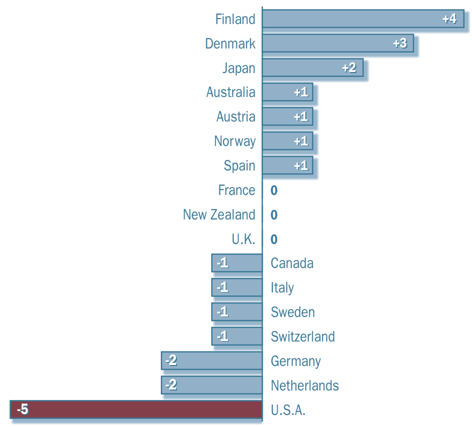


Figure 2-5. Projected Innovation Index, Change in Ranking: 1995 vs. 2005



a high and increasing level of investment in long-term innovative capacity which may be decisive in generating growth for that economy over the long run. Largely as a result of the continued transition costs associated with reunification, Germany's position is projected to erode slightly; one could imagine that the end of transition and renewed attention to long-term investments in national innovative capacity, however, could alter these projections.

In contrast, the United States is projected to cede much of its relative standing over the next decade in the absence of changes in policy or investment patterns here or abroad. Chapter 3 details several of the specific trends this projected shift; the U.S. declines are a result of several underlying factors rather than arising from a single area of weakness.

Stage Four: Emerging Centers of Innovation

In the final stage of the Index analysis, the methodology is expanded to include eight emerging economies: China, India, Ireland, Israel, Malaysia, Singapore, South Korea, and Taiwan. Though the data are likely less reliable for these economies and there is more uncertainty associated with their innovative potential, these data provide a starting point for evaluating the potential of these economies to become international centers of innovative activity. In addition to calculating the Index up until 1995, we use the best available data to estimate the recent trajectory of resource and policy choices to project innovative capacity in the future (See Figure 2-6).

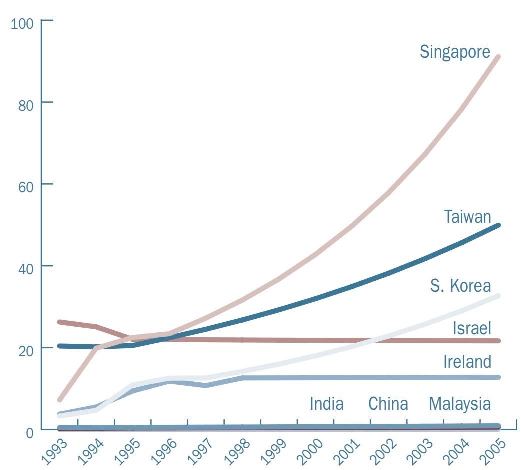
The analysis suggests that a number of historically less advanced countries are developing innovative capacities that have or will soon approach the levels of at least the middle tier of the OECD countries. Over the last decade, Taiwan, Singapore, and South Korea have each made substantial investments to upgrade innovative capacity. Notably, these particular three East Asian economies have been relatively less affected by the difficulties in Asia than other economies that have not made such investments.

Beyond the Pacific Rim, both Israel and to a lesser extent Ireland seem to have established the underlying infrastructure together with several clusters consistent with strong national innovative capacity. Indeed, given the poor performance of the United Kingdom, the analysis suggests that Ireland and the United Kingdom may develop similar levels of innovative capacity over the next several years.

It is interesting to note that several countries that have drawn much attention as potential economic powers have not been investing rapidly enough to improve their innovative capacity across economic sectors to levels similar to OECD countries. Even if one examines absolute levels of innovative activity, India, China, and Malaysia have registered virtually no international patenting through the mid- to late 1990s, in sharp contrast to countries such as Taiwan or Israel. These three countries have increased their investments in areas related to innovation, but at modest levels compared to historical innovator economies on a per capita basis. Indeed, each of these large and still developing countries are still imitators, not innovators.

While the projections suggest that none of the emerging countries will overtake the United States or other top-tier innovators in the near future, each may be able to establish itselfs among the second tier of innovator economies. Taiwan, Israel, Singapore, South Korea, and Ireland are rapidly moving from fast followers to true innovators.

Figure 2-6. Projected Innovation Index for Emerging Nations, 1993-2005



Assessing U.S. Innovative Capacity

The United States has been on a roller coaster trajectory over the past three decades in its support for innovation, as measured by the Index (See Figure 2-7). From a high starting point, the late 1970s and early 1980s were characterized by declining investments in the environment for innovation together with poor overall macroeconomic performance. During the 1980s, these trends were reversed. As a result of rising commitments to R&D spending, growth in scientific and technological personnel, and relative increases in spending on secondary and tertiary education, the United States improved both its innovative potential as well as its actual innovative performance.

Figure 2-7. Drivers of U.S. Innovative Performance Show a Static or Downward Trend in the 1990s

	1970s	1980s	First Half of 1990s
Level of R&D expenditures	↓	↑	↓
Number of R&D personnel	↓	↑	↓
Share of GDP spent on secondary and tertiary education	↓	↑	↓
Protection of intellectual property		↑	↔
Openness of market to international competition		↑	↔

The resurgence of U.S. investment in the "fundamentals" of innovation reached a peak in 1985. While investments in innovative capacity can sustain benefits for long periods of time, the data show that the innovative intensity of the U.S. economy was substantially higher through the mid-1980s than throughout the 1990s. Indeed, during the first half of the 1990s, the Innovation Index has remained essentially flat for the United States, and the value of the Index for the United States is actually lower in 1995 than it was in 1975.

The decline and stagnation in the U.S. Index over the past decade reflects several patterns:

- a decline in the growth rate of R&D funding and employment
- flat or declining spending on education as a fraction of GDP
- a fall in relative international openness
- slow growth in GDP per capita at least through the early 1990s

The decline in policy and resource commitments toward innovation—perhaps driven in part by the end of the Cold War—has occurred in an environment where increasing commitments to innovation are necessary just to stand still. It is also important to recognize that U.S. stagnation has occurred during a period in which other countries have upgraded their innovative capacity.

While no one of these factors is decisive in evaluating recent U.S. performance, their combination has contributed to the erosion of a considerable advantage in international innovation that the United States once enjoyed. While other countries have followed the lead of the United States by upgrading their innovative capacity, the United

States has gone through a period of disinvestment (particularly at the Federal level, in part because of the end of the Cold War). The end of the Cold War coincided with a concern about the ability of U.S. firms and industries to commercialize technologies, and several positive policy developments encouraged a more downstream focus (e.g., the Bayh-Dole Act or opening up Federal laboratories to partnership with industry). However, the encouragement of downstream activities seems to have come at the expense (rather than as the complement to) upstream investment in long-term assets. Overall, the United States is relying ever more on clusters to carry the load of the national investment in innovation.

Our finding of relative U.S. stagnation is not biased by the fact that some emerging technological areas, such as software and the Internet, do not rely heavily on patenting. Instead, our findings reflect the fact that growth in manpower and funding in these emerging areas has not made up for the reductions in our common innovation infrastructure and in other fields—such as defense, automobiles, or aerospace—which have long been important to the nation's innovative effort. It is also ironic that, at a time of increased availability of venture capital, there is a falling commitment to long-term R&D funding in American companies.

Recent initiatives such as the increase in the U.S. R&D budget for FY 1999 are encouraging. However, it is important to note that simply increasing the Federal R&D budget will have relatively moderate effects on the prognosis for the United States. Based on the model, even a 50 percent increase in the annual Federal R&D budget would increase the value of the U.S. Index by less than 5 percent or about 6 to 7 points in the value of the Index. By comparison, the United States Index value grew by over 60 points (or by over 33 percent) during the early to mid-1980s when a number of elements contributed to boost national innovative capacity. Simply raising Federal funding of R&D, then, will not be sufficient to materially raise U.S. national innovative capacity. Rather, a whole array of policies and resource commitments must be modified, suggesting the need for a concerted rethinking of our entire national innovation strategy.

Reconciling the Index with Current U.S. Economic Performance

At first glance, it may seem alarmist to speak of weaknesses in U.S. innovation performance at a time of steady economic growth and a greatly improved U.S. competitive outlook. It is important to understand, however, that the Index does not measure the ability of countries to be successful at a given point in time or to commercialize current technologies. The Index is not a measure of near-term competitiveness. Rather, the Index captures the potential to sustain productivity growth and competitiveness in the long term.

The declining Index score for the United States implies that its underlying environment has become relatively less supportive of innovation at the frontiers of technology. The national capacity for innovation depends on commitments to the common national innovation infrastructure as well as policies that encourage innovation-oriented competition at the cluster level. The payoffs from such commitments and choices are inherently long term. Today's prosperity is in part the function of investments and policies that were put in place as much as four decades ago. The current performance of the U.S. economy should not obscure concerns raised by the Index about the future.

The strong U.S. economic growth and improvements in wealth during the first half of the 1990s were driven mainly by increased participation in the labor force and higher returns to capital, not strong growth of aggregate productivity. Under intense competitive and financial market pressures, companies have done a better job of operating efficiently and getting products more quickly to market. While the current expansion has seen record labor force participation and profitability, *productivity* growth has lagged behind prior periods of economic expansion (see Figure 2-8).

Figure 2-8. Slower Productivity in the Economic Boom Period

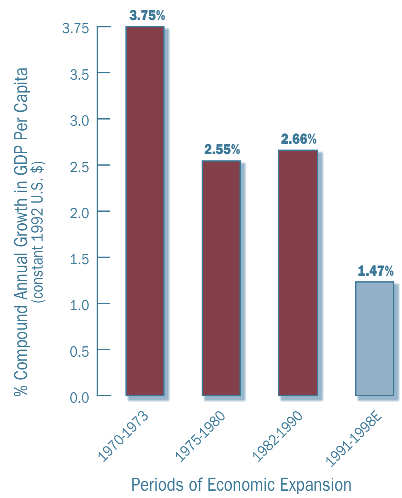
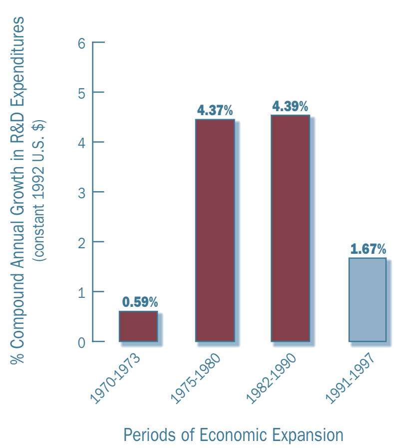


Figure 2-9. Growth in R&D Spending is at its Lowest Level since the Economic Expansion of the early 1970s



Source: Figure 2-8: U.S. Census Bureau; National Science Foundation. Figure 2-9: National Science Foundation

As a percentage of GDP, the value of total U.S. R&D expenditures is still lower today than it was during the 1980s. Moreover, even recent increases in R&D still lag behind the rate of growth that occurred in the economic expansions of the late-1970s and 1980s (see **Figure 2-9**). The only boom period that experienced a similarly sluggish growth in R&D spending was the expansion of 1970 to 1973, the years that preceding a decade-long fall in America's Innovation Index value. While one can argue that firms are using each R&D dollar more effectively, it is also true that far fewer firms seem to be investing in the more fundamental, basic research upon which others can build. While "efficient" for individual companies, the contribution of corporate R&D spending to long-term national innovative capacity may indeed be declining rather than rising.

Furthermore, total spending on basic research (typically university-based) has been declining even more steeply as a percentage of GDP than overall R&D. The decade of the 1990s saw substantial disinvestment by the Federal government in both the performance and funding of research and development—a decline that goes beyond the reductions in defense spending that accompanied the end of the Cold War. Indeed, Federal R&D as a percentage of GDP fell 26 percent between 1990 and 1997.

Even with apparently strong demand for R&D workers in many clusters, the number of workers employed in R&D has actually declined in the United States versus a decade before. In large part, this seems to reflect a disinvestment at the infrastructure level in terms of the supply of skilled technical workers. Graduate school populations in the physical sciences—and even in computer science—have been declining consistently. An ever-higher share of U.S. graduates are foreign born, but, unlike previously, leave the United States after their studies are completed. An important consequence of this shift away from scientific and engineering training is a gradual weakening of the science base and pool of talent upon which clusters can draw.

Finally, the policy environment of the United States, while not degrading, has not improved appreciably. During the 1980s, the United States achieved important extensions of intellectual property protection and was a leader in expanding international trade opportunities. At best, these policy drivers have remained static for most of this decade, while other countries have harmonized their intellectual property systems with that of the United States and greatly expanded their openness to international competition.

Taken together, these trends support the finding from the Innovation Index that the innovative capacity of the United States has stagnated and perhaps declined in a relative sense over the past decade. In the concluding chapter, we examine each of the contributors to American innovative capacity in more detail, and highlight the challenges to crafting a new national innovation strategy.

