SCIENCE AND TECHNOLOGY

# A NEW WORLD IN THE MAKING?

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## ABSTRACT

While prospects for scientific and technological development vary across Asian countries, most states in the region see science and technology as critical for the achievement of national goals and are developing new policies for research and innovation. This chapter examines indicators of the upward trend of technological development in Asia, and interprets these in light of the globalization of science and technology, the growth of global production networks in high technology fields, and the emergence of new science-based industries. Of special note is the growing international importance of China and India, and increasing intra-regional cooperation in science and technology. These developments create new challenges for the United States in reconciling the security interests of the war on terrorism with long-term interests in maintaining international leadership in science and engineering.


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## Introduction

In recent years, scientific and technological development throughout Asia has attracted increasing attention in the United States. American surprise at the growing sophistication of Japanese technology in the 1970s and 1980s has given way to admiration for the technological achievements of the South Korean and Taiwanese economies, and more recently to attempts to understand the depth and breadth of the scientific and technological potential of India and China. As a recent report from the U.S. National Science Foundation suggests, this attention is warranted:

> A range of indicators traces a trend that shows growing competitive strength in the Asian region outside of Japan, chiefly in China, South Korea, Malaysia, Singapore, and Taiwan. Scientists based in those countries produce a growing share of the S&T articles appearing in the world's leading journals, and development of regional scientific collaboration (centered on China) is apparent. These Asian economies have an expanding world market share of high technology production. They have in place, or are instituting, policies and incentives to retain their highly trained personnel, attract expatriates, or otherwise benefit from their nationals working abroad, chiefly in United States.[1]

At the same time, the role of the United States in enabling scientific and technological development in Asia also cannot be overstated. It helps to create a mutuality of interests at work which, arguably, has not been fully recognized, but which is likely to become far more important in providing political, economic, and cultural resources for U.S. interactions with Asia. It is important that this mutuality be better understood to ensure that, in the face of immediate concerns over the war on terrorism, it is not squandered or dissipated.

A first step in enhancing understanding is to recall the historical roots of modern science and technology (S&T) development in Asia. For many of the countries of the region, these roots go back more than a century, and grow out of humiliating encounters with the West. Although the timing and circumstances differed from country to country, the anger and frustration from these encounters engendered fundamental questions of identity involving the role of S&T in culture, and the relationships between S&T and the creation and maintenance of national wealth and power. Gradually, such questions became central themes in the ideologies of modernization which have shaped the region, with the achievement of scientific and technological capabilities becoming defining characteristics of what it means to be "modern." Whether it be imperial Russia, a new Soviet Union, post-independence India, China in its Republican or People's Republican forms, Meiji Japan, or Korea under military rule, modernizing elites have placed the development of S&T high on their agendas. While wars, domestic political turmoil, misguided policies, and cultural resistance have all slowed the pace of S&T development in Asia, the fundamental equation of science and modernity has acquired deep roots in belief systems throughout the region. Thus, the evidence of growing scientific and technological capabilities that we now witness should not be surprising. These developments have deep ideological and emotional roots, and reflect decades of policy initiatives and institution building.

But, while the countries of Asia have continued to build their capabilities, S&T in the West has continued to evolve. Whereas the relationships between the trajectory of scientific and technological development in the West and Asia had been until recently rather oblique, these trajectories are now intersecting in important ways. The nature of that intersection is being shaped by the forces of globalization and by exciting new developments in knowledge itself. The countries of Asia are attempting to find those points of intersection through a variety of policy innovations for research, human resource development, and for harmonizing domestic industrial development with foreign investment.

## Reconfigurations

To understand the nature of this intersection, it may be helpful to reflect on an article appearing in a recent issue of *Fortune* magazine. Entitled "Big-league R&D Gets Its Own e-Bay," author David Kirkpatrick describes the ways in which American pharmaceutical companies are outsourcing research and development (R&D) work via the Internet. Using a global network of R&D "solvers" registered with an Internet hub called InnoCentive, companies can post requests for innovative solutions to problems at the InnoCentive site and receive creative ideas by e-mail for which they will pay, if useful, from $5,000 to $100,000. The objective is to use the Internet to tap into technical talent, wherever it might be in global society. Registered "solvers" now number more than 50,000 in more than 100 countries. While the greatest concentration of these remains in the United States, it is expected that the number in China will soon surpass them.[2]

While this approach to research and innovation is unlikely to supplant more conventional organizational arrangements, it does remind the United States that in addition to the war on terrorism, other transformative forces of globalization are at work, including major changes in the ways in which knowledge is produced and utilized in support of national security and economic objectives. For instance, as science and technology become among the more globalized of activities, the importance of spatial arrangements to create and use knowledge successfully has had to be reconsidered. Physical proximity for certain types of tasks has become relatively unimportant, as growth in international co-authoring and the rise of "distributed" R&D activities among dispersed but networked scientists and engineers illustrates. But there has also been a resurgence of spatial concentration, or "clustering," of innovative activities in order to capture the complementarities and "agglomeration" benefits of such activities.[3]

The *Fortune* piece demonstrates that the current era of industrial production is structurally quite different from 20 years ago. Whereas efficiency, technological development, and industrial prowess were once characterized by vertically-integrated organizational arrangements, current trends indicate an age of de-verticalization in which the "value chain" of business activities is broken into a number of components, or modules, which are outsourced to specialists around the world. Components are then co-ordinated electronically and reintegrated by leading innovative firms that control the intellectual property rights (IPRs), standards, and "technological architecture" of the high value-added products in the international economy, or by sophisticated "contract manufacturing" firms which "re-verticalize" the production process through globally distributed suppliers.[4] As the *Fortune* account illustrates, knowledge creation itself can be modularized in the operation of international production networks, a point demonstrated by the growth of overseas R&D investments—increasingly in Asia, with as many as 400 in China alone—by global technology leaders.

Finally, the *Fortune* article reminds us that intellectual and institutional resources for S&T—once concentrated in Europe and North America—are now more widely distributed around the world, with an increasing share in Asia. A recent UNESCO survey of R&D trends during the 1990s indicates that R&D expenditures in Asia, in purchasing power parity (PPP) terms, increased from 23 percent of the world total in 1990 to 30.5 percent in 2000, while those in North America declined slightly from 38.2 to 37.2 percent and those in Europe shrunk from 33.9 in 1990 to 27.2 percent in 2000.[5] Many Asian countries are emerging as important reservoirs of talent, and are becoming important nodes of innovation in a global network of knowledge creation and utilization.[6] These resources are being tapped for inclusion in distributed R&D tasks, or form the bases for new regional innovation clusters which are linked with clusters elsewhere in the world.

Most countries in Asia now regard their capabilities in S&T as central to the military, economic, environmental, and security challenges they face. While all understand that S&T capabilities do not provide sufficient conditions for the proper management of these issues, they nevertheless regard them as fundamental for meeting critical goals. Most countries of the region are also aware of an impending technological revolution involving nanotechnology, biotechnology, new materials, and new energy and environmental technologies (fuel cells, hydrogen, etc.). These new technologies are seen as important for solving pressing national problems, and in shaping the direction of the global economy in the coming decades.[7] Most Asian countries want to be deeply involved—as leaders, or as gainful participants—in what is perceived to be the coming industrial revolution.

In a world where security and well-being are increasingly dependent on S&T, technical talent becomes a valued resource. The management of human resources, therefore, becomes an especially important dimension of S&T policies. However, decisions over who controls and manages high-level human resources—and the institutional assets of national innovation systems more generally—in key countries in the region, is an open question at the moment. Claimants for these human and institutional resources are divided between state and private interests, defense and civilian interests, and national and multinational interests.

For many countries of the region, multinational corporations (MNCs) have been more successful in extracting value from national technical resources than national governments or national corporations. MNCs have been both agents for the globalization of S&T, as well as a source of concern to countries in the region uncomfortable with ceding their technological futures to actors only loosely accountable to national agendas. As a result, discussions of the roles of S&T in Asia must recognize that MNCs, along with states, are playing critical roles in the development of technical capabilities in the region. While national political purpose is certainly evident in the national innovation systems of Asian countries, the impact of foreign investment leads to the reconfiguration of scientific and technological development efforts in such a way that the "national" in "national innovation system" requires qualification.[8] It thus makes sense to approach a discussion of S&T in Asia with reference to a highly contingent relationship between national policy initiatives in support of national objectives ("techno-nationalism") and the new realities of "techno-globalism"—extensive international cooperation in research and global partnerships for technological innovation.[9]

## Puzzles and Ambiguities

While scientific and technological development in Asia is attracting attention, many significant questions of interpretation and assessment remain.