1999

CHAPTER 3

Charting the U.S. Innovation Agenda

Chapter 3:

Charting the U.S. Innovation Agenda

The Innovation Index highlights a series of policy and resource commitments that underpin national innovative capacity: the size and composition of R&D investments; the supply of technically trained workers, scientists and engineers; national policies that support innovation; and, the innovation orientation of clusters. Our findings raise serious concerns about the health of the U.S. innovation environment, with implications for both public policy and strategies and investments by the private sector.

This chapter explores the elements of national innovative capacity in greater detail. We disaggregate the broad indicators utilized in the Index into their constituent parts, and examine the historical and comparative performance of the United States. The focus is on the cross-cutting areas that make up the common national innovation infrastructure. As well, we include a short discussion of the Council's continuing efforts to enrich understanding of the health of innovation in particular clusters.

In addition, the chapter includes discussions by a group of corporate CEOs and university presidents who are central participants in the U.S. innovation effort. Echoing many of our quantitative findings, these commentaries provide further context for the challenges facing the United States going forward.

Taken together, the aim is to deepen our understanding of the findings of the Index and identify those areas requiring attention in the formulation of a new national innovation strategy.

Patterns of R&D Investment

As discussed in Chapter 2, the share of U.S. national output devoted to R&D has been flat or declining over the past decade. It has averaged about 2.5 percent of GDP versus a peak of 2.74 percent in the mid-eighties. Despite a recent uptick in total R&D spending, the United States is still committing a smaller share of national resources to R&D than in any year since 1981.

The single largest influence on the changing of U.S. R&D investment has been the disinvestment by the Federal government from all forms of research and development. The Federal share of total R&D investment dropped from nearly 60 percent of the nation's total R&D investment in 1970 to around 30 percent in 1997.

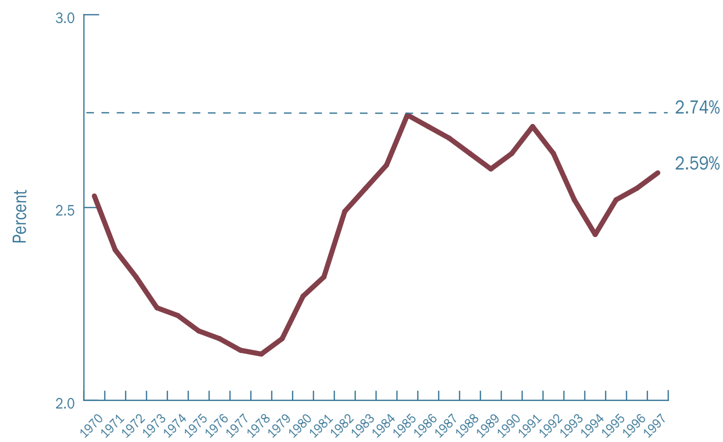
With this decline has also come a marked shift in the mix of R&D spending. The share of national resources committed to basic research has fallen from 0.45 percent of GDP to 0.39 percent. Given the broad public benefits that accrue from basic research, government, by necessity, has been the mainstay of its funding. While the Federal government contributed about 70 percent of the nation's funding for basic research through the early 1980s, the Federal share of funding for basic research has declined to 56 percent by 1997. To put this in dollar terms, had the Federal government maintained its commitment to basic research at the 70 percent level, over an additional $100 billion would have been earmarked for basic research from 1980 to 1997.

For R&D overall, investment by the private sector has partially compensated for the contraction in Federal R&D spending. The increase in industry investment, however, has been heavily concentrated in product development. The share of total private investment in basic science has also been declining. The slow upward trend in the share of GDP devoted to basic research between 1970 and 1991 has shifted to stagnation (if not decline) since then.

The lackluster growth in U.S. R&D spending does not reflect a global phenomenon. Indeed, many nations are steadily increasing both the percent of national resources committed to R&D and the higher annual growth rate of R&D spending.

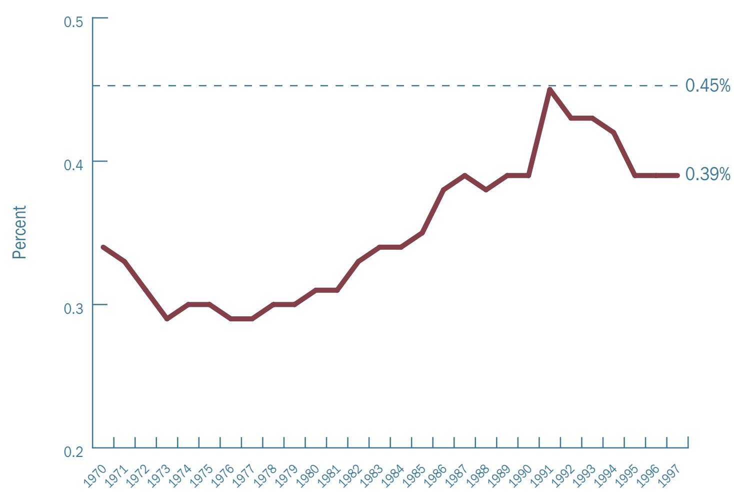
U.S. R&D spending as a share of national resources has declined since 1985.

Figure 3-1. U.S. Research and Development as a Percentage of GDP



The share of national resources committed to basic research is on the decline.

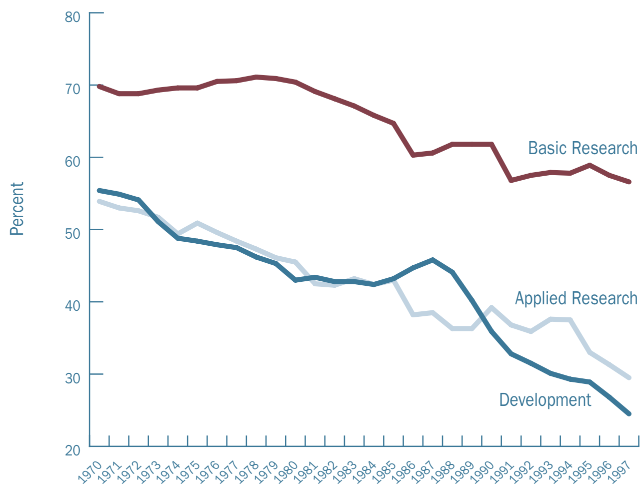
Figure 3-2. Total U.S. Basic Research Expenditures as a Percentage of GDP



Source: Figure 3-1: National Science Foundation. *Science & Engineering Indicators–1998.*
Figure 3-2: Based on National Science Foundation. *Science & Engineering Indicators–1998.*

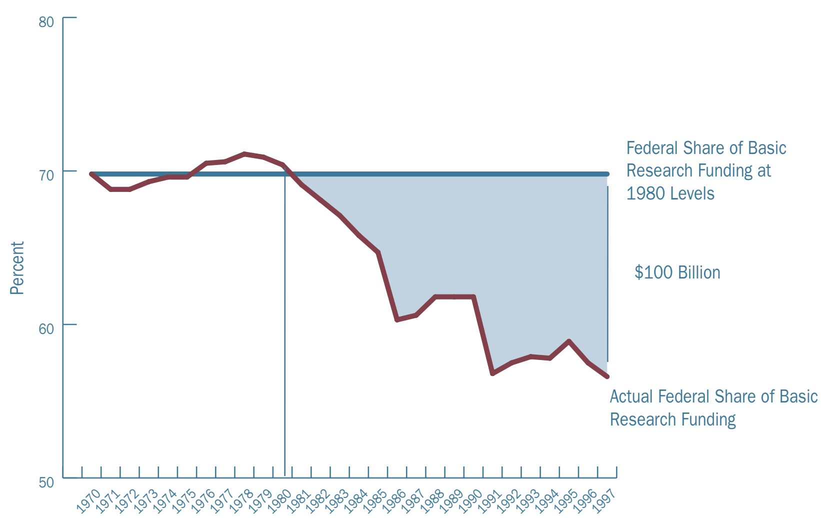
The Federal government has disinvested in all forms of research and development.

Figure 3-3. The Federal Share of Total U.S. Funding of Basic Research, Applied Research, and Development



If the Federal government had maintained its share of basic research funding at the same level as in 1980, over an additional $100 billion would have been invested in basic research.

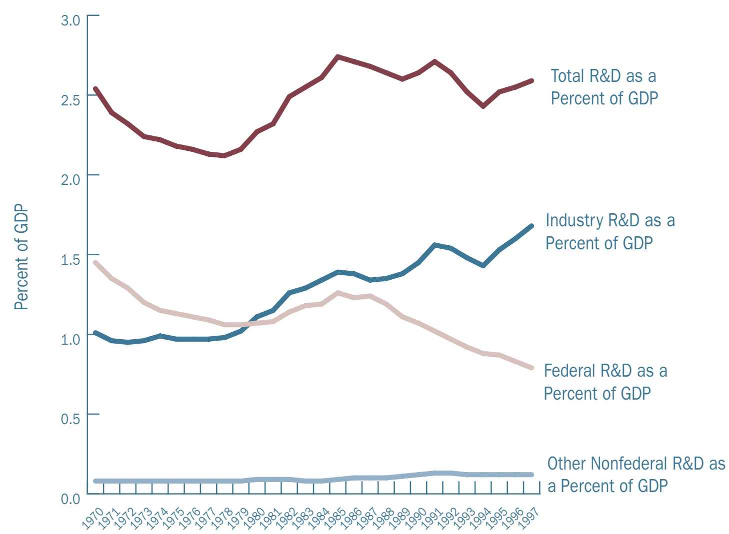
Figure 3-4.



Source: Figure 3-3: National Science Foundation. *Science & Engineering Indicators–1998.*
Figure 3-4: Based on National Science Foundation. *Science & Engineering Indicators–1998.*

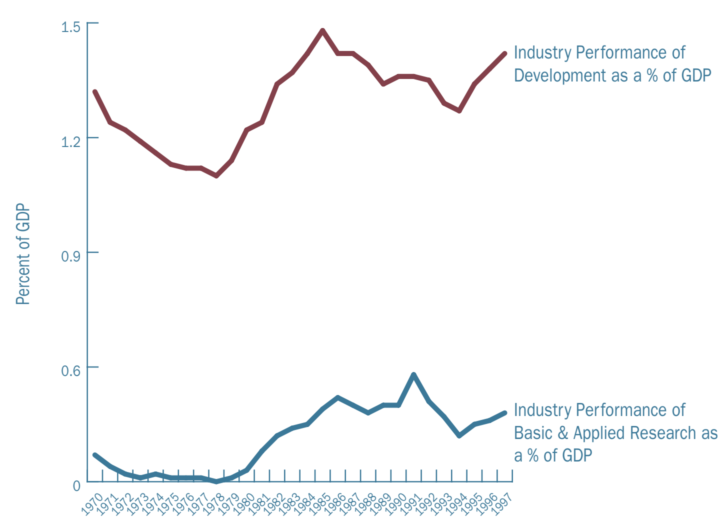
All real increases in U.S. R&D expenditures over the past decade have come from industry investment.

Figure 3-5. U.S. R&D Funding as a Percentage of GDP, by Source



But, increases in industry R&D investments are heavily concentrated in product development.

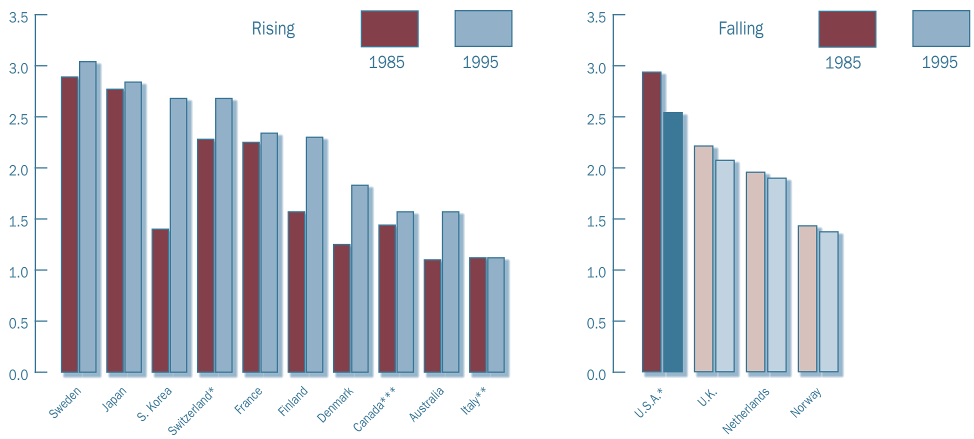
Figure 3-6. U.S. Industrial Performance of Basic & Applied Research and Development as a Percentage of GDP



Source: Figure 3-5: National Science Foundation. *Science & Engineering Indicators–1998.*
Figure 3-6: National Science Foundation. *Science & Engineering Indicators–1998®.*

Even as U.S. R&D intensity is declining, R&D intensity in much of the OECD is rising…

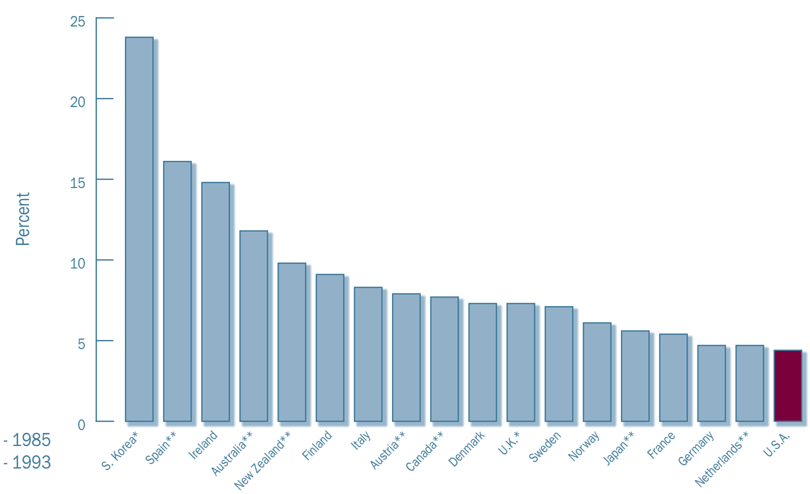
Figure 3-7. Research and Development Expenditures as a Percentage of GDP



* = 1983 and 1995; ** = 1985 and 1997; *** = 1985 and 1996

…Many nations outpace the United States in the growth of their R&D investments.