A recent World Bank study, for instance, suggests that despite the build-up of national innovation systems, and S&T capabilities more generally, most economies in the region still rely upon innovations from the advanced industrial countries. In this view, most countries of Asia face significant challenges of devising creative public policy to improve secondary and tertiary education, encourage innovative firms to co-locate in support of technological agglomeration, and to further exploit the opportunities available from information technology. At the same time, the study also acknowledges that pockets of excellence are emerging in the region, with signs that indigenous innovation is beginning to take root.[10] Other data call attention to notable technical achievements in the region and growing contributions to the world stock of knowledge.[11]

Interest in the development of "knowledge-based economies"[12] has underscored the importance of national innovation systems, and we see in most countries attention shifting from an older "science and technology policy" orientation to a more inclusive "innovation policy" approach which is cognizant of many of the institutional and cultural issues pertaining to knowledge economy development. At the same time, a number of other institutional, infrastructural, and cultural factors seem to be necessary ingredients, along with innovative capacity, for the development of a knowledge-based economy. Skeptics argue that these conditions are not being met in most countries of the region. Others point to the renewed efforts to deploy modern information technologies and promote use of the Internet. In Table 1, we see trends in expenditures for the promotion of information and communication technology (ICT) and in Table 2, we see patterns of Internet penetration. Both indicate considerable regional diversity, but with trends indicating commitments to greater "informatization."

As discussed further below, given the importance of S&T for national objectives, it is not surprising that Asian countries have been seeking to reform and revitalize their S&T systems. The reforms have been concerned with strengthening national basic research capabilities, establishing new incentives and institutional arrangements for linking research to the economy, finding new mechanisms for meshing the national innovation system with trends toward the globalization of research and innovation, strengthening capacities for international cooperation in science, and rethinking the relationships between military-related research and the civilian economy. Reforms appear necessary to move these countries to positions of greater capability for research and innovation, but questions remain as to their political viability and the speed which they can be effected.

With the growing concern for international cooperation in research and innovation, and the national initiatives for strengthening S&T in the region, questions about intra-regional research cooperation and regional technological integration have also become important. As seen in Table 3,

**Table 1. ICT Expenditures (share of GDP)**

| | 1992 | 1996 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|
| China | 1.9 | 3.1 | 5.4 | 5.7 | 5.8 |
| India | 1.7 | 1.8 | 3.8 | 3.9 | 2.8 |
| Japan | 5.7 | 6.4 | 8.3 | 9.6 | 5.3 |
| Malaysia | 4.7 | 5.4 | 6.8 | 6.6 | 7.3 |
| Russia | 1.5 | 1.7 | 3.7 | 3.3 | 3.7 |
| Singapore | 6.8 | 7.3 | 9.7 | 9.9 | 6.5 |
| South Korea | 4.9 | 5.9 | 6.6 | 7.4 | 6.5 |
| Thailand | 2.9 | 2.9 | 3.6 | 3.7 | 4.7 |
| Vietnam | 2.2 | 4.1 | 6.5 | 6.7 | 2.4 |

Source: *World Development Indicators*, World Information Technology and Services Alliance, International Data Corporation.

**Table 2. Internet Penetration (users per 1,000 people)**

| | 1996 | 1998 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|
| China | 0 | 2 | 17 | 26 | 46 |
| India | 0 | 1 | 5 | 7 | 16 |
| Japan | 44 | 134 | 299 | 384 | 449 |
| Malaysia | 9 | 69 | 214 | 265 | 320 |
| Russia | 3 | 8 | 20 | 29 | 41 |
| Singapore | 82 | 191 | 324 | 412 | 504 |
| South Korea | 16 | 68 | 414 | 521 | 552 |
| Thailand | 2 | 8 | 38 | 58 | 78 |
| Vietnam | 0 | 0 | 3 | 12 | 18 |

Source: *World Development Indicators*, International Telecommunication Union, World Telecommunication Development Report and Database.

intra-regional research cooperation is increasing, as Japan continues to be the central focus while China is becoming a more important collaborator.

Efforts to assess the growth of a regional system of S&T cooperation must consider how the regional fits with the global. As suggested above, sources of innovation for countries in the region still typically originate outside the region among global leaders, and this is true both for commercial technologies and academic research. While ties with the United States still constitute the main extra-regional relationship, the European Union has taken the tasks of international scientific and technological cooperation with Asia quite seriously, and has been seeking to strengthen commercial, academic, and governmental S&T relations. An especially important factor linking the regional to the global is the critical role played by diasporic communities of scientists and engineers in North America and Europe—especially from India and China—as agents of high technology development and research collaborators in cutting-edge fields.[13]

**Table 3. Intra-Asian Research Collaboration, 1986–97**

| | 1986–88 | | 1995–97 | |
|---|---|---|---|---|
| | Instances of collaboration | # co-authored articles | Instances of collaboration | # co-authored articles |
| Japan | 1,009 | 8,259 | 3,308 | 21,608 |
| China | 415 | 2,626 | 2,808 | 7,982 |
| South Korea | 191 | 686 | 1,139 | 3,892 |
| Taiwan | 157 | 754 | 599 | 2,813 |
| Singapore | 62 | 318 | 423 | 1,147 |
| Thailand | 134 | 493 | 381 | 976 |
| Malaysia | 70 | 249 | 270 | 554 |
| Philippines | 96 | 247 | 219 | 454 |

Source: National Science Foundation, 2000. Cited in Shahid Yusuf, *Innovative East Asia: The Future Growth*, Washington, DC: The World Bank, 2003, p. 211.

The linkage between technology and national security figures prominently in the S&T programs of many Asian countries, but also generates its own puzzles. Since the end of the Cold War, many Asian S&T programs have shifted toward emphasizing the importance of developing high technology, high value-added civilian production. This is not to say that military needs have been ignored. However, there seems to be a growing realization that dedicated military programs have only limited utility in the absence of a strong, technologically sophisticated civilian industrial base. This realization has been reinforced by the performance of U.S. forces in the Gulf wars and in the Balkans. The lesson seems to be that the wherewithal for modern warfare involves systems employing know-how and devices whose sophistication is derived from commercial competition. The appearance of a "dual-use" mentality, though, carries with it risks associated with the development and dissemination of dual-use technologies—risks which have become considerably more serious in an age of terrorism.

Throughout the 1990s, most countries in Asia saw the enhancement of their scientific and technological capabilities in terms of devising national strategies for exploiting the opportunities presented by globalization and the systemic changes it engendered. The policies of the U.S. government, the accessability of U.S. research universities, and the activities of U.S.-based MNCs have been among the more powerful forces behind globalization and the promotion of what we have called techno-globalism. While these forces clearly are still at play, it is also true that a rethinking of U.S. national security interests prior to September 11 had already begun a process of questioning the wisdom of an unqualified techno-globalism.[14] Since September 11, and the initiation of the war on terrorism, these concerns have come into sharper focus, and the dynamics of globalization have been altered. The significance of these changes for

Asia is complex, and the implications are subtle and by no means obvious. It is clear, for instance, that the smooth movement of professional manpower across national borders is important for techno-globalism, and that post-September 11 immigration policies are raising disturbing problems for this type of mobility. At the same time, there are a variety of countervailing forces continuing to promote the dynamics of globalization. These countercurrents raise complex policy issues, discussed below.

## Diversity of Experiences

The levels of scientific and technological development of the countries of Asia are quite different, as are efforts to build effective twenty-first century national systems of innovation. Hence, the ways in which the puzzles surrounding the region's scientific and technological development manifest themselves in particular countries vary considerably. Some commonalities exist, however, and it will therefore be useful to consider the diverse national experiences in the region in terms of the following categories.

### Global Innovator

With its large economy, technological depth, and established research tradition, Japan stands somewhat apart from other countries in the region. As indicated in Table 4, Japan has one of Asia's largest R&D workforces, with the number of research personnel per 1,000 workers in economy being among the world's highest.

Japan also excels in terms of its expenditures on R&D as a percentage of GDP, which are second only to the United States in absolute terms.[15] Most other countries in Asia pale by comparison, as seen in Table 5.

Japan's capacity for innovation is perhaps best symbolized by its patenting activity. Japanese innovators dominate the competition among Asian countries for U.S. patents, and rank second overall to those in the United States in receiving U.S. patents (the number of U.S. patents in 2001 awarded to Japanese innovators, 33,223, dwarfs those awarded to Chinese innovators, 195). Seven of the top ten companies awarded U.S. patents in 2001 were Japanese (one was South Korean).[16] While Japan is thus a world leader in innovative activities, distinctive aspects of its national innovation system set it apart from other OECD countries, and some of these features have been the source of policy concerns over the past two decades, as discussed further below.