Figure 3-8. Compound Annual Growth Rate in Total R&D Expenditures, 1985-1995



* = 1984 - 1985
** = 1983 - 1993

Source: Figure 3-7: National Science Foundation and OECD.
Figure 3-8: Based on data from the National Science Foundation and the OECD.

G. Wayne Clough
President
Georgia Institute of Technology

1999

Sustaining a Vital R&D Enterprise

U.S. technological prowess is so powerful that it is tempting to assume our lead is unassailable. Yet, the commitment that built the foundation for our success today has weakened, and our global competitors are positioning themselves not only to catch up, but to pass us.

The robust economy that the United States has enjoyed over the past decade can be attributed, in large part, to sustained investment in research and development (R&D) since World War II. Today, we are reaping the fruits of the research seeds planted 20 years ago (seeds that led to the Internet, electronic commerce, life-extending biotechnological advances, more efficient transportation systems, and unparalleled defense capabilities). Along with the remarkable new technologies available to our society, previous investments in research also helped to educate generations of engineers and scientists who form an essential component of the modern workforce.

But, the R&D enterprise that propelled the United States into a leadership position is today at risk. Increasing competition has focused industry's attention to short-term research and production line development. The lack of a global military threat has reduced the sense of urgency that drove Federal research support in the past, and stresses on the Federal budget have made it more difficult to justify funding for research. Already the United States has fallen to eighteenth in the rate of growth of R&D among the nations that form our global competitors. The key elements of the old R&D model are breaking down, and a clear alternative has yet to emerge.

Research universities, dependent on external funding for their activities, are concerned about the emerging trends, but also recognize that we cannot continue "business as usual" or fight to maintain the status quo. At Georgia Tech, we are preparing to enter the new century by changing the way we do research and deliver education.

We believe that, in order to garner the support it needs, the relevance of university research has to be established by focusing on the key strategic themes that will dominate future societal and economic trends. The first involves creating approaches to enable us to work more closely with industry, particularly in assisting with research that companies in the new, highly competitive environment have difficulty performing internally. A second part of the strategy calls for the formation of alliances with the private sector and state and Federal government to leverage resources and build support for research with broad objectives. Finally, we are encouraging support for interdisciplinary approaches to research and learning through both reward and incentive mechanisms within the university and through innovative uses of facilities.

Our approach to facility design calls for the creation of high-energy learning complexes. Presently under construction on our campus is the "BEM" Complex which clusters three buildings for bioengineering and biosciences, environmental sciences, and molecular and materials sciences. The BEM Complex recognizes that solutions to tomorrow's problems will require a merging of ideas from biology, chemistry, physics, computing, nanotechnology, and engineering. A business incubator is also included to encourage the flow of ideas from the laboratory to become the products of the business world.

Keeping the R&D enterprise of the United States vital will require not only innovative efforts, but also commitment from all the entities involved. The Federal government has a role no other entity can fill, including support for basic science, national defense, space exploration, and large-scale projects like the development of the Internet.

Recent efforts show a growing awareness of the magnitude of the challenge, and attempts are being made to improve Federal research support levels. Yet a return to the days of yesteryear cannot be counted upon. We must look to increase the participation of states and industry, and these efforts must be optimized through greater use of alliances. Finally, we must better communicate the value of R&D to the public to create an understanding of its critical value to our future.

History's lessons show all too often the consequences of complacency. We have time to regain the momentum that fuels our lead in innovation over our global competitors, but only if we are prepared to create a new model that will fit the next millennium.

Human Talent Resources

At a time that seems filled with technological opportunity, the United States faces enormous challenges in both the supply of scientists and engineers and in the technological competence of the overall workforce. At a national conference sponsored by the Council on Competitiveness, over 150 top decision makers from industry, labor, universities, and the public sector ranked the quality and availability of the national labor force as the leading concern for future U.S. innovative capacity and the top priority for policy.[16]

Their concern seems well-founded. In terms of the supply of technically trained workers devoted to innovation, the number of U.S. scientists and engineers employed in research over the past decade has been flat or declining. Despite a belief by many that the U.S. innovative effort far outstrips other nations, the United States actually ranks well below other leading innovator nations in the proportion of R&D personnel in the workforce.

More important, perhaps, there are few signs that these trends will be reversed any time soon. With the exception of the life sciences, enrollment in scientific and engineering disciplines is either static or actually decreasing. The United States currently ranks exceptionally low in the number of 24-year-olds with natural science or engineering degrees. Exacerbating these trends is the fact that a large share of these technically trained graduates do not pursue careers which exploit their training.[17]

Historically, the United States has relied on a heavy concentration of foreign nationals graduating from U.S. universities to augment the nation's science and engineering labor pool. Even while a rising share of advanced degree graduates are from outside the United States, an even greater number of these students are returning home upon completion of their studies, attracted by attractive R&D job opportunities in their home countries.

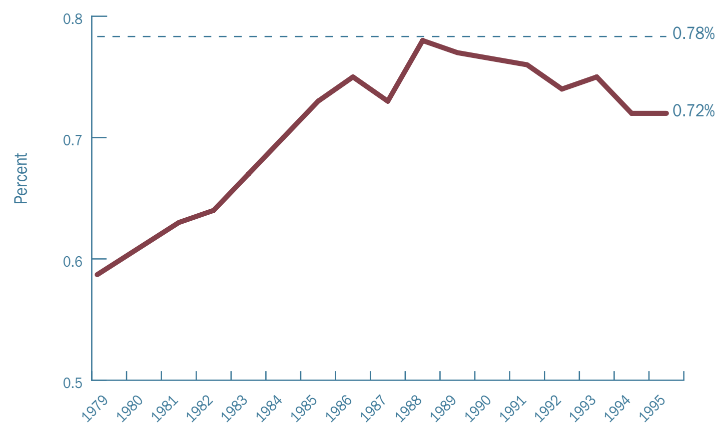
The stagnating supply of advanced technical workers seems to be at least in part a consequence of a broader, even more discouraging, trend in the American educational system. American students have performed dismally on international math and science assessments, raising concerns that the opportunities for a science or engineering career are being foreclosed early in the educational system. While the relationship between expenditures and achievement can be debated, it remains the case that public investment in secondary education now represents a smaller share of national wealth than in the majority of other OECD countries; moreover, spending on tertiary education as a percent of GDP is actually declining.

These trends also pose broader challenges. Companies fear that the overall technological competence of the workforce, so important to innovation at every stage of product development, production, and marketing process, will not be able to take advantage of new technologies. Moreover, a technically skilled workforce creates a demanding customer base. Raising the bar through their choices as consumers, well-educated and well-trained citizens focus commercialization activities on producing best-in-the-world products and technologies. As its citizens lag in technical training and educational attainment, then, the United Sates runs the risk of losing another important historical advantage.

16 The Council on Competitiveness held the first National Innovation Summit at the Massachusetts Institute of Technology on March 12-13, 1998. The Summit, which brought together 150 of the nation's top corporate, university, labor, and government leaders, sought to: emphasize the vital U.S. stake in innovation, assess national strengths and vulnerabilities, set priorities for maintaining long-term leadership, and generate momentum for the Council's two-year National Innovation Initiative. See *Competing Through Innovation,* Council on Competitiveness, 1998.
17 Burton and Parker, 1999.

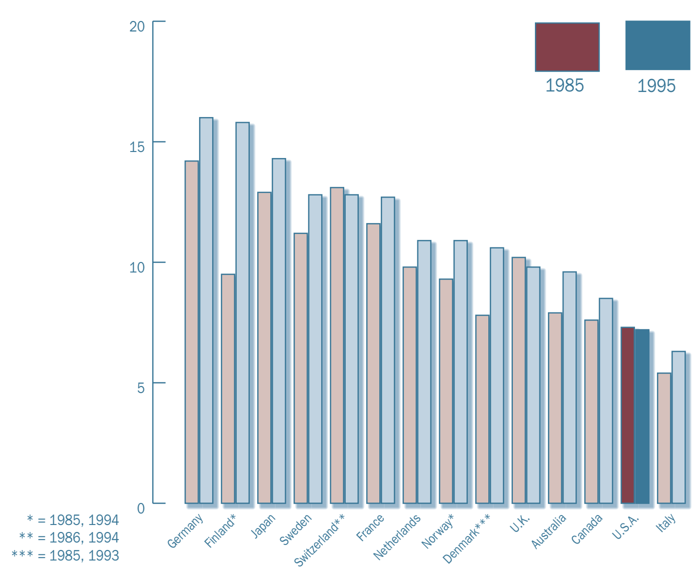
The pool of scientists and engineers engaged in R&D in the United States is a declining portion of the U.S. labor force…

Figure 3-9. U.S. S&Es Engaged in R&D as a Percentage of the Civilian Labor Force



…And is a smaller percent of the total workforce than in many OECD nations.

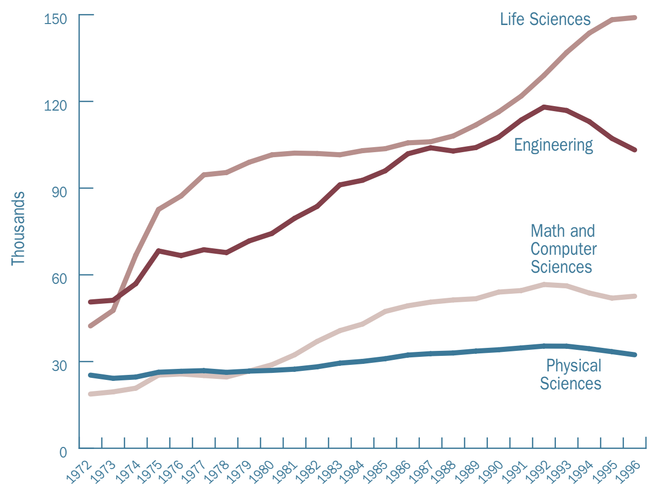
Figure 3-10. Total R&D Personnel per 1,000 Labor Force



Source: Figure: 3-9: OECD and the U.S. Bureau of Labor Statistics.
Figure: 3-10: Based on data from the World Economic Forum, IMD, and the World Book.

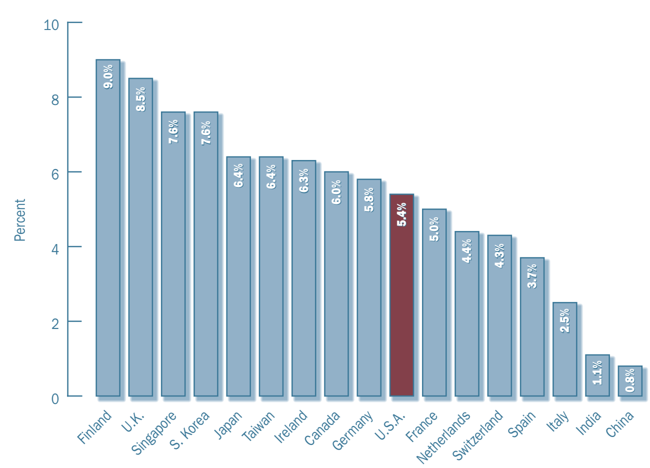
With the exception of the life sciences, graduate enrollments in physical sciences, math, and engineering are static or declining.

Figure 3-11. Graduate School Enrollments by Discipline



The percent of American 24-year-olds with natural science or engineering degrees lags behind that in both OECD and emerging economies.