### Strategic Science Powers

The three large continental powers, China, India, and Russia, are referred to here as "strategic science powers." Although there are major differences

**Table 4. R&D Personnel (Full-Time Equivalent), 1997–2002**

| | Researchers (thousands) | | | Researchers per 1,000 | | |
|---|---|---|---|---|---|---|
| | 1997 | 2000 | 2002 | 1997 | 2000 | 2002 |
| China | 588 | 695 | 810 | 0.8 | 1.0 | 1.1 |
| Japan | 625 | 647 | 675* | 9.2 | 9.7 | 10.2* |
| Russia | 532 | 506 | 491 | 8.2 | 7.8 | 7.5 |
| Singapore | 9 | 16 | 18 | 5.3 | 7.9 | 9 |
| South Korea | 102 | 108 | 136* | 4.8 | 5.1 | 6.3* |
| Taiwan | 47 | 55 | 59* | 5.2 | 5.8 | 6.4 |

Source: OECD *Main Science and Technology Indicators 2003*; *Indicates figure is for 2001. India data for 1997 are 1998 figures, data for 2000 are 1999 figures.

among them, their S&T systems have long shown some interesting similarities.[17] They are all rich in technical talent, as Table 4 indicates, and have extensive systems of S&T institutions which were built up over many decades. Important to note, though, is that these were established originally 1) in non-market contexts, and 2) initially were strongly oriented toward performing important strategic national security missions.[18] The pursuit of these missions have left a legacy of achievement in atomic energy and nuclear weapons, space, other military technologies, and some areas of basic research, but much less in the way of innovative commercial products. However, the combination of market reforms and the reach of globalization into these countries creates significant new conditions for the work of R&D systems, and in some ways is having the effect of "unlocking" the potential of under-utilized resources and talents.

While all of the strategic science powers have large numbers of research scientists and engineers, in both China and India, research personnel still account for a very small percentage of the total workforce. As seen in Table 5, expenditures on R&D in Russia and China are increasing, although with somewhat different patterns. At the time of the breakup of the Soviet Union, Soviet expenditures on research and development exceeded 2 percent of GDP, and were comparable to levels seen in the OECD countries. These expenditures plummeted dramatically in the early 1990s, but are gradually increasing, reaching 1.24 percent in 2002. In the Chinese case, the ratio of gross domestic expenditure on research and development as a percentage of GDP (GERD/GDP) remained quite low during most of the last 25 years of economic reforms, but has been growing steadily since the late 1990s.[19] It reached 1.29 percent in 2002. At this level, Chinese R&D expenditures, in PPP terms, had grown to the world's third largest, after the United States and Japan, according to the OECD. In the Indian case, we have not yet seen the kinds of significant increases in the GERD/GDP that are evident in China and Russia; expenditures have remained below one percent,

**Table 5. Gross Domestic R&D Expenditure, 1997–2002**

| | Expenditure ($bn PPP) | | | Expenditure (% of GDP) | | |
|---|---|---|---|---|---|---|
| | 1997 | 2000 | 2002 | 1997 | 2000 | 2002 |
| China | 25.4 | 48.5 | 72.1 | 0.7 | 1.0 | 1.3 |
| India | 13.2 | 20.0 | ... | 0.6 | 0.7 | 0.8 |
| Japan | 90.8 | 98.3 | 103.8* | 2.8 | 3.0 | 3.1* |
| Russia | 8.9 | 11.1 | 14.2 | 1.0 | 1.1 | 1.2 |
| Singapore | 1.1 | 1.8 | 2.1 | 1.5 | 1.9 | 2.2 |
| South Korea | 16.2 | 18.9 | 22.0* | 2.7 | 2.7 | 2.9* |
| Taiwan | 7.9 | 10.3 | 10.9* | 1.9 | 2.1 | 2.2 |

Source: OECD *Main Science and Technology Indicators 2003*. *Indicates figure is for 2001; India figures from UNESCO, Institute for Statistics, 2004.

reportedly reaching just 0.84 percent in 2001, but India's 2003 report on "Science and Technology Policy" calls for the GERD/GDP to reach at least 2 percent by the end of the 10th Plan (2002–2007).[20]

The strategic science powers, especially Russia, can claim many impressive technical achievements. However, their innovation systems were ill-adapted to the creation of innovative and technologically dynamic civilian economies, or for exploiting opportunities in the international economy. With the fall of communism in the Soviet Union, and the initiation of economic reforms, first in China, then in Russia and India, the national innovation systems of the strategic science powers have been undergoing reforms to make them more suitable to serve the needs of market economies. Although many of the institutional and human resources from the pre-reform systems have proven to be ill-suited to new circumstances, many others are becoming important reservoirs of talent, facilities, and traditions of research and training excellence that give the strategic science powers a special niche in Asia, which warrants particular attention. As these assets get combined with the talents of new generations of internationally-trained scientists and engineers, with the managerial skills and incentive structures of MNCs, and with the financial resources now available from national governments, national firms, and increasingly, MNCs, we are likely to see the birth of an important new early twenty-first century model of scientific and technological development of great international importance.

## Fast Followers

South Korea, Taiwan, and Singapore have seen steady and relatively rapid development of their S&T resources over the past 20 years. Starting from positions far more under-developed than the "strategic science powers," they have pursued human resource development and research policies that generally have been synchronized with creative combinations of state industrial policies and market discipline. As seen in Tables 4, 5, and 6, they are becoming important players in research and innovation.

Relying heavily on low-cost labor and imported technology during earlier phases of industrialization, the fast followers began to see their competitive advantages slipping away in the 1980s and realized that the future of their economies would require greater knowledge intensity and higher value-added production. They therefore strengthened higher education, including the introduction of graduate programs, and built up more sophisticated national innovation systems involving both government-sponsored research and policies to strengthen R&D in industry.The challenges of devising effective strategies for scientific and technological development are especially acute for the fast followers since they are subject to economic pressures from both global technological leaders and, at the low end, from low-cost manufacturers. An especially telling case is that of Taiwan, which has seen the gradual migration of much of its successful semiconductor manufacturing industry to China. Taiwanese authorities are attempting to keep the higher value-added activities of the industry in Taiwan and, in addition, the government has been actively supporting R&D in biotechnology and nanotechnology to stimulate new science based industries.[21] But, here too we see the squeeze, as Japan (as well as the United States and other European OECD countries) gear up for the new industries, while China not only enjoys low-cost manufacturing advantages, but has a relatively sophisticated research system which is already deeply involved in such fields as biotechnology and nanotechnology.

Notable in all three of the fast followers, but especially in Singapore and Taiwan, was the introduction of special science parks to encourage clustering, technological entrepreneurship, and the incubation of new high technology firms. As seen in Table 5, all three of the fast followers now have GERD/GDP ratios above 2 percent, with R&D personnel constituting an increasing percentage of total employment, as seen in Table 4. Indeed, in many ways, the term “fast followers” requires qualification, given that they now have leading roles in global high technology industry, are engaged in internationally cutting edge research in selected fields, and take an increasing share of U.S. patents.[22] In South Korea, high technology products now account for more than 30 percent of total manufacturing output, well above most other OECD countries including the United States, where the figure is just under 25 percent.[23]

## Slower Starters

Most of the ASEAN countries (other than Singapore) have experienced much slower development of their national innovation systems. All have seen considerable technological progress over the course of the past 15 years as a result of foreign technology transfers. However, their endowments of technically-trained human resources, institutional assets for S&T, and traditions of R&D trail those of countries in the other three categories.[24] This situation has dampened technological learning and made the slower starters more dependent on MNC technologies transferred to the region in connection with the surge of foreign investment in the late 1980s and the early 1990s. Most of the slower starters felt the full brunt of the Asian financial crisis, but have begun to devise distinctive strategies of "local technological accumulation" to capture greater value from their positions in global production networks. These include government policies for "technological deepening" (e.g., policies to encourage the strengthening of technological capabilities of small and medium-size enterprises), for the co-location of foreign-invested design, engineering, and R&D activities with manufacturing facilities, and for the clustering of MNC activities in particular industries. One observer refers to the these strategies as "post-national industrial policy."[25]

## Contingencies

Despite many differences, countries in all four categories are facing a number of critical questions about their national innovation systems. Most of these, in one way or another, are driven by the challenges and opportunities of new technologies (especially in biotechnology, nanotechnology, and new information technologies), and by those presented by globalization and the spread of international production networks. How these questions are handled in the near future will have important effects on the performance of the national innovation systems and their roles in global research and innovation processes.

### Institutional Reform

The challenges of institutional reform vary from country to country. Nevertheless, they are prominent for S&T policy agendas of virtually all countries. In the Japanese case, for instance, a system that had served it so well for catching up with the West began to show real problems under conditions of technological parity with global leaders, especially in light of Japan's prolonged deflationary experience of the past decade. Japan's financial and labor market arrangements, for example, produced stable, long-term commitments on the parts of both workers and employers which had been " ... conducive ... to the accumulation of firm-specific human skills and the close intra-firm (and intra-corporate-group) information sharing, which made continuous technological innovation easier."[26] However, these successful practices of the past have proven to be inappropriate for the new challenges and opportunities presented by science-based industries and changing international production networks.[27]

Concerns for Japan's competitiveness under these new conditions, thus, have called attention to the adequacy of a number of inherited institutional arrangements; in particular, the nature of university-industry relations, the IPR regime, market conditions for labor and finance to support of new startup firms, and the "R&D boundary of the firm" issues.[28] Japan has seen reform in all of these areas, with a new national approach to IPR policy, the development of a new stock market supportive of high technology start-ups, a growth in S&T cooperation agreements among companies and with universities and research institutes, and changes in the university system which make cooperation with industry much easier.[29] At the policy level, the role of S&T has been significantly strengthened by the establishment of the position of minister of state for science and technology and a new National Council for Science and Technology Policy.[30]

The problems of institutional reform in the strategic science powers have been alluded to. They start with basic problems in the political economy that stem from reforming socialism, but also involve long-standing issues of establishing effective working relationships between the research sector (long characterized by the prominence of free-standing government research institutes) and industrial sectors which have a tradition of resisting innovation and investing in R&D. Thus, a much greater share of the national R&D expenditure in Russia and India still comes from government and goes to public research institutes than is the case in the OECD countries. That was true in China as well, until the latest round of reforms began to gain traction. With more than 60 percent of the national R&D effort now coming from the industrial sector, China is beginning to look more like the OECD countries in terms of the sectoral distribution of R&D expenditures.[31] There are signs, however, that change is occurring in India and Russia as well. In India, for instance, even though the GERD/GDP has not increased notably, the share coming from private industry has increased from only 13.8 percent in 1990–91 to 21.6 percent in 1998–99.[32]

The slowness of structural reform in Russia—especially with regard to industrial research—is striking when compared with China. While reforms in the industrial research system in China have also been (and continue to be) very difficult, notable progress is now evident. Chinese enterprises, which now face increasingly stiff market competition, have begun to take the challenges of technological innovation far more seriously. As noted above, China reports that more than 60 percent of the national R&D effort is now supported by industry, and demand for technological innovation is far more evident today than just a few years ago. In addition, hundreds of public research institutes that had been under industrial ministries (a classic feature of the Soviet model), have now either been merged into enterprises or have become enterprises themselves, including 242 important national research institutes. In Russia, by contrast, it has been difficult to do away with government supported public research institutes; there were still 4,089 of them in 1999, down only 12 percent from 4,646 in 1990. The Russian government was still supplying more than 50 percent of the country's R&D funds, and Russian industry still seemed quite reluctant to take up the challenges of technological innovation. Reportedly, only 6 percent of Russian enterprises engaged in innovative activities in 1998.[33]

The problems of institutional reform in all three of these countries are daunting and rooted in the most fundamental political problems the three governments face. Thus, even after two decades of serious S&T system reforms in China, many institutional problems persist—ranging from higher education curriculum and university governance problems to serious distortions in the financial system, corruption, and a widespread lack of social trust. The persistence of such problems detract from the contributions which should emanate from the country's large pools of talent.[34] Similar institutional problems are found in Russia and India as well.

In spite of the considerable differences among the individual countries of the region and different categories of countries, there is a remarkable similarity among them with regard to reform objectives. Many of these objectives are inspired by admiration for the successes of the U.S. system. To one degree or another, the reforms are concerned with the kinds of issues William Blanpied has identified as important for Japan: developing "a strategic approach to government research investments; building a competitive research environment; enhancing the independence and mobility of young researchers; improving the research evaluation system; utilizing research outcomes by promoting cooperation among the academic, industrial and government research sectors;" and building public support and understanding for science by "enhancing communications with society."[35]

## Spending Levels and Priorities

A second crucial issue faced by all countries in the region involves levels of spending on science and technology, and the purposes to be served by this spending. This takes a number of different forms.

First, there is a question of the research intensity of the economy that is summarized by the GERD/GDP statistic. Most Asian countries have felt a need to increase research intensity and push up the GERD/GDP, although doing so often means dealing with arguments favoring acquisition of us-able technologies through international technology transfer instead. The sectoral distribution of expenditures is also an issue. The pattern for the global innovators has been for industry to assume an ever larger share of the national R&D expenditure burden, typically more than 60 percent. Various countries in the region—Japan, Korea, and China—have all been following this pattern, but many others do not. The question of levels of industrial research is also evident in other countries and is manifest in decisions about whether to conduct R&D in-house or seek technical cooperation with other firms or research centers with complementary knowledge assets. This involves the critical question of university-industry relations, an important and difficult matter of institutional reform in most countries.

While the level of commitment to research by industry is an important issue for all Asian countries, they all also recognize the importance of government expenditures, especially with regard to the high risks associated with frontier research in the new technologies. The question here involves the levels of effort to be given to R&D in support of public goods—typically with regard to defense, agriculture, public health, the environment, and basic research—and the role of targeted R&D programs in support of national high technology aspirations. With regard to basic research, it has been a political challenge in a number of the countries to enhance expenditures on basic science after long periods when applied R&D were critical components of catch-up strategies. For Japan, the fast followers, and the strategic science powers, basic research has taken on a new importance in light of the prospects for new science-based industries emerging out of biology, material science and nanotechnology, and information technology.

Making the transition from applied research traditions to greater support for basic research is complicated by the strategic national S&T programs in a number of the countries. These relatively well-funded efforts are intended, through focused research expenditures, to keep the technical communities of the various countries competitive as active researchers in support of new science-based industries. The initiation of such national programs, while welcomed by many researchers, also have raised questions about the capabilities of governments to direct programs of original research "from above," in contrast to bottom-up, investigator-initiated research favored by many scientists.

Most countries of the region have also initiated various research planning exercises intended to mobilize resources in support of strategic research opportunities. Typically, these plans lay out research objectives, develop manpower projections, set spending targets, *and* include measures for institutional reform to address some of the problems noted above. An especially interesting planning exercise at the moment is China's effort to devise a long-term, 15-year plan for the 2005–20 period. Involving some 20 working groups, the plan is expected to be the foundation for moving China toward international scientific and technological distinction by 2020.

## Intellectual Property Rights

The globalization of science and technology and the development of science-based industries has made the protection of intellectual property rights a matter of intense international attention. IPR concerns have taken on greater importance for most countries in the region and are evident in their research and innovation policies. In Japan, the patent system is undergoing extensive reform while China is seeking to significantly enhance its capabilities to protect IPR, not only as part of its obligations as a new member of the World Trade Organization, but also to protect its own innovators. Indeed, efforts to establish indigenous intellectual property claims are a central part of China's post-WTO technology policy.[36]

In his recent analysis of the challenges facing Russian S&T, Alfred Watkins calls particular attention to the confounding problems of IPR in Russia's efforts to transform its national system of innovation. The problem is not solely one of widespread pirating (as in China), or ambivalence about the imposition of new IPR standards by a global regime (as in Indian concerns over WTO obligations),[37] although both concerns are present in Russia as well. It is more a problem of ambiguities over intellectual property, who owns it, and how it should be exploited for commercial purposes. The problem stems largely from the significant achievements of the Soviet research system, and the lack of suitable institutional mechanisms during the Soviet era for defining IPR and providing for their protection. Since discoveries and inventions derived from public investments, Russia is trying to decide whether the technical knowledge produced during the Soviet period should belong to the Russian state, or not. If so, how should it now be made available for commercial exploitation? If the Russian state continues to be the principal supporter of R&D, should it continue to hold ownership of intellectual property and, if so, how will commercial value be appropriated from the progress of research?[38]

In ways that are reminiscent of Chinese frustrations over their own problems of turning scientific research findings into profitable products, but which are far more poignant in the Russian case, there is deep unease about Russia's inability to capture commercial value from notable intellectual achievements. This unease is heightened by the knowledge that the value of these intellectual achievements is instead being exploited by foreign companies, the beneficiaries of an outflow of Russian scientists and engineers resulting from the dreadful conditions for science in the initial post-Soviet years. At the same time, the unsettled and ambiguous state of IPR has threatened the kinds of foreign investment and joint venture formation which promises to stimulate Russian high technology industry, in much the same way as it did in China.