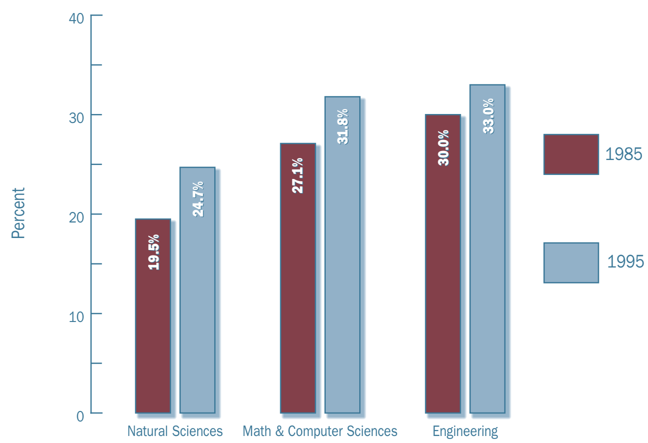
Figure 3-12. Percent of 24-Year-Olds with Life Science, Engineering, Math + Computer Science, and Physical Science Degrees



Source: Figure: 3-11: WebCASPAR Database. National Science Foundation.
Figure: 3-12: National Science Foundation. *Science & Engineering Indicators–1998.*

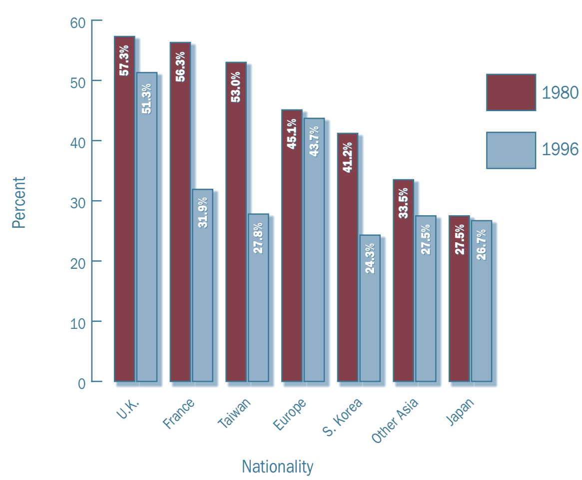
Foreign nationals make up a sizeable percentage of the science and engineering doctoral degrees earned in the United States…

Figure 3-13. Percent of Doctoral Degrees Earned in U.S. Universities by Foreign Nationals



…But, an increasing number are returning home to work.

Figure 3-14. Percent of Foreign S&E PhD Recipients with Firm Plans to Stay in the United States



Source: Figure: 3-13: National Science Foundation. *Science & Engineering Indicators–1998.*
Figure: 3-14: National Science Foundation. *Science & Engineering Indicators.*

Weak secondary school performance dims the future outlook for the U.S. science and engineering pool.

Figure 3-15. International Eighth Grade Mathematics and Science Assessments

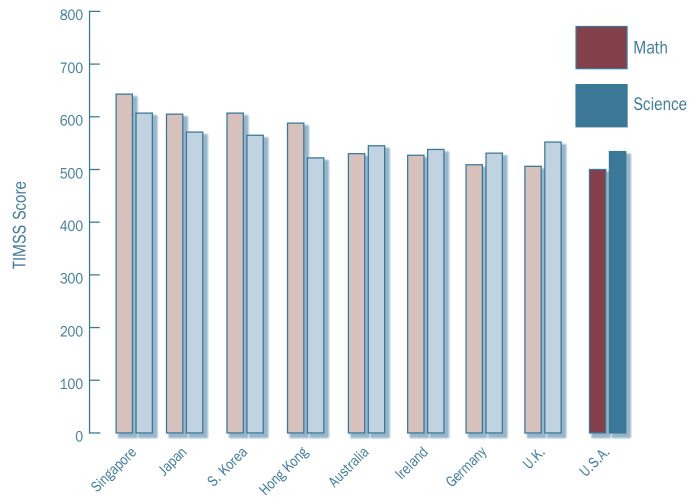
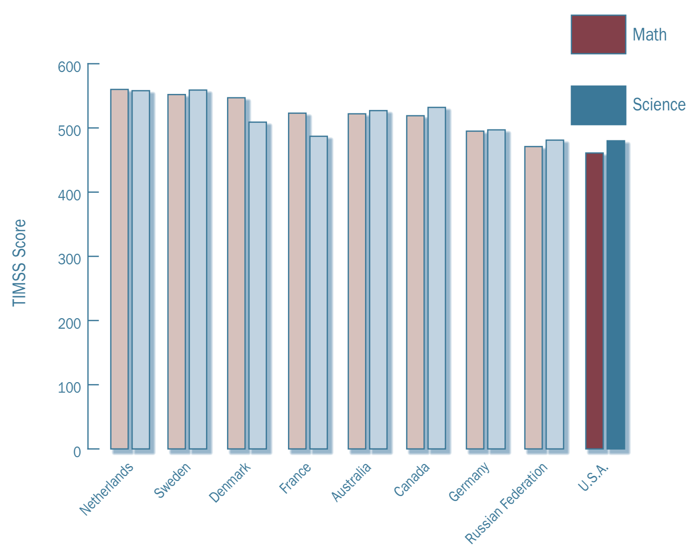


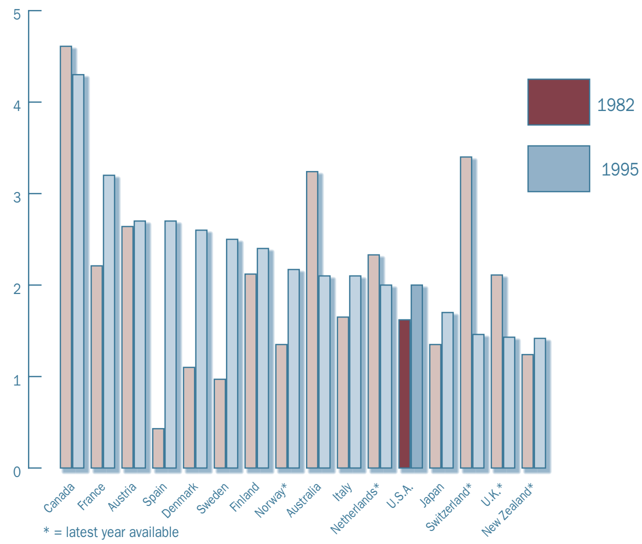
Figure 3-16. International Twelfth Grade Mathematics and Science Assessments



Source: Figure: 3-15: IEA. *Third International Mathematics and Science Study.* 1994-95.
Figure: 3-16: IEA. *Third International Mathematics and Science Study.* 1995-96.

U.S. public investment in secondary education as a share of GDP lags many OECD countries…

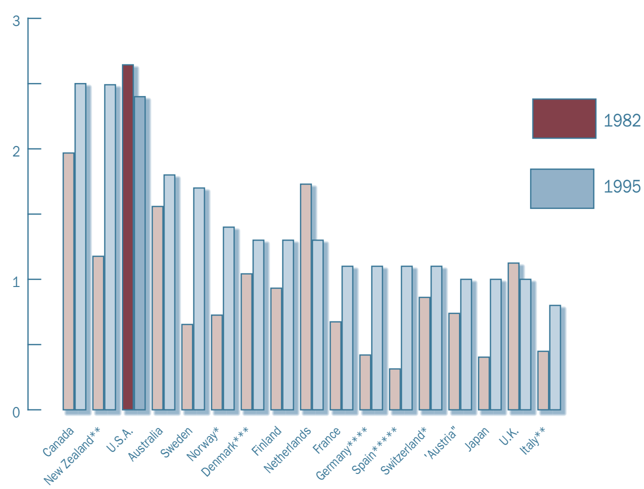
Figure 3-17. Public Spending on Secondary Education as a Percentage of GDP



* = latest year available

…And U.S. public spending for tertiary education, an area of strength, is declining as a percent of GDP.

Figure 3-18. Public Spending on Tertiary Education as a Percentage of GDP



* = latest year available; ** = 1983; *** = 1980; **** = 1976; ***** = 1979

Source: Figure: 3-17: OECD. Figure: 3-18: OECD.

Robert Berdahl
Chancellor
University of California, Berkeley

1999

Energizing the National Commitment to Education

When we look at the conditions that propel innovation, nothing is more basic or more necessary than creative, energetic, educated people. Whatever one may wish to call it—the talent pool or the work force—it is people able to generate new ideas and prepared to transform ideas into products, processes, and services who matter most.

The United States created the model of how to cultivate innovation through quality education connected with research. Take, for example, biotechnology, a field synonymous with both innovation and entrepreneurship. Universities, by nurturing scientific discovery and producing a highly educated work force, have been the catalyst for this growing industry. Today, one in three U.S. biotech companies are located within 35 miles of a University of California campus. Six of the 10 best-selling biotech drugs stem from University of California (UC) research, and 85 percent of California's biotechnology companies employ alumni with graduate degrees from the University of California.

Not surprisingly, countries eager to realize the economic prosperity enjoyed by the United States have made concerted efforts to prepare their own populations for a future of innovation. Ironically, when we look today at key work force indicators—such as student enrollment growth in engineering and the physical sciences or increases in R&D personnel—we see that the United States has begun to lag behind many other countries.

If the United States is to sustain its impressive capacity for innovation and economic competitiveness in a global, information-based economy, the country must be prepared to renew its national commitment to quality education at every level—from kindergarten through graduate research training—and to reinforce the values of life-long learning. Further, we at universities need to focus our considerable research talents on understanding how people learn and develop new models for learning to secure our powerful advantages in information technology.

At UC Berkeley, we are marshaling our intellectual and imaginative resources in disciplines across campus so that we can help improve the education of young people in California. With a program called the Berkeley Pledge, UC Berkeley students work as tutors in five neighboring school districts. Our aim is to partner with principals and teachers in these schools, which typically are in disadvantaged neighborhoods, to raise the academic performance of children in literacy, science, and mathematics. At the other end of the educational spectrum, Berkeley Extension, our continuing education arm, offers 1,200 courses to adult learners eager to keep their skills honed and themselves abreast of industry advances.

These kinds of undertakings are crucial if we are to ensure the kind of literate and technically proficient work force that future prosperity will demand. The capacity for innovation requires a refined and educated mind. As we educate our young people in what is practical and useful, however, we should also remember that nothing is more practical than critical thinking and nothing more useful than a mind that can grasp genuine complexity.

Innovation and the Public Policy Environment

Government clearly plays an important role in augmenting national innovative capacity through its support of education and research. As important, however, is the impact of the public policy environment. Numerous public policies affect the incentives and opportunities for innovation. Many of these range from tax policy to competition policy, and are captured indirectly by the Index. By including R&D spending by industry, the Index measures the overall health of the policies that encourage private investments in innovation.

However, the Index measures directly two public policy areas that are closely linked to innovative output: the protection of intellectual property and openness of markets to international trade. We delve more deeply into these two areas to reveal some of the challenges faced by the United States.

Intellectual Property Protection

Because the production of intellectual property is vital for innovator nations, most OECD countries have a long tradition of valuing and protecting intellectual property rights. After all, more than $1 billion per day is being spent on R&D in the leading innovator nations to generate intellectual property. The ability of local companies to reap the benefits of innovative activity not only sustains their future investment, but underpins national innovative capacity.

In some areas of intellectual property protection, particularly patent protection, the United States has clearly been a leader. The international harmonization of patenting standards along the lines of the U.S. model reflects an awareness of these strengths and provides an opportunity for the United States to exercise leadership.

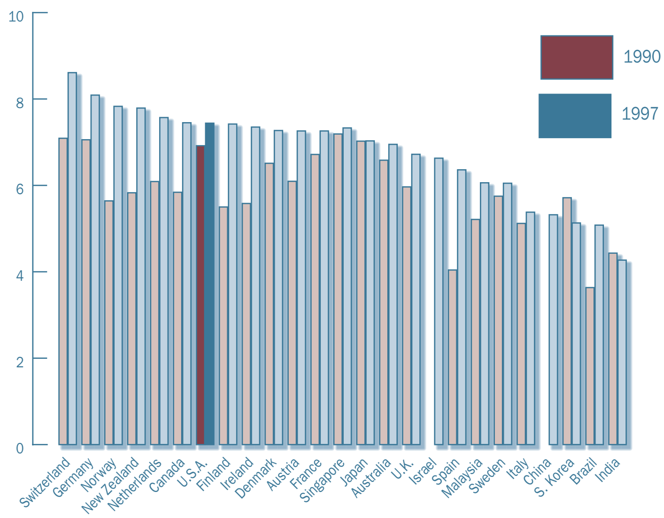
However, only a relatively small portion of all innovations is effectively protected by patents. The means of establishing and enforcing property rights through alternative mechanisms such as copyrighting or formal trade secrecy are much less developed. Particularly in emerging areas such as software algorithms and genomic information, the United States has room for improvement.