## Managing Foreign Investment

A central issue faced by most countries in the region is how to respond to foreign investment and how local research and manufacturing capabilities should fit into the production networks of the global economy. Foreign investment, and accompanying transfers of technology and managerial capabilities, have been critical factors in the technological development of the region. At the same time, the countries of Asia typically have pursued aggressive national industrial policies motivated by a deep sense of techno-nationalism and a desire to avoid technological dependency. Most now realize, however, that effective national S&T policies that do not conform to the realities of globalization are not likely to succeed. We thus see the widespread employment of strategies throughout the region which conform to what Atsushi Yamada has called "neo-techno-nationalism."[39] Such policies are intended to enhance national S&T capabilities in order to improve the national position in an international division of labor which is largely set by the global innovators. The challenge is a daunting one, but cases of success are evident throughout the region.

Nevertheless, the specter of technological dependency hangs over most Asian countries and creates a fundamental ambivalence about foreign investment. This is especially true as global innovation leaders seek to employ the best and brightest in the region through the outsourcing of increasingly sophisticated professional services and the establishment of R&D centers throughout the region. Such activities clearly enhance local knowledge and facilitate participation in high value-added production, but they also draw off valuable human resources which could be employed in support of national research and industrial development activities.

## Social Relations of Science

The dominant interest in scientific and technological development in Asia has been to foster high technology development and national strength. Voices concerned with the social relations of science, and with what might be called the "science for what?" question have not, until recently, been especially notable. This may now be beginning to change in a number of the countries. The recent Indian election was a reminder that a vast underdeveloped country still exists side by side with a high-tech "India shining."[40] In China, we see a similar reconsideration of developmental trajectories, albeit not expressed through democratic elections. In both countries, thoughtful members of the political and technical elites are asking questions about a better deployment of S&T to overcome problems of underdevelopment, and to manage the issues symbolized by ideas such as the digital divide.[41] Such concerns are evident in other countries as well. Severe environmental degradation throughout Asia, and a growing environmental awareness in the region are also making the "science for what?"question one that is becoming difficult to avoid, especially in the face of the looming technical problems associated with critical energy-environment dilemmas, and new political dynamics associated with growing tendencies toward democratization in the region.

Finally, the social and ethical impacts of new technologies are getting increasing attention. As the successful experimentation with human cloning in South Korea and Japan's recent decision to permit limited research on therapeutic cloning illustrate, the social relations of science are becoming far more salient in national S&T policy deliberations. Among other issues, differing ethical interpretations of technological possibilities may make the harmonization of regulatory systems for new areas of research more difficult. This, in turn, could privilege countries with more liberal interpretations of what types of research is ethically acceptable. More permissible attitudes toward stem cell research in Singapore and China, for instance, have had the effect of attracting scientists from other parts of the world, including the United States, where more restrictive rules are in place.

## Quality and Culture

In many countries of the region, there is also considerable concern about the conduct and quality of research. As R&D budgets increase, so have expectations as to the significance of the work being supported, in large part because of disappointments that much research is derivative and unoriginal. In a series of articles appearing in *Nature* this past spring, a number of distinguished Chinese researchers working abroad offered critiques of Chinese science, calling attention in particular to the persistence of cultural attitudes of excessive deference to authority and conformity, which discourage critical thinking.[42] In response to the articles on China, C.P. Rajendran of India's Center for Earth Science Studies, Akkulam, argued that Indian science too is plagued by the persistence of deferential attitudes and acceptance of hierarchy.[43] Similar concerns are heard elsewhere in the region, as reformers struggle to change higher education and research environments in order to stimulate creativity—or, perhaps more accurately, to change institutional arrangements which dampen the creativity of research personnel, especially young scientists.[44]

## Implications

The growth and diffusion of scientific and technological capabilities in Asia have a number of important implications in a world affected by the U.S.-led war on terrorism. Some of these are rather direct; most, however, are somewhat more oblique.

### Role of Asia in International Science

In the first instance, the growing Asian scientific capabilities are having important effects on international science. This is evident in such output measures as contributions to the world scientific and engineering literatures, the growth of patenting, and the expansion of high technology exports.[45] With strong government support for science, and with steadily improving institutions for higher education—and some cases, institutions with long-standing international reputations for excellence—Asian educational systems are making notable contributions to the global supply of scientists and engineers, as Table 6 indicates.

Most of those in the cohorts of new graduates, of course, remain in their home countries where they are advancing the research enterprises and technological levels of the domestic economies. They anchor the domestic innovation systems and serve as the local counterparts of research and engineering personnel from Europe and North America. A small, but significant proportion of those in these manpower pools develop careers in international science and play important roles in research and advanced training in leading corporate, academic, and government research centers. Of growing importance is a third group, the members of which are playing increasingly important roles in bridging activities at the global research centers with those of the national innovation systems in the region—as visiting professors, holders of special academic appointments, and as key managers of MNC knowledge production in Asian countries.[46]

### Role of Asia in Global High Technology

Asia plays an increasingly important role in high technology trade. It is the growing source of many high-tech products and absorbs high technology exports from Europe and United States. The combined high technology exports from China, South Korea, Malaysia, Singapore, and Taiwan, for instance, increased from roughly 8 percent of the world's total in the early 1980s to almost 28 percent in 1999.[47] However, a central issue in the role of Asia in global high technology is that of the terms of trade, reflected in debates throughout the region on the relative and absolute gains from trade in high technology products.

**Table 6. Earned Doctoral Degrees, 1991–2000**

| | All Fields | | | Science/Enginnering | | |
|---|---|---|---|---|---|---|
| | 1991 | 1995 | 2000 | 1991 | 1995 | 2000 |
| China | 2,556 | 4,364 | 11,383 | 1,198 | 3,417 | 7,304 |
| India | 8,374 | 9,070 | ... | 4,212 | 4,000 | ... |
| Japan | 10,758 | 12,645 | 15,357 | 3,874 | 5,205 | 7,089 |
| South Korea | 2,984 | 4,462 | 6,143 | 1,135 | 1,920 | 2,865 |
| Taiwan | 410 | 848 | 1,400 | 370 | 650 | 931 |
| United States | 37,534 | 41,743 | 41,340 | 24,022 | 26,536 | 25,951 |

Source: National Science Board, *Science and Engineering Indicators*, 2004.

As the impressive developmental experiences of most Asian countries indicate, notable absolute gains have been realized from participation in the global high technology economy. However, relative to the gains made by global high technology leaders, whose investments in the region have been so important to stimulate economic growth and technological development, these absolute gains are sometimes seen as disappointing, unfair, or both, in large part because the terms of trade are largely the result of a production system designed and controlled by those outside the region. It is for this reason that IPR issues have become so important—those who control the IPR enjoy significant economic advantages[48] and structural power.[49] Thus, much sharper focus is being given to enhancing the innovative capabilities of national firms through the encouragement of increased R&D, other incentive programs, and restructuring. Clearly, the ability to alter the terms of trade vary considerably from global innovator Japan, with its demonstrated success in doing so, to the slower starters. For the latter, it will be decades before strong traditions of advanced science and engineering education and research excellence are established, and until then, a measure of technological dependency is unavoidable. Nevertheless, aggressive policy responses designed to assimilate technology and enhance human resources can improve their relative positions.

The relative gains/absolute gains issue is more complex and more interesting as it affects the strategic science powers, the fast followers, and the relationships between these two categories of countries. The fast followers have clearly indicated considerable sophistication in changing the terms of trade and moving up the value chain in global production networks. In selected areas of high technology, they are establishing themselves as original innovators and have also begun to build world-class scientific research projects in selected fields. On the other hand, they are under enormous pressures from lower-cost producers in the region and from the ongoing flows of innovation emanating from the global innovators in Europe, North America, and Japan.

For the strategic science powers, the relative gains/absolute gains challenge plays itself out in somewhat different ways. In all three, there is a consciousness that their large well-established research systems should be generating streams of innovation for new products and processes, permitting new opportunities for absolute gains. On the other hand, the persistence of institutional obstacles from the pre-reform era frustrate the realization of these aspirations, and work to reinforce their subordinate positions in global production networks and the international division of labor. The enormous pools of inexpensive labor in India and China, and the natural resource endowments of Russia strongly influence natural comparative advantage and deflect attention from efforts to break out of positions of technological subordination through research and industrial policies. Nevertheless, as we have seen, all three are also taking the challenges of building innovative capabilities from their R&D establishments much more seriously, and in all three IPR concerns figure prominently.

One of the more interesting issues to be monitored for understanding the directions of S&T in Asia is the relationships that develop among the strategic science powers and between them and the fast followers. The potential for the latter is perhaps most evident with China as it builds a variety of commercial, governmental, and academic S&T relationships with South Korea, as Taiwan's information technology (IT) industry becomes ever more intertwined with that of China's, and as Singapore and China pursue more intimate ties (as illustrated, for instance, by the employment in Singapore of Chinese researchers, many of whom have received advanced training in the United States). Relations among the strategic science powers are also intriguing, as shown in the exploratory patterns of cooperation between the IT industries in India and China, and in Sino-Russian cooperation in defense technologies.

Regardless of the development of relations between the strategic science powers and the fast followers (and, indeed, among the strategic science powers themselves), the strategic science powers are sure to play a more important role in global high technology development. MNC global technology leaders are showing increasing interest in the science and engineering talent found in the strategic science powers and seek to exploit the professional achievements and cost advantages they offer. There is much potential to save on personnel costs through outsourcing of R&D and professional services to countries such as China and India. Whereas the salary of an engineer in the United States may average $70,000, a comparably skilled and educated counterpart would average only $25,690 in China, and an enticing $13,580 in India, according to one estimate.[50] MNCs have been developing more sophisticated commercial intelligence to identify opportunities to invest in these talent pools, and we are seeing an increase in outsourcing of R&D and sophisticated technical services to these countries to the point where the future health of the research and innovation enterprises in United States is questioned.[51]

## Security Issues

The evolution of science and technology in Asia carries a number of implications for security. However, these are not all entirely straightforward. On one hand, national programs to enhance technological capabilities combined with gainful participation in international production networks are raising general technological levels that cannot help but be supportive of the defense industrial bases in the region. Capabilities in support of dual-use technologies will surely improve, positive spillovers for defense technologies can be expected, and technological resources of use to terrorists are likely to become more available.

At the same time, the current trajectory of scientific and technological change in Asia is very much tied to the dynamism of civilian economies and the play of market forces. While dedicated military programs continue to be important for countries in the region, there seems to be a widespread recognition that military modernization through such programs cannot be achieved in isolation from a dynamic civilian economy. Thus, if the enhancement of technological capabilities is inseparable from active participation in the global economy, we should expect that the fundamental political orientation of countries in the region should be toward de-emphasizing defense policy and promoting instead domestic reform and the international institutions supporting liberalized trade and investment.

Yet, should priorities change as a result of altered perceptions of the security environment, military modernization programs would be a more efficient and effective process once they are part of a more vibrant civilian technological system. Thus, the relationships between national security programs and civilian research and innovation activities bear watching. For instance, a Chinese space program embedded in a technologically dynamic civilian economy is likely to be far more effective than the high priority strategic weapons programs of the past, which were isolated from the civilian economy, and where the economy itself was far less dynamic. Especially in the strategic science powers, there is also an interesting issue dealing with the diffusion of knowledge through institutional and informal personal networks linking civilian activities and security programs.[52] Given the important roles that the latter played in the scientific and technological development in these countries, and that a number of scientists and engineers who are now playing key roles in the civilian economy came out of such programs, it would only be natural to assume that there is a fair degree of diffusion and cooperation occurring.

A special set of security issues pertain to Russian science and the employment of scientists out of the weapons programs of the former Soviet Union. Special programs—such as the Civilian Research and Development Foundation and the International Science and Technology Center—initiated by the United States, the countries of Western Europe, and Japan, have attempted to support Russian researchers in the pursuit of peaceful avenues for science, and to prevent their recruitment into clandestine weapons programs being sponsored by states or non-state actors. A further reinvigoration of the Russian innovation system in support of a more competitive civilian economy will work to reinforce these objectives.

## Challenges and Opportunies for the United States

The security implications for the United States from the enhancement of Asian technological capabilities take various forms. Countries of the region can use strengthened technological capabilities to improve their own military positions. A major concern in the United States at the moment is Chinese efforts to use information technologies to enhance China's ability to prevail in asymmetric conflicts. On the other hand, more sophisticated technological capabilities in the hands of traditional allies, such as Japan, have led—and will continue to lead—to opportunities for mutually beneficial cooperation with the United States on defense technologies.

Growing scientific and technological sophistication in Asia also, inevitably, means that dual-use technologies will be further diffused throughout the region, and will be more available to non-state actors bent on hostile acts. The 1995 Aum Shinrikyo gas attack on the Tokyo subway system, involving the cooperation of technically trained individuals and delusional fanatics, is a reminder of the vulnerability of society to the misuse of scientific and technical knowledge. In an age when a range of new technological opportunities are emerging from exciting new fields of science, but in the context of a global terrorism threat, there is clearly a need for much more attention to the security of R&D and production facilities and to effective policies for regulating potentially harmful substances, devices, and processes. There is much the United States could do by working with the countries of Asia to disseminate best practices in these areas. At the same time, it will be a challenge to all parties to ensure that the pursuit of new levels of security does not compromise traditions of open exchange on which creative science and successful innovations depend.

Construing security implications more broadly, it is useful to recall that countries in Asia face a number of national problems that are characterized by 1) having significant technical content, and 2) important transnational implications which ultimately affect the United States. These include matters of agriculture, public health, energy, and the environment. The United States maintains important bilateral relations with a number of countries in the region that address some of these issues. As the problems themselves become more significant, especially the complex interrelationships among energy supplies and global environmental change, the United States should be using its ties with the countries of Asia to build on the growing capabilities in the region for more enhanced cooperation in the face of these challenges. The U.S. government maintains active S&T cooperation agreements with Russia, India, China, Japan, and Korea, and these all provide opportunities for cooperation with countries in the region on these significant problems. As Asian capabilities increase, so too will opportunities for mutually beneficial research.

In many ways, though, the most important implications for the United States of the growth of S&T capabilities in Asia involves the health of the U.S. system of innovation. There is a growing body of thought in the United States that future economic well-being and national security are dependent upon the maintenance of U.S. comparative advantage in advanced S&T development.[53] If this assumption is true, then we must be asking ourselves whether the growing technological capabilities of Asia are best seen as imposing new competitive challenges or as a source of new opportunities. In many ways, they are both.

The health of the U.S. innovation system has long been improved by the many contributions made by scientists and engineers from around the world to its academic science and industrial research. The countries of Asia send the greatest number of foreign students to the United States, a large percentage of these are in science and engineering, and many remain in the United States in academic and industrial positions. But, as the innovation systems in Asia improve, including the improvement in Asian institutions of higher education, it is inevitable that the institutions of the U.S. innovation system will increasingly be in competition with their Asian counterparts for these talents.[54]

This is a competition in which the United States should prevail, but the extent of the challenge must be appreciated. We should recognize, in the first instance, the extent to which the U.S. economy, and the opportunities for employment it generates, is based on science and engineering. Since 1980, for instance, the number of science and engineering positions in the U.S. labor force has risen more than four times faster than employment opportunities in general.[55] Foreign-born scientists and engineers have played an important role in filling these positions as the appeals of study-ing science and engineering among U.S.-born students has declined. The science and engineering workforce, however, is now experiencing the same sort of aging as the population as a whole, with more than 50 percent of the scientists and engineers comprising it now 40 years of age or over. Thus, over the next two decades, there will be a rapid growth in retirements from this segment of the labor force.[56] It is difficult to see how replacements can be found without increasing reliance on foreign-born technical personnel, especially those from the countries of Asia. But, with the growth of increasingly sophisticated research enterprises and knowledge intensive economies in Asia, opportunities for Asian-born scientists and engineers at home will surely increase.