The effective protection of intellectual property is an increasingly important priority not only for the OECD but also for emerging nations. Their ability to participate in joint ventures, license technology, or attract foreign investment is clearly dependent on the strength of their intellectual property regime. More important, perhaps, is that without adequate intellectual property laws and aggressive enforcement, a country is unlikely to develop a local industrial base that relies on the generation of intellectual capital for its competitiveness.

Piracy is a growing concern that works against innovation. Copyright violations are estimated at almost $15 billion by the Intellectual Property Association. Patent infringement, where there is less quantitative data, is an equally serious problem. Tolerating piracy produces short-term gains for a country but undermines the process of economic upgrading and raising per capita incomes. Here, again, the United States can provide international leadership through the encouragement of effective and enforceable rules which encourage international competition on the basis of innovation.

Many nations are working to improve their intellectual property protection.

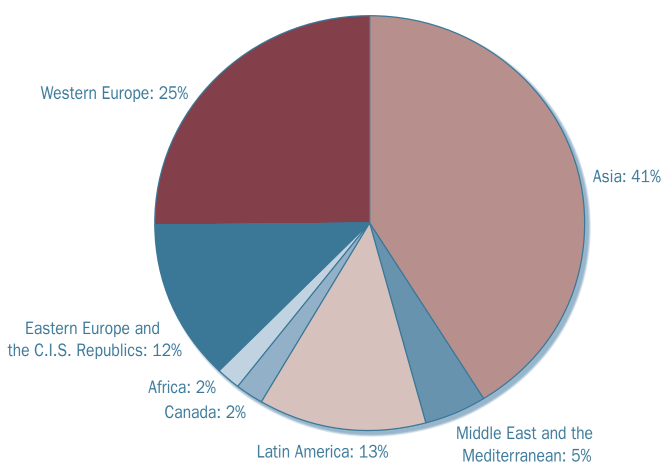
Figure 3-19. Adequacy of Intellectual Property Protection



10=ADEQUATE; 1=INADEQUATE

The United States has a compelling stake in global intellectual property protection.

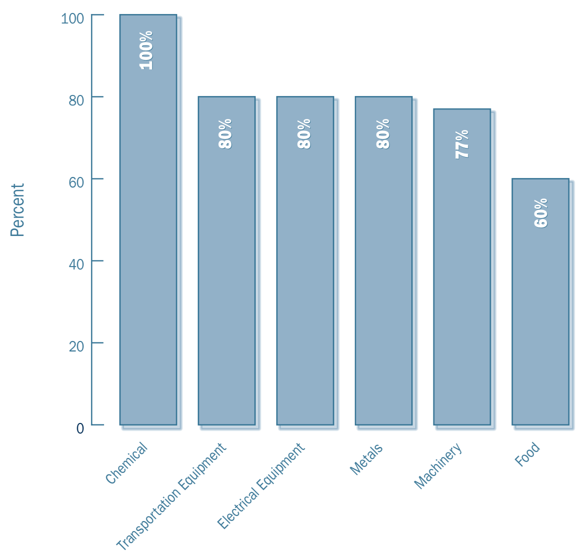
Figure 3-20. Total Foreign Copyright Piracy Losses for U.S. Industries in 1995: $14.64 Billion



Source: Figure: 3-19: World Economic Forum and IMD.
Figure: 3-20: www.iipa.com/html/worldp_piracy_losses.html.

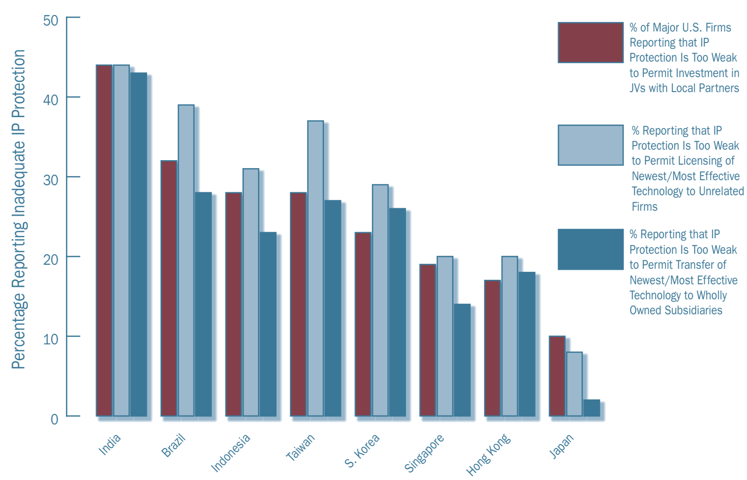
Failure to protect intellectual property slows foreign direct investment in R&D….

Figure 3-21. Percentage of Firms Indicating that IP Protection Has a Major Effect on Where They Invest in R&D Facilities



…And deters joint ventures, technology transfer and licensing.

Figure 3-22. Percentage of Firms Reporting Inadequate IP Protection



Note: Mean Percentage of All Industries

Source: Figures: 3-21 and 3-22: Mansfield, Edwin. "Intellectual Property Protection, Foreign Direct Investment, and Technology Transfer." Discussion Paper 19. International Finance Corporation. 1994.

L.D. DeSimone
Chairman of the Board and Chief Executive Officer
3M

1999

Intellectual Capital: the Keystone to Competitiveness

The capacity for innovation is embedded in 3M's culture and tradition. It has been and will continue to be the engine of our growth. At the core of 3M's capacity for innovation is a commitment to research and development that topped one billion dollars in 1997. Through this investment, we are able to offer tens of thousands of products based on our leadership in more than two dozen core technologies.

Our innovations find markets worldwide. 3M's international sales account for 52 percent—or nearly $8 billion—of total sales. We have 64 international companies around the world, 44 of which manufacture. 3M has 29 international companies with laboratories that support these businesses. Less than one percent of the employees who staff these foreign companies are U.S. nationals.

Intellectual capital is quite literally the keystone of our competitiveness. We leverage our leadership in intellectual capital to be able to move quickly and with agility. Thirty percent of each year's sales are targeted to come from products less than four years old. The four-year goal sets the tone, but in this global economy, four years is a distant horizon. We've recently added another goal that 10 percent of our sales should come from products that have been in the market for just one year.

Not so very long ago, a technological breakthrough could generate margins of leadership that would last for years. Today, the grace period of market dominance for new products and technologies is short—and getting shorter. Infringement of our intellectual capital erodes that window of leadership even further and handicaps our ability to plow revenues back into research for future innovation.

Our concerns extend to the important intellectual capital that resides in our manufacturing processes as well. Market leadership is not simply a capacity to invent new products, but depends equally on the ability to commercialize them effectively. Protecting our process technologies in overseas operations is also a high priority.

As a result, we hold back from investing in markets in which our intellectual property cannot be secured. Our posture is clearly not unique. Studies sponsored by the World Bank reinforce the message that a majority of research-intensive firms will not transfer technology to countries with weak intellectual property protections. They are less likely to license technology, participate in joint ventures, invest in R&D, or transfer the latest technology even to a wholly owned subsidiary.

For us, weak intellectual property enforcement may mean lost market opportunities and revenues. But, for those who fail to institute and enforce intellectual property protection, it is far more damaging. At stake is nothing less than the ability for countries to grow their own innovation infrastructure and raise their prosperity over the long term.

Strong intellectual property regimes create win-win solutions for companies as well as countries. Working together to achieve adequate safeguards creates synergy, innovation, and economic growth.

Market Openness

One of the defining economic trends of the past decade has been the increase in the intensity and scope of international competition. According to a recent estimate, the value of the world economy that is "globally contestable"—that is, open to global competitors in product, service, or asset ownership markets—will rise from approximately $4 trillion in 1995 to over $20 trillion by 2000.[18] Ever-increasing levels of trade and investment are only possible because of the substantial progress made in recent years in opening economies to international competition.

For companies, access to international markets creates growth opportunities that fuel investments in innovation. Most discussions of the benefits of market openness for countries emphasize the pure efficiency benefits of exploiting comparative advantage, including the availability of lower-cost goods to consumers. However, recent research suggests that the value of market openness in terms of fostering innovation and stimulating improvements in competitiveness is at least as if not more important. Market openness creates an opportunity for consumers to be exposed to new products and technologies that would simply not be available in the absence of international competition.[19] More open economies are able to absorb and benefit more rapidly from R&D activities elsewhere.[20] More broadly, openness to international competition heightens competitive pressure on domestic clusters, pushing domestic competitors to compete on the basis of innovation or be displaced by imitative lower-cost substitutes from abroad.[21] At the same time, openness frees the flow of inputs, machines, and ideas that drive new ways of competing, while creating richer opportunities for international corporate relationships.

For companies, access to international markets creates growth opportunities that fuel investments in innovation. The removal of trade barriers has coincided with a movement toward higher and steeper growth paths by liberalizing countries.[22] Consistent with this prior research, the Index finds a strong relationship between openness and national innovative output.

Since World War II, U.S. policy leadership has been regarded as indispensable to the process of global trade liberalization. However, the United States is no longer seen as setting the pace in market opening. While substantial trade agreements have been reached with our closest neighbors, these developments pale in comparison with the sea change elsewhere in the world.

Further, while formal trade barriers are declining, "behind the border" barriers, including regulatory procedures and limitations on foreign investment, persist. In these areas, the United States has the opportunity to exert leadership both by improving its own record and by fostering the establishment of rules which reward innovation in the international provision of knowledge-intensive services.

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18 Frazer, Jane and Jeremy Oppenheim, "What's New About Globalization," *The McKinsey Quarterly,* no.2 (1997): 172.
19 Romer (1994).
20 Helpman (1997).
21 Porter (1990; 1998).
22 Ben-David and Loewy(1997).

Global trade and investment opportunities have expanded dramatically.

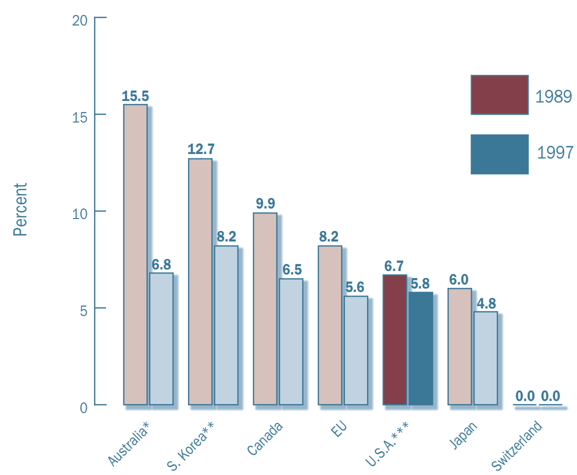
Figure 3-23.

	Before Mid-1980s	After Mid-1980s
Ratio of growth in merchandise trade to global output	1.2-1.6*	2.9*
Foreign direct investment as a percentage of global GDP	0.4-0.6***	0.9-1.2****
Royalty and licensing fees to U.S. companies	$7 billion (1980)	$29 billion (1996)

*=1950-1984; **=1984-1997; ***1970-1985; ****1990-1996

There have been broad multilateral reductions in tariff barriers…

Figure 3-24. **Mean Tariff on Manufactured Products**

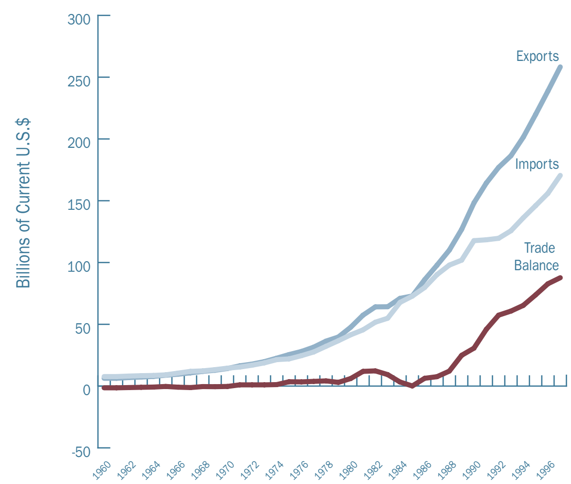


*=1991; **=1990; ***=1996

Source: Figure 3-23: Preeg, Ernest H. *From Here to Free: Essays in Post-Uruguay Round Trade Strategy* (University of Chicago Press/CSIS, 1998), p.18, with some updates.
Figure 3-24: World Bank. *World Development Indicators 1998* (CD-ROM).

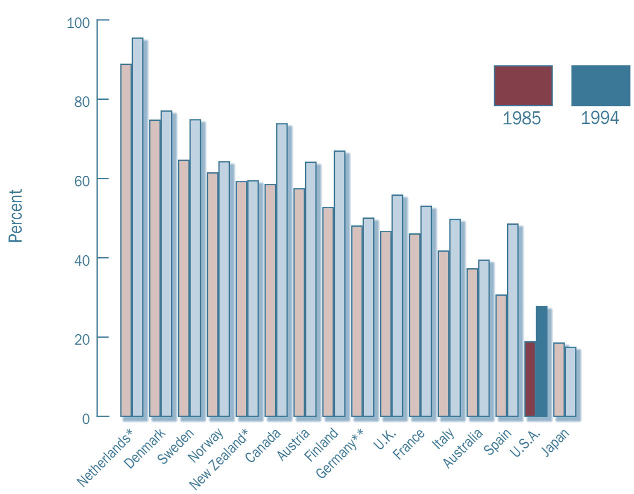
…And substantial opening of international markets in services.

Figure 3-25. U.S. International Trade in Services



Exposure to foreign competition in manufactured goods is rising in most OECD countries…

Figure 3-26. Exposure to Foreign Competition in Manufactured Goods



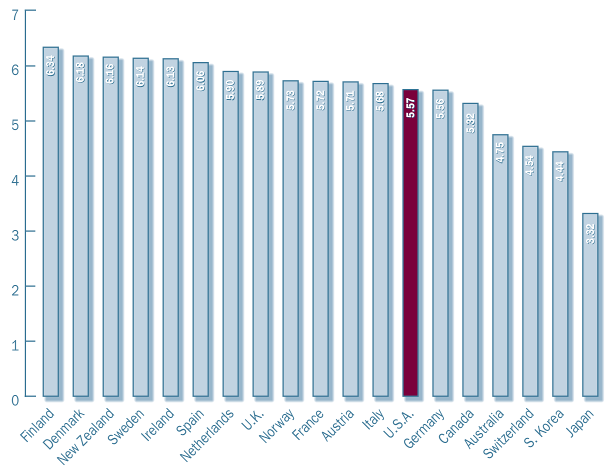
Based on ISIC 3 data: *=1993 instead of 1994; **=Figures for Germany for 1994 refer to unified Germany

The indicator is calculated as [Exports/Production] + (1 - [Exports/Production]) (Imports/[Production + Imports - Exports])

Source: Figure 3-25: U.S. International Trade Administration, Department of Commerce.
Figure 3-26: OECD, *Science, Technology and Industry Outlook 1998,* Annex Table 3.8, p. 267.

Yet, wide-ranging non-tariff barriers persist both in the OECD…

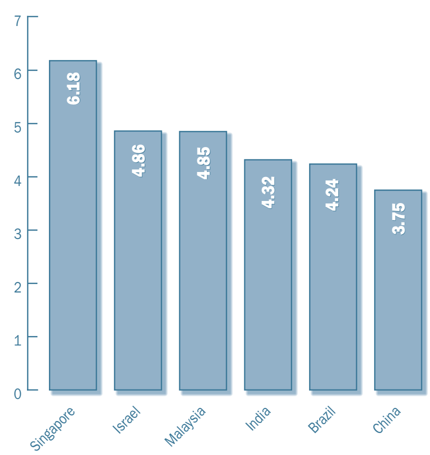
Figure 3-27. Absence of Hidden Import Barriers in the OECD



7 = hidden import barriers **ABSENT**
1 = hidden import barriers **PERSIST**

…And in the developing world.

Figure 3-28. Absence of Hidden Import Barriers in Selected Emerging Economies



7 = hidden import barriers **ABSENT**
1 = hidden import barriers **PERSIST**

Source: Figure 3-27: World Economic Forum.
Figure 3-28: World Economic Forum.

George Fisher
Chairman and Chief Executive Officer
Eastman Kodak Company

1999

Open Markets Matter

Conventional economic wisdom suggests the price of protectionism is measured in higher costs to local consumers and lost market opportunities for foreign companies.

Certainly, these are important matters. For Kodak, barriers to access are a serious concern. Overseas markets offer tremendous growth opportunities. Over one-half of the world has yet to take its first picture. In China, only about four-tenths of a roll of film is used each year per household—compared to about seven rolls of film for the United States and Japan. If we could get China to use film at the rate they do in Taiwan, it would increase the world's usage of film by 50 percent. New markets and opportunities will continue to drive our business, as long as we have the access and level playing field on which to compete.

Professors Michael Porter and Scott Stern, however, have added a new dimension to our understanding of the penalties of protectionist policies. The Innovation Index demonstrates that closing markets to outside competition puts a country's long-term competitiveness at risk. If open markets influence national innovative capacity significantly, then protectionism attacks the heart of a nation's innovation enterprise—and its innovative spirit.

Over the past three decades, significant progress has been made in lowering formal tariff barriers and eliminating quotas. But, barriers to market entry do not stop at the customs office. More obvious restraints on trade have given way to less transparent and more complex forms of protection which are even harder to challenge. The system of barriers to competition through patent, regulatory, and distribution controls creates a de facto network of government-supported anti-competition policies—policies that work directly against innovation.

Sometimes, government action to lower trade barriers, either through bilateral negotiations or through the World Trade Organization (WTO), will be necessary. Combined with sound commercial strategies, government action to tackle foreign trade barriers can help open new opportunities for U.S. firms.

The WTO has been highly successful in liberalizing trade in many areas. But, as Kodak and the world have learned, its tool kit is not adequate to deal with structural barriers to trade that are less obvious than tariffs and quotas. Leveling the playing field with respect to domestic regulatory policies poses some thorny issues that have yet to be adequately addressed or resolved.

Systemic barriers to trade must receive renewed attention as the pace of global integration accelerates. The goal must be enforceable commitments to open markets; transparent and non-discriminatory regulatory systems; and effective national treatment not only at the border but also within the domestic economy. The Index helps us to understand that this is in the interest of all nations.

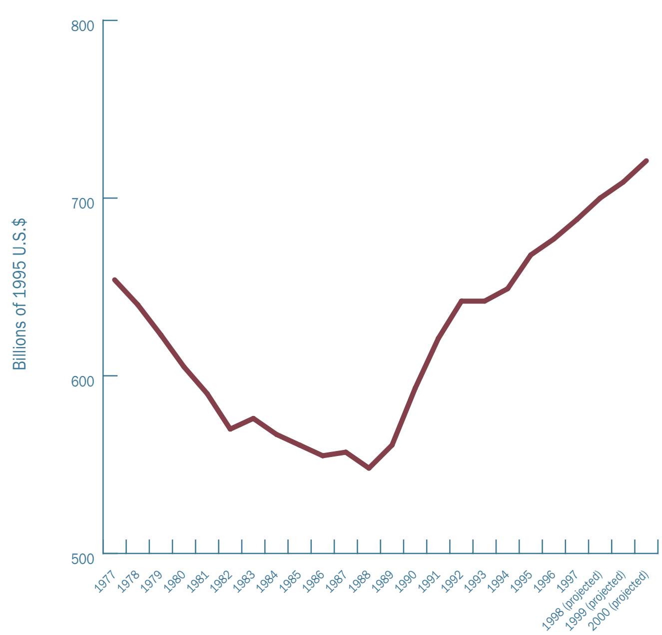
Other Legal and Regulatory Policies

In a world in which companies have many choices about where to invest, the policy framework that encourages or impedes investment in innovation is becoming ever more important. Through policy choices, government can create an array of structural incentives (or impediments) to investments in innovation. Regulatory processes surrounding new products and processes are also important. The effect of regulatory processes on cost and time-to-market has an especially strong influence on innovation.

Over the past three decades, the United States has experienced steady growth in the number and cost of regulatory requirements. Estimated costs of compliance increased from $561 billion in 1985 to $668 billion in 1995 and are projected to grow to $721 billion by the end of the decade. About a third of the total is attributed to increased paperwork requirements. Current regulatory costs are estimated to represent about nine percent of America's gross domestic product.

Costs of Regulations

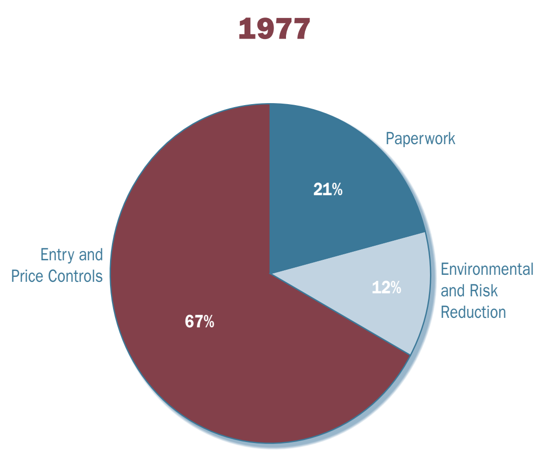
Figure 3-29. Total Regulatory Costs

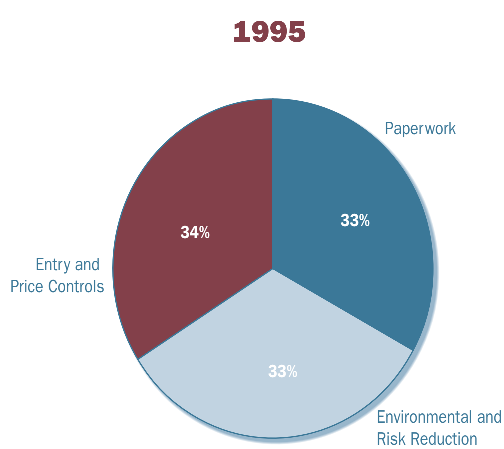


Source: Figure 3-29: Hopkins, Thomas D., *Profiles of Regulatory Costs,* U.S. Small Business Administration Contract SBAHQ-95-M-0298 (Draft Final Report, 1995) Table A.

Distribution of Regulatory Costs: 1977 vs 1995

Figure 3-30.



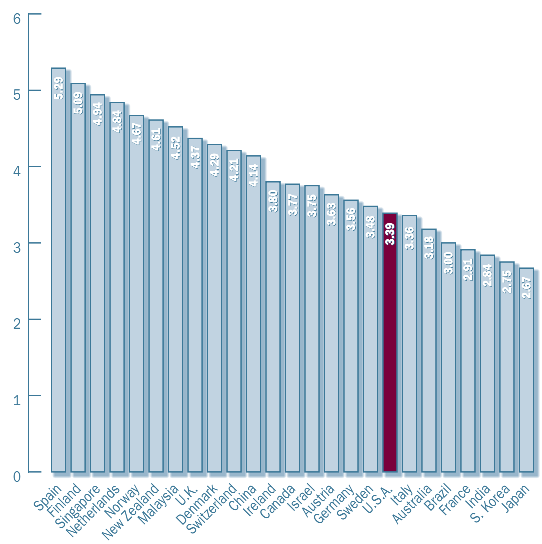


Source: Figure 3-30: Hopkins, Thomas D., *Regulatory Costs in Perspective,* Center for the Study of American Business, Washington University, 1996.

As a consequence, perhaps, the United States does rank low in international comparisons of the national regulatory environment—eighteenth out of a field of 25.

Regulation is not bad per se. Indeed, high regulatory standards for environmental protection, safety, energy usage, etc. can foster innovation.[22] The problem facing the United States is not high standards but inefficient, litigious, and time-consuming regulatory processes. The nation needs to streamline these processes and make them more flexible, and pro-innovation.

Figure 3-31. Impact of Government Regulations on Business Competitiveness



7=government regulations **DO NOT IMPOSE BURDENS**
1=government regulations **IMPOSE A HEAVY BURDENS**

According to many heads of research of U.S.-based multinationals, the United States also lags other nations in the incentives for investment in R&D, and particularly the Research and Experimentation (R&E) behind tax credit. For companies that spend heavily on research, the availability and quality of the R&E tax credit have become factors affecting the global allocation of R&D investment. In the case of the United States, the lack of permanence and predictability, limitations on the scope of qualifying activities, and relatively lower benefits obtainable compared to other countries handicap the United States in attracting investment in innovation.

22 Porter and van der Linde (1995).
Source: Figure 3-31: World Economic Forum.

International Comparison of Research Tax Incentives

Figure 3-32.

France
- 50% credit for incremental R&D expenses
- R&D buildings qualify for 50% supplementary first year depreciation
- Grants are available to assist foreign investors in locating R&D centers

Germany
- Software development costs deductible
- Loans and/or major grants for R&D or new technology may be obtained from the Federal Ministry of Research and Technology

Japan
- Tax credit is available for up to 20% of incremental R&D expenditures—including those for new product development, product improvement, and invention or design of new techniques

S. Korea
- Technology and manpower development credit of up to 50%
- Research and experimental facilities credit of 5% (or special depreciation of 50% of the acquisition cost of facilities)
- Technical license royalties are tax-exempt for 5 years
- 5-year tax holiday may be obtained for foreign investors bringing in high technology

Singapore
- Double tax deduction for R&D expenses in certain cases
- Capital investment allowance of 50% in certain cases
- Initial 25% investment allowance and 3% annual allowance for R&D buildings
- Grants of 20%-30% of the costs of certain R&D activities with potential technological benefit to the country

U.K.
- Capital grants, below-market interest loans, loan guarantees, and/or tax incentives may be granted for various R&D programs

U.S.A.
- Credit of 20% of qualified expenditures exceeding the firm's base amount (1984-88) or 1.65%-2.75% of research expenses exceeding 1% of revenues
- Credit of 20% of incremental R&D spending at universities or qualified non-profits over a fixed base period (1981-85)

Source: Figure 2-32: Council on Competitors, *Going Global: The New Shape of American Innovation,* 1998.