The changed post-September 11 security environment makes the challenge significantly more complex, especially regarding employment of foreign-born technical personnel in sensitive management positions in government and industry, and in sensitive fields of research. The problems of developing an immigration policy which successfully reconciles redefined national security objectives and traditions of scientific openness further complicates matters. Post-September 11 changes in U.S. immigration policy have led to an increase in the denial of visas to highly skilled individuals, and have apparently also discouraged applications from such individuals.[57] Thus, at a time when economic and demographic changes are creating more demand for scientists and engineers from Asia, and when opportunities in Asia are improving, the effects of the war on terrorism for immigration policy may be undermining long-term U.S. competitiveness. It will become increasingly difficult to maintain a winning position in the competition for high-quality human resources if scientists and engineers from the region are faced with long and demeaning visa processes to enter the United States.[58]

The visa problem, however, may be symptomatic of a larger, more profound issue of state-society relations in the United States and in Asia itself. As many observers have noted, globalization has the potential for eroding state sovereignty and weakening the state relative to other international actors. But, as the war on terrorism reminds us, we still look to the state for security against the worst forces of globalization. Inevitably, however, a reassertion of state interests may run counter to those of other societal actors. Many of the latter are important players in the national innovation system, with strong vested interests in globalization. Thus, with regard to the visa issue, we see American universities and U.S. high technology firms—leading agents in the globalization of S&T—being most affected by this reassertion of classic sovereign prerogatives of protecting borders and ensuring security.[59] The perennially contentious policy realm of export controls also illustrates this point, especially in the recent history of U.S.-China relations, where state judgments of U.S. national security interests are often at odds with those of private sector judgments, and where the former often seem to be insensitive to the consequences of controls for the strategic technological trajectories of the private sector.[60]

While the visa problem is not exclusively a problem for the countries of Asia, its effects have been felt most extensively in connection with those countries.[61] Not only do the largest number of foreign students in science and engineering come from Asia, so do many business partners. A recent study of the effects on U.S. companies of post-September 11 immigration policies, which puts the dollar cost to U.S. firms of these new immigration procedures at more than $30 billion, noted that U.S. visa applications for business travel have been most troublesome for applicants from China, India, and Russia, with Malaysia, Indonesia, and Korea being ranked next.[62]

Thus, the growing S&T capabilities of Asia, and the globalization of which they are a part, call for a major re-examination of assumptions about the relationships among trade, technology, and security. Prior to the war on terrorism, and in spite of traditions of government-industry and government-academia tensions, a reasonable equilibrium existed between state and societal interests in arriving at balanced understandings of such matters as export controls, international scientific cooperation, educational exchanges, and high technology trade. As the leading sponsor of the globalization of S&T, the United States could view this historical trend with the confidence that U.S. interests were being served. Understandably, the September 11 attacks required a reassertion of the state's security role. The launching of the war on terrorism, as the operationalization of this reassertion, would inevitably disturb the equilibrium.

The difficulty for the United States is that global processes other than the war on terrorism also have profound effects for U.S. well-being. While not entirely independent of the war on terrorism, they nevertheless have a logic and dynamism of their own. The changing shape of S&T in Asia is highly representative of these processes. The equilibrium, noted above, worked to position the United States favorably for the management and control of these processes. The loss of that equilibrium requires that a workable new equilibrium be found. As noted above, one of the more important geo-political implications of the trends in Asian S&T is toward the acquisition of scientific and technological capabilities for commercial gains and civilian purposes. Put slightly differently, the national innovation systems of most countries in the region have been notably reoriented toward capturing gains from globalization in ways that, in general, de-emphasize national defense as the primary focus of technological development. It is in U.S. interests to reinforce that tendency. Doing so, however, requires that any drift toward a more exclusive and protective techno-nationalism in the United States be checked.

Critical requirements for the globalization of S&T have been the traditions of excellence found in the U.S. national system of innovation, especially those of the great research universities and leading corporations. But, in addition, access to these traditions enjoyed by the best and brightest from around the world as a result of welcoming immigration policies ensured the continued centrality of the United States, even as capabilities became more widely diffused globally. While foreign governments and corporations have unquestionably gained from the costs borne by the United States in sustaining these traditions, the benefits for the United States far outweighed the gains realized by others. The United States, thus, faces tragic losses if, in the face of the immediate challenges of fighting the war on terrorism, it neglects the necessary measures required to maintain scientific and technological excellence, including its traditions of free and open international travel and exchange.

## Conclusion

Asian countries regard S&T development as critical for managing the cardinal economic, security, and environmental challenges they face. As a result, new policy commitments in support of the development of research and innovation capabilities are evident throughout the region. These commitments come with a recognition that:

- S&T is among the world's most globalized activities
- The world is poised for a new industrial revolution resulting from advances in biotechnology, information technology, and nanotechnology/materials science
- The structure of the international high technology economy is undergoing profound changes resulting from the introduction of global production networks.

All major countries of the region are making adjustments to their national innovation systems to accommodate these realities in ways which will allow them to both strengthen national indigenous technological capabilities as well as to better exploit opportunities resulting from the changing global division of labor. The nature of these adjustments, however, vary considerably among those who qualify as "global innovators," "strategic science powers," "fast followers," and "slower starters."

The enhancement of S&T capabilities in Asia has a number of profound short- and long-term implications for United States. On one hand, such capabilities will contribute to military modernization in a number of countries in the region, principally through industrial development with dual-use implications. Capabilities for turning dual-use technologies toward weapons development will increase, and it will be important for the United States to monitor these developments and attempt to create incentives to discourage this direction of technological development. It will also be important for the United States to work with countries in the region to develop safeguards for the protection of lethal technologies resulting from new areas of research.

The encouragement of technological development paths emphasizing civilian use, however, will strengthen the countries of the region as potential commercial competitors, and developments in this area may be of far greater significance for the United States over the longer term. At a time when the war on terrorism has once again elevated security concerns to the top of policymakers' list of priorities, it is especially important that these problems of competitiveness not be minimized. They call for creative new forms of cooperation among government, the corporate world, and universities to ensure continued U.S. leadership in scientific research and technological innovation. Such leadership, however, is increasingly dependent upon the creative contributions of scientists and engineers from the countries of Asia. But changes in U.S. immigration policy are directed at precisely those countries of Asia which are helping to supply the personnel for academic research excellence and creative industrial R&D.

Throughout most of the past 50 years, the United States has been able to use its dominant position in science and technology to advance its interests by providing access to its scientific assets and technological resources, and in some cases, controlling or denying it. However, with the diffusion of scientific and technological capabilities around the world, and especially into Asia, there has been a decline in the *relative* dominance of the U.S. position, as centers of excellence emerge elsewhere. This trend will only increase. Successful policies of using science and technology in support of U.S. interests can no longer be based solely on the promise of access to distinctive technical assets. Policies of access control, under conditions of globalization, will prompt those denied access to seek technical assets—higher education opportunities and opportunities for research collaboration, as well as high technology equipment—from other suppliers. The continuation of policies of denial and access control without deft new countervailing policies to exploit the realities of globalization invite failures and loss of U.S. influence. The needed redirection of U.S. policy, however, will be a daunting task, requiring widespread attitudinal change among policymakers and some significant government restructuring.

Just as countries in Asia are undergoing extensive reforms in anticipation of further globalization and a new technological revolution, so too must the United States not allow its current focus on the war on terrorism to divert attention from institutional reforms needed to address other central challenges of globalization. As a start, the United States should accord a much higher position to the role of S&T in foreign policy generally and to relations with Asia in particular. It needs a high-level mechanism to integrate information about developments in academic and industrial research, the activities of the government's own technical agencies, trends in international science and technology, and foreign policy challenges. Such a mechanism should have the powers to shape this information into policy supportive of long-term U.S. interests. The United States still enjoys a richness of institutional resources to make such restructuring successful, but it has lacked the political leadership and confidence necessary for the more radical restructuring that the new circumstances demand.

## Endnotes


1 National Science Board, *Science and Engineering Indicators 2004*, Arlington: National Science Foundation, pp. O–19.

2 David Kirkpatrick, "Big-league R&D Gets Its Own e-Bay," *Fortune*, May 3, 2004, p. 74.

3 The agglomeration effects of clusters involve increasing returns to investments in infrastructure and to the stock of human capital through the reduction of transaction costs, the sharing of institutional assets, and improved conditions for social learning. On the importance of clusters for Asian innovative capacity, see Shahid Yusuf, *Innovative East Asia: The Future Growth*, Washington, DC: The World Bank, 2003, ch. 6.

4 On global production networks, see Dieter Ernst and Linsu Kim, "Global Production Networks, Knowledge Diffusion, and Local Capability Formation," *Research Policy*, vol. 31 (2002), pp. 1417–29; and Timothy J. Sturgeon, "Modular Production Networks: A New American Model of Industrial Organization," *Industrial and Corporate Change*, vol. 11, no. 3 (2002), pp. 451–96. On the significance of "technological architecture," see Sangbae Kim and Jeffrey A. Hart, "The Global Political Economy of Wintelism: A New Mode of Power and Governance in the Global Computer Industry," in James M. Rosenau and J.P. Singh, *Information Technologies and Global Politics*, Albany: SUNY Press, 2002. On the growing importance of contract manufacturing, see Boy Luthje, "Electronics Contract Manufacturing: Global Production and the International Division of Labor In the Age of the Internet," *Industry and Innovation*, vol. 9, no. 3 (2002), pp. 227–47.