Innovative Capacity at the Cluster Level

The nation's innovative capacity is built on the combined strength of the common innovation infrastructure and the vitality of the environment for innovation in particular clusters. Although quantitative measures of cluster vitality are not readily available, research by the Council on Competitiveness offers substantial insight into a number of important clusters, namely health care, information technology, advanced materials, automotive, and express package transport.

This research, based on the surveys of 120 heads of R&D at companies and universities in these clusters, is summarized in **Figure 3-33.** Significantly, the subjective concerns of R&D executives about the health of innovative capacity in their own clusters closely mirror those quantified by the Index.

Figure 3-33. Concerns by Cluster

	Health	IT	Advanced Materials	Automotive	Express Package
Support for University Research	✓	✓	✓	✓	
Availability of Scientists and Engineers	✓	✓	✓	✓	✓
Graduate Enrollments in Science and Engineering	✓	✓	✓	✓	
K -12 Education Achievement	✓	✓	✓	✓	✓
University/ Government Lab/ Industry Partnerships			✓	✓	
Regulatory Environment	✓	✓	✓	✓	✓
Intellectual Property	✓	✓	✓		
Tax Policy	✓	✓	✓	✓	
Trade Policy	✓	✓	✓	✓	✓
Physical and Information Infrastructure	✓				
Availability of Risk Capital			✓		

Source: Figure 3-33: Council on Competitiveness, *Going Global: The New Shape of American Innovation,* 1998.

Jack Harding
President and Chief Executive Officer
Cadence Design Systems, Inc.

1999

Location and Innovation

It is no secret that the digital revolution—the transformational capability to move bits and bytes around the world—is changing just about every aspect of our lives. From the way we communicate, conduct commerce, educate and entertain ourselves, the personal computer—and at its heart, the silicon chip—has irrevocably transformed society.

Although it is clear that the world is and will continue to be a vastly changing place, thanks to the impact of technology, there is still considerable debate about how this era will alter the world's balance of power from an economic and competitiveness standpoint.

Leadership in the new economy will be based on the intellectual capital that a company or region may or may not have access to. This is a dramatic change from previous generations in which leadership was based on geographic advantages, natural resources, manufacturing capacity, and efficiency. In many cases, access to such resources depended either on chance or deep pockets.

But, knowledge-based businesses are less and less affected by these factors or by physical distances, boundaries, or borders. Modern telecommunications technology allows critical company assets (embodied in bytes not atoms) to be quickly and safely transferred around the globe. Even access to capital is no longer a barrier. As a result, globalization takes on a new dimension for high-tech companies looking outside the United States not just for new markets to sell to, but for new sources of intellectual capital.

In a recent survey conducted by Cadence among its blue-chip customers (leading producers of semiconductors, computers, telecommunications equipment, and other electronic products), executives indicate that the number one motivation to transfer innovation assets offshore is access to talent. This factor far outweighs any other consideration. In order of importance, executives value:

- Access to properly trained engineering talent, especially the presence of teaching and research universities that are producing well-trained engineers.
- Access to a critical mass of talent working in specific market or applications segments (e.g. digital TV, mobile communications, high-bandwidth communications).
- Proximity to customers (both the downstream companies and end consumers) and the ability to move people and intellectual property into and out of the region efficiently to support development of products for world markets.
- Presence of a supportive regulatory environment that provides an efficient and secure structure for trading intellectual property and inter-company collaboration. The security and efficiency of these trading or licensing transactions are becoming a bottleneck in some product developments.

These priorities should serve as a warning flag for the United States. Companies are looking for a total package of resources when selecting where they will locate their next investment. This package needs to include: a superior pool of talent; pro-active and collaborative government involvement on such issues as intellectual property protection; and forward-looking regulation and legislation that is developed within the context of the emerging knowledge-based economy.

By contrast, there are a few issues on which executives do not place a high priority when considering locating their investments, including:

- Desirable living standard or lifestyle.
- Attractive government incentives. This is a low priority for most design operation executives but a much higher priority for manufacturing operation executives.

My company recently made the decision to locate our largest chip design operation in Scotland, a country not traditionally considered an economic powerhouse. But, the package we were able to put together with the Scottish Enterprise, the country's main development agency, included a visionary view of its legal system and an unprecedented collaboration of the leading engineering schools at its universities. This three-way partnership of business, government, and academia should stand as a blueprint for all countries, including the United States, in how to attract, develop, and maintain an ecosystem of intellectual capital-rich companies.

To maintain our national competitiveness and continue to create wealth as a world-class economy, the United States must adopt to the rules of the knowledge-based economy. This will require new agendas not only for domestic issues such as education, government cooperation with industry and funding for advanced research, but also a more enlightened view of our role in the global economy.

Toward a New National Innovation Strategy

The Index findings make it clear that a new national consensus on the importance of innovation is needed in the United States. Outside of health care, the approach to innovation that has worked so well in the past is in need of revision. NASA remains an innovation driver, but its size and significance have fallen. National defense will continue to be an important stimulus for new technology advancement, but its sheer impact will inevitably fall. There is also a growing recognition that civilian needs are broader, more advanced in some respects, and different from those of the military. This reveals the need for a substantial program of investing in innovative capacity that is separate and distinct from defense.

A new national innovation strategy will be necessary to renew the foundations of our innovative capacity in order to ensure America's future prosperity.

First, the downward slide of federal support for R&D outside the health sciences must be reversed. But simply increasing the federal R&D budget, as desirable as this would be, is insufficient. Encouraging private R&D spending, particularly on long-term projects, and attending to the vitality of basic research at universities need to be part of the solution. Making the R&D tax credit permanent is but one example of a specific policy that would encourage higher R&D investment.

Second, the United States must rebuild its dwindling pool of scientists and engineers. This will require major changes and investments in K-12 education, together with a concerted effort to rebuild undergraduate and graduate training in technical disciplines.

Third, policies for improving intellectual property protection in areas such as copyrights must become a top priority. As a nation whose assets are increasingly knowledge based, America should be taking the lead in crafting intellectual property tools that address new forms of innovative output and new uses for it.

Fourth, historic American leadership in market-opening efforts both at home and abroad must be renewed. The United States cannot lead the world in innovation if we lack access to global markets and restrict access to ours.

Fifth, we must revisit the national regulatory environment in order to encourage innovation while maintaining high standards. In a world in which companies have many choices about where to invest, a policy framework that encourages investment in innovation is becoming ever more important.

The crux of the challenge is to rebuild the broad national consensus that created the assets upon which the nation is now drawing. That consensus, which rested for four decades on national security threats and the legacy of scientific and technical achievement during World War II, has dissolved since the end of the Cold War. It can only be restored if Americans feel a sense of urgency about the need to renew the foundations of long-term U.S. economic prosperity.

Technical Appendix and References

This Appendix provides a brief, more technical review of the procedures underlying the calculation of the Index and includes both the results from our regression analysis and the specific values of the Index for each country for each year through 1995. We proceed by reviewing the procedures associated with each of the four stages of the analysis.

Stage I: Developing a Statistical Model of National Innovative Capacity

The first stage consists of creating the database of variables relating to national innovative capacity for our sample of 17 OECD countries from 1973 to 1993. This database is used to perform a time series/cross sectional regression analysis determining the significant influences on per capita international patenting and the weights associated with each influence. A complete listing of the variables, definitions, and sources are listed in Table A-1. Table A-2 lists the 17 countries in the primary sample and the eight emerging economies examined in the analysis in Stage III. Finally, Table A-3 provides some summary statistics.

Our data draws on several public sources, including the most recently available data from the OECD *Main Science and Technology Statistics,* the World Bank, and the National Science Foundation (NSF) *Science & Engineering Indicators.* One of the key challenges in assembling such a data set is gathering comparable measures across countries and across time. As such, we subjected each of the variables to extensive analysis and checking, including confirming that the pattern of the data conformed with the comparable data provided by national statistical agencies. In addition, where appropriate, we interpolated missing values for individual variables by constructing trends between the data points available. For example, several countries only report educational expenditure data once every other year; for missing years, our analysis employs the average of the years just preceding and following. All of the financial variables are expressed in 1985 U.S.$ adjusted for purchasing power parity (PPP).

The primary measure of innovative output employed in the Index is international patent output. The data are provided by CHI Research, a leading provider of patent and bibliometric data. For all countries except the United States, the number of patents is defined as the number of patents granted in the United States to establishments located in the country. Since nearly all U.S.-filed patents by foreign companies are also patented in the country of origin, we believe that international patents provide a useful metric of a country's commercially significant international patenting activity. For the United States, we utilize the number of patents granted to establishments (non-individuals) both in the United States as well as in one other country. To account for the fact that U.S. patenting abroad may follow a different pattern than foreign patenting in the United States, we include a dummy variable for the United States in the regression analysis (the coefficient is both quantitatively small and statistically insignificant). It is crucial to recall that international patenting rates are used only to calculate and assign weights to the variables in the Index. The Index itself is based on the weighted sum of the actual components of national innovative capacity described in Chapter 2 and in Table A-1.

Our statistical model draws heavily on a rich and long empirical literature in economics and technology policy (Dosi, Pavitt, and Soette, 1990; Romer, 1990; Jones, 1998). Consistent with that literature, we choose a functional form that emphasizes the interaction among elements of national innovative capacity, namely a log-log specification between international patent production and the elements of national innovative capacity:

$$
\begin{aligned}
\text{L PATENTS}_{j,t+3} = {} & \beta_t \text{YEAR}_t + \beta_{USA}\text{US DUMMYj} + \\
& \beta_{FTE}\ \text{L FTE S\&E}_{j,t} + \beta_{R\&D\ \$}\ \text{L R\&D \$}_{j,t} + \\
& \beta_{OPENNESS}\ \text{OPENNESS}_{j,t} + \beta_{IP}\ \text{IP}_{j,t} + \beta_{ED\ SHARE}\ \text{ED SHARE}_{j,t} + \beta_{GDP/POPP}\ \text{L GDP/POP}_{j,t} + \\
& \beta_{PRIVATE\ R\&D}\text{PRIVATE R\&D FUNDING}_{j,t} + \beta_{UNIV\ R\&D}\text{UNIV R\&D PERF}_{j,t} + \epsilon_{j,t}
\end{aligned}
$$

This specification has several desirable features. First, most of the variables are in log form, allowing for natural interpretation of the estimates in terms of elasticities. This reduces the sensitivity of the results to outliers and ensures consistency with nearly all earlier empirical research (see Jones, 1998, for a simple explanation of the advantages of this framework). It is useful to note that the variables expressed as ratios are included as levels, also consistent with an elasticity interpretation.

Second, under such a functional form, different elements of national innovative capacity are assumed to be complementary with one another. For example, under this specification and assuming that the coefficients on each of the coefficients is positive, the marginal productivity of increasing R&D funding will be increasing in the share of GDP devoted to higher education. Third, to account for the delay between discovery and the awarding of patents, we impose a constant three-year lag between the components of national innovative capacity and the measure of innovative output, international patenting. As discussed further below, we evaluated the robustness of this framework to a large number of alternatives; we found that the qualitative results are consistent across a wide range of specifications, and that the chosen regression equation serves to highlight the principal empirical drivers of international patenting output.

Table A-4 reports the results from the principal regression. Each of the regressors is statistically significant and positive at the one percent level. Consistent with prior research, the time dummies δ_t ,decline over time, suggesting a substantial "raising the bar" effect over the past 25 years (see Jones, 1998, for a discussion of declining worldwide research productivity). As noted above, the coefficient on the U.S. DUMMY is quantitatively small and statistically insignificant. Further interpretation of the results from the regression equation is found in Chapter 2.

In our development of the Index, we experimented extensively along three dimensions: the components of national innovative capacity, the choice of the dependent variable, and the appropriate lag structure.[23] Along the first dimension, we explored a number of other variables that could be included in the regression equation, including measures of the methods of financing innovation in different countries, the extent of antitrust enforcement, measures of overall capital market access, and measures of the composition of R&D (e.g., research versus development; basic versus applied). In some cases, we excluded some of these variables because of data limita-

23 A full discussion of these alternatives is presented in Stern, Porter, and Furman (1999).

tions or interpretation. For example, there is no consistently comparable way to measure the division of expenditures between research and development by performer and funder (this data exists for the United States and only for selected years for a small number of other countries). In other cases, no robust statistically significant or quantitatively important relationship could be established. In particular, we found no evidence of a relationship between different private sector institutions for financing R&D (venture capital versus corporate funding) and economy-wide innovative capacity. As discussed in Chapter 2, some of these results reflect our use of intermediate measures that should capture the effects of many underlying determinants.

Second, we experimented with alternatives to international patenting as our measure of national innovative output. In one variant, we explored measures much closer to the realized commercial success of a country in technology-intensive fields (e.g., overall world market share in high-technology industries; balance of licensing payments). A second variant explored a measure more distant from commercialization, such as the production of international scientific articles. While all of these measures (international patenting, high-tech export share, and academic paper production) are themselves correlated, international patenting was decisively superior in its precise statistical relationship with the components of national innovative capacity. Moreover, both the level and accumulated stock of international patenting were found to be important statistical determinants of more outcome-oriented measures such as high-tech market share and licensing revenues. In contrast, after controlling for the level of international patenting, academic paper production could not be tied statistically to downstream commercial success (though this relationship might involve a much longer "lag" [see Adams, 1990]). Taken together, we believe that the international patenting measure is both highly correlated with other outputs of the innovative process and is a useful intermediate step between purely inventive activity and the eventual competitive advantage from application of new technologies.

Finally, we experimented with the lag structure between international patenting and the elements of national innovative capacity. Consistent with prior research, we found that a three-year lag ensured the best fit and that none of the qualitative results changed if we employed either a two-year or four-year lag.

Stage II: Calculating the Index

In Stage II, the Innovation Index was calculated using the results of the regression analysis in Stage I. The Index for a given country in a given year is derived from the predicted value for that country based on its regressors. This predicted value is then exponentiated (since the regression is log-log) and divided by the population of the country:

$$\text{Innovation Index}_{j,t} = \frac{\exp(X_{j,t}'\hat{\beta})}{POP_{j,t}}$$

One important difference between Stage I and II is that we extend the data set to include the most recent data for 1994 and 1995. While the patenting variables for these years were not yet available for inclusion in the regression equation, the data on actual resource commitments and policy choices in these years can be used to calculate the value of the Index. To make our results comparable across countries, we excluded the U.S. DUMMY coefficient in the calculation. Since it is small and constant over time, its inclusion or exclusion makes no substantive change in the results.

Table A-5 provides the Index value for each country for each year. The Index, interpreted literally, is *the expected number of international patents per million persons given a country's current configuration of national policies and resource commitments.* It is important *not* to interpret the Innovation Index as a tool to predict the exact number of international patents that will be granted to a country in any particular year. Instead, the Index provides an indication of the relative capability of the economy to produce innovative outputs based on the historical relationship between the elements of national innovative capacity present in a country and the outputs of the innovative process.

Stage III: Projecting the Index Into the Future

The third stage of the analysis began by modeling the future evolution of each element of national innovative capacity for each country. For the policy measures (intellectual property protection and openness), we assumed that the policy environment was maintained at its 1996 level. For the other variables, the projected value was set equal to its value for the last observed year (in most cases, 1995 or 1996) plus an increment which depended on the trajectory of the variable in the country between 1985 and 1995. In other words, we regressed each variable on a first and second order time term, and then assumed that the resulting slope could be used to project future changes from the last observed level. This procedure can result in extreme values based on imprecise estimates, so we were careful to check our results against this possibility.

Once these projected regressors were derived, the Index was recalculated following the procedure described in Stage II.

Stage IV: Emerging Centers of Innovation

Finally, we repeated the procedure from Stages II and III to eight emerging economies (listed in Table A-2). As noted in the main text, the data are less reliable and comparable for these countries. Most of the data came directly from national statistical agencies or the World Bank. For each country and for each variable, we gathered as much data as publicly available and, using a similar technique as described in Stage III, extrapolated the evolution of each variable into the future.

We were able to calculate the Index based on observed data for most countries up through 1995; Index estimates after 1995 are based on predicted levels of each variable. The results are dependent on the assumption that innovative capacity operates similarly in OECD and emerging economies, because we employ the same weightings that were derived from Stage I. A careful analysis of the countries that have emerged as international innovators compared to those that remain at low levels reveals that the results are driven by upgrading along several dimensions rather than a single dominant one. Hence, the qualitative nature of the findings appears to be robust across Index formulas, including the one employed here, that emphasize the strength of interactions across different areas of innovative capacity.

TABLE A-1. VARIABLES* & DEFINITIONS

VARIABLE	FULL VARIABLE NAME	DEFINITION	SOURCE
INNOVATION OUTPUT			
$PATENTS_{j,t+3}$	International Patents	Patents granted in the United States to establishments in country j in year (t+3); for the United States, the number of patents filed both domestically and in at least one other CHI-documented country	CHI U.S. patent database
QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE			
FT $S\&E_{j,t}$	Aggregate Personnel Employed in Research & Development	Full time equivalent scientists & engineers in all sectors	OECD Science & Technology Indicators
R&D $\$_{j,t}$	Aggregate Expenditures on Research & Development	R&D expenditures in all sectors in millions of PPP-adjusted 1985 U.S.$	OECD Science & Technology Indicators
$OPENNESS_{j,t}$	Openness to International Trade & Investment	Average survey response by executives on a 1-10 scale regarding relative openness of economy	IMD World Competitiveness Report
$IP_{j,t}$	Strength of Protection for Intellectual Property	Average survey response by executives on a 1-10 scale regarding relative strength of intellectual property	IMD World Competitiveness Report
ED $SHARE_{j,t}$	Share of GDP Spent on Secondary and Tertiary Education	public spending on secondary & tertiary education divided by GDP	World Bank
GDP / $POP_{j,t}$	GDP Per Capita	Gross Domestic Product in thousands of PPP-adjusted 1985 U.S.$	World Bank
CLUSTER-SPECIFIC INNOVATION ENVIRONMENT			
PRIVATE R&D $FUNDING_{j,t}$	Percentage of R&D Funded by Private Industry	R&D expenditures funded by industry divided by total R&D expenditures	OECD Science & Technology Indicators
QUALITY OF LINKAGES			
UNIV R&D $PERF_{j,t}$	Percentage of R&D Performed by Universities	R&D expenditures performed by universities divided by total R&D expenditures	OECD Science & Technology Indicators

*The natural logarithm of a variable, X, is denoted L X.

Table A-2. Sample Countries (1973-1995)

OECD DATA FROM 1973-1995 (STAGES I-III)

Australia	France	Netherlands	United Kingdom
Austria	Germany*	Norway	United States
Canada	Italy	Spain	
Denmark	Japan	Sweden	
Finland	New Zealand	Switzerland	

EMERGING ECONOMIES DATA FROM 1990-1995 (STAGE IV)

China	Malaysia
India	South Korea
Ireland	Taiwan
Israel	Singapore

*Prior to 1990, figures are for West Germany only; after 1990, results include all Federal states.

TABLE A-3. Means & Standard Deviations

OBSERVATIONS = 368	MEAN	STANDARD DEVIATION
INNOVATION OUTPUT		
PATENTS	4071.43	8421.77
QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE		
FT S&E	235153.30	397414.00
R&D $	13433.77	27418.05
OPENNESS	2.56	3.32
IP	1.53	2.77
ED SHARE	3.03	1.18
GDP / POP	18.59	5.00
CLUSTER-SPECIFIC INNOVATION ENVIRONMENT		
PRIVATE R&D FUNDING	49.12	12.76
THE QUALITY OF LINKAGES		
UNIV R&D PERF	21.21	6.16

TABLE A-4. Innovation Index Regression Model

DEPENDENT VARIABLE = L PATENTS

QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE	
L FT S&E	0.87 (0.04)
L R&D $	0.29 (0.04)
OPENNESS	0.06 (0.03)
IP	0.22 (0.04)
ED SHARE	0.15 (0.02)
L GDP / POP	0.78 (0.09)
CLUSTER-SPECIFIC INNOVATION ENVIRONMENT	
PRIVATE R&D FUNDING	0.02 (0.001)
THE QUALITY OF LINKAGES	
UNIV R&D PERFORMANCE	0.01 (0.003)
CONTROL VARIABLES	
U.S. DUMMY	-0.03 (0.08)
YEAR EFFECTS	Significant
REGRESSION STATISTICS	
R-SQUARED	0.99
NUMBER OF OBSERVATIONS	368.00

Table A-5. Historical Innovation Index, 1973-1995

Year	Australia	Austria	Canada	Denmark	Finland	France
1973					30.31	56.47
1974					28.03	48.98
1975	32.29	22.95	51.65	28.02	28.49	51.64
1976	27.05	23.15	52.00	27.87	28.87	51.52
1977	24.75	23.32	55.64	26.60	28.94	48.81
1978	23.27	24.54	55.40	27.52	29.31	52.97
1979	19.85	21.58	50.03	23.71	29.20	45.89
1980	18.60	21.55	48.96	23.11	31.02	44.98
1981	23.01	25.61	52.58	27.31	39.56	51.74
1982	27.26	26.64	68.40	30.40	45.29	56.74
1983	28.63	27.42	67.56	33.12	46.83	55.38
1984	34.75	29.35	74.81	39.68	58.14	60.58
1985	33.56	25.80	72.71	36.77	55.85	51.64
1986	38.51	31.90	79.01	46.39	72.76	53.38
1987	34.90	29.57	68.09	43.91	71.13	49.43
1988	35.85	30.17	64.88	46.78	73.67	51.65
1989	32.74	36.36	58.42	65.09	71.36	58.25
1990	35.32	26.26	51.95	62.60	53.98	52.77
1991	29.23	29.14	59.53	55.02	66.92	42.29
1992	42.10	29.28	64.93	66.10	64.77	51.17
1993	52.21	32.82	68.41	83.38	58.35	68.58
1994	51.24	33.36	56.43	75.07	62.45	65.68
1995	47.25	36.87	60.13	80.07	85.27	69.71

Year	Germany*	Italy	Japan	Netherlands	New Zealand	Norway
1973	73.70		94.63	78.21	8.41	31.05
1974	63.05		82.27	71.66	8.15	29.07
1975	66.84	17.41	77.59	67.98	8.15	31.69
1976	66.45	16.38	73.95	65.02	7.95	32.88
1977	69.23	15.33	71.08	58.61	7.47	32.15
1978	77.05	16.70	76.25	59.31	7.61	31.94
1979	71.79	14.05	67.53	50.78	6.35	30.26
1980	66.91	12.93	61.88	42.48	6.68	26.85
1981	75.94	15.82	95.08	49.03	8.58	31.99
1982	79.63	16.35	101.33	48.28	9.04	35.78
1983	80.37	16.62	117.90	47.54	9.50	38.87
1984	92.96	18.05	155.74	50.82	12.15	48.09
1985	82.80	16.58	140.55	45.87	10.85	46.36
1986	108.47	18.42	165.51	57.28	11.89	54.60
1987	102.50	18.88	153.00	54.30	10.68	48.49
1988	100.66	21.38	164.35	50.47	10.61	45.17
1989	119.32	13.48	120.82	54.34	10.27	40.76
1990	108.43	15.80	154.63	50.03	9.95	30.83
1991	108.68	19.09	183.10	49.53	9.35	35.92
1992	102.93	17.95	153.44	42.11	12.57	36.43
1993	100.66	13.61	137.48	45.25	16.13	43.59
1994	98.40	13.34	115.44	45.11	14.81	57.11
1995	104.89	13.78	119.59	48.26	19.11	56.81

* For 1973-1989, the Index value is for West Germany only.

Table A-5. (Continued) Historical Innovation Index, 1973-1995

Year	Spain	Sweden	Switzerland	U.K.	U.S.A.
1973	2.95	78.91	153.68	44.24	193.47
1974	3.22	70.40	147.76	39.18	161.11
1975	3.26	72.65	152.19	39.10	146.03
1976	3.25	70.04	142.85	40.77	143.47
1977	3.20	65.06	161.39	39.48	139.42
1978	3.41	64.11	176.93	38.86	142.71
1979	2.86	55.46	149.74	30.45	123.88
1980	3.19	58.52	139.93	28.01	115.56
1981	3.15	73.95	151.63	34.68	143.42
1982	3.34	75.63	173.34	37.32	143.47
1983	3.22	78.60	193.22	38.48	148.93
1984	4.63	100.54	220.83	44.84	184.61
1985	3.95	87.95	186.44	39.70	159.91
1986	4.54	102.08	233.45	42.04	174.72
1987	4.69	94.59	210.37	38.64	142.63
1988	5.93	92.97	213.46	38.86	147.20
1989	4.17	100.01	232.03	34.19	127.92
1990	4.76	75.18	194.39	36.23	141.78
1991	7.25	77.33	180.16	29.98	147.45
1992	6.83	78.72	149.45	28.77	133.48
1993	6.62	90.43	145.41	34.52	132.74
1994	8.00	90.83	148.24	38.29	144.53
1995	9.51	110.55	137.02	36.12	145.23

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