5 "A Decade of Investment In Research and Development (R&D): 1990–2000," *UIS Bulletin on Science and Technology Statistics*, no. 1, April 2004.

6 See U.S. National Science Foundation, *Science and Engineering Indicators, 2004*, Washington, DC: National Science Foundation, 2004.

[7] For an account of the significance of these technological possibilities, see P. S. Anton et al., *The Global Technology Revolution: Bio/Nano/Materials Trends and Their Synergies with Information Technology by 2015*, Washington, DC: The RAND Corporation, 2001.

[8] The term "national innovation system" is used here to refer to the complex, interactions among a nation's R&D institutions and its systems of production. It was introduced, in part, to capture the idea that innovation is a systemic process, and not simply the application of the results of R&D, as in an older "linear model" of innovation. Since the initial introduction of the term in mid-1980s, it has been applied to a variety of settings and has come to take on a variety of meanings. There is now a general understanding that with the growth of global knowledge flows, an important aspect of any national innovation system is the way in which it relates to patterns of research and innovation internationally as well. For a authoritative discussion of the term, see Bengt-Ake Lundvall, "Innovation System's Approach to Nation States, Social Capital And Economic Development," unpublished paper presented to the ASIALICS International Conference on Innovation Systems and Clusters in Asia: Challenges and Regional Integration, Bangkok, April 1–2, 2004.

[9] On "techno-nationalism" and "techno-globalism," see S. Sylvia Ostry and Richard Nelson, *Techno-Nationalism and Techno-Globalism: Conflict and Cooperation*, Washington, DC: The Brookings Institution, 1995; S. Montresor, "Techno-globalism, Techno-nationalism and Technological Systems: Organizing the Evidence," *Technovation*, vol. 21 (2001), pp. 399–412; Atsushi Yamada, "Neo-techno-Nationalism: How and Why It Grows," *Columbia International Affairs Online*, March 2000; and Richard P. Suttmeier and Yao Xiangkui, "China's Post-WTO Technology Policy: Standards, Software, And the Changing Nature of Techno-Nationalism," NBR *Special Report*, Seattle: The National Bureau of Asian Research, no. 7, May 2004.

[10] See Yusuf, *Innovative East Asia: The Future Growth.*

[11] U.S. National Science Foundation, *Science and Engineering Indicators, 2004.*

[12] Defined here as economies " … in which research, its commercial exploitation, and other intellectual work play a growing role in driving economic growth." U.S. National Science Board, *Science and Engineering Indicators, 2004,* pp. O–3.

[13] For an interesting discussion of this phenomenon as it pertains to possibilities for nanotechnology in India and China, see Jayanthi Iyengar, "Asia's Rising Star: Nanotechnology," *Asia Times,* April 20, 2004.

[14] With regard to China, for example, consider the report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China (the Cox Committee).

[15] According to reports from the Tokyo office of the National Science Foundation, Japan's GERD/GDP ratio in 2003 had risen to 3.5 percent, the highest in its history.

[16] National Science Board, *Science and Engineering Indicators, 2004*, pp. 6–23.

[17] See Richard P. Suttmeier, "Science and Technology and Reform in the Giants," in Richard Feinberg et al., eds., *Economic Reform in Three Giants: U.S. Foreign Policy and the USSR, China and India,* New Brunswick: Transaction

Books, 1990.

[18] The Indian record is illustrative of these priorities. Since independence, India's atomic energy program has consumed 13 percent of cumulative R&D spending, the space program 20 percent, and military R&D 30 percent. See B. Mahesh Sarma, "India's National System of Innovation: Retrospect and Prospects," unpublished paper presented to the ASIALICS International Conference.

[19] During the 1950s, the Chinese GERD/GDP exceeded 2 percent. The years of the Cultural Revolution led to significant declines in expenditures, and during the first 15 years of the reform era from 1980 to 1995, China attempted to address its technological needs through the importation of foreign technology.

[20] Government of India, *Science and Technology Policy, 2003*.

[21] Charles Kelley et al., *High Technology Manufacturing And U.S. Competitiveness*, Washington, DC: The RAND Corporation, 2004, ch. 7.

[22] William J. Broad, "U.S. Is Losing Its Dominance in the Sciences," *New York Times*, May 3, 2004, p. 1.

[23] National Science Board, *Science and Engineering Indicators, 2004* … pp. O–16.

[24] In the Malaysian case, the GERD/GDP is only 0.5 percent and the number of research scientists and engineers per 10,000 members of the labor force is 15.6. Malaysian policy calls for these numbers to rise to 1.5 percent and 60, respectively, by 2010. See K. Thiruchelvam, "Toward a Dynamic National System of Innovation in Malaysia: Enhancing the Management of R&D In Public Research Institutions and Universities," unpublished paper presented to the ASIALICS International Conference; The GERD/GDP in Indonesia, in 1998, was 0.035 percent. For a recent assessment of the Indonesian NIS, see P. Gammeltoft and E. Aminullah, "The Indonesian Innovation System at a Crossroads," unpublished paper presented to the ASIALICS International Conference.

[25] Greg B. Felker, "Southeast Asian Industrialization and the Changing Global Production System," *Third World Quarterly*, vol. 24, no. 2 (2003), pp. 255–82.

[26] Hiroyuki Odagiri, "Advance of Science Based Industries and the Changing Innovation System of Japan," unpublished paper presented to the ASIALICS International Conference, p. 23.

[27] Odagiri, "Advance of Science Based Industries ...," p. 23.

[28] The organization of R&D in Japanese firms, typically in centralized corporate research centers, began to be recognized as a problem in the 1990s, as information flows between laboratories and business units became disconnected. Outsourcing now encourages firms to look to others for routine R&D services, including software development and the manufacture of prototypes. As Odagiri notes, "They may form R&D alliances by commissioning research from other established firms, new startup firms, universities, or public laboratories, or starting joint research projects with them. They may also acquire technologies by licensing in. In such diverse manner, firms today are extensively utilizing outside capabilities."

[29] Odagiri, "Advance of Science Base Industries ... ."

[30] William A. Blanpied, *The Second Science and Technology Basic Plan: A Blue-*

*print for Japan Science and Technology Policy*, Tokyo: National Science Foundation, Tokyo Regional Office, 2003.

[31] The meaning of Chinese statistics on industrial research remains unclear. Hence, the 60 percent figure must be used with care. However, the trend in China is clearly toward shifting more of the national R&D burden to industry, and considerable progress has been made.

[32] It should be noted that in India, unlike China, statistics on industrial research differentiate between funds coming from private industry and from public enterprises. R.T. Krishnan, “The Evolution of a Developing Country Innovation System During Economic Liberalization: The Case of India,” unpublished paper presented to the ASIALICS International Conference.

[33] Alfred Watkins, “From Knowledge to Wealth: Transforming Russian Science and Technology For a Modern Knowledge Economy,” *World Bank Policy Research Working Paper*, Washington, DC: The World Bank, 2003, pp. 14–15.

[34] For a useful recent discussion of how deep political problems affect technological development in China, see George J. Gilboy, “The Myth behind China’s Miracle,” *Foreign Affairs*, July/August 2004.

[35] Blanpied, “The Second Science and Technology Basic Plan”; compare with Linsu Kim, “Crisis, Reform, And National Innovation in South Korea,” in William Keller and Richard Samuels, eds., *Crisis and Innovation: Asian Technology after the Millennium*, New York: Cambridge, University Press, 2003, pp. 86–107.

[36] See Suttmeier and Yao, “China’s Post WTO Technology Policy.”

[37] See, for instance, Dinesh Abrol, “Knowledge Diffusion Under Post-TRIPS Pharmaceutical Scenario,” unpublished paper presented to the ASIALICS International Conference.

[38] Watkins, “From Knowledge to Wealth.”

[39] Yamada, “Neo-Techno-Nationalism.” Yamada uses the term to describe policy orientations in which one sees both “expanded state commitments” to technological development (in keeping with techno-nationalist assumptions), but also active public-private partnerships, a more welcoming openness toward foreigners in national technology programs, and greater commitment to international rule-making and policy coordination. The notion of neo-techno-nationalism accommodates these changes in ways that the more established ideas of techno-nationalism and techno-globalism do not.

[40] See T.V. Padma, “India Appoints New Science Minister,” *Science and Development Network*, June 1, 2004.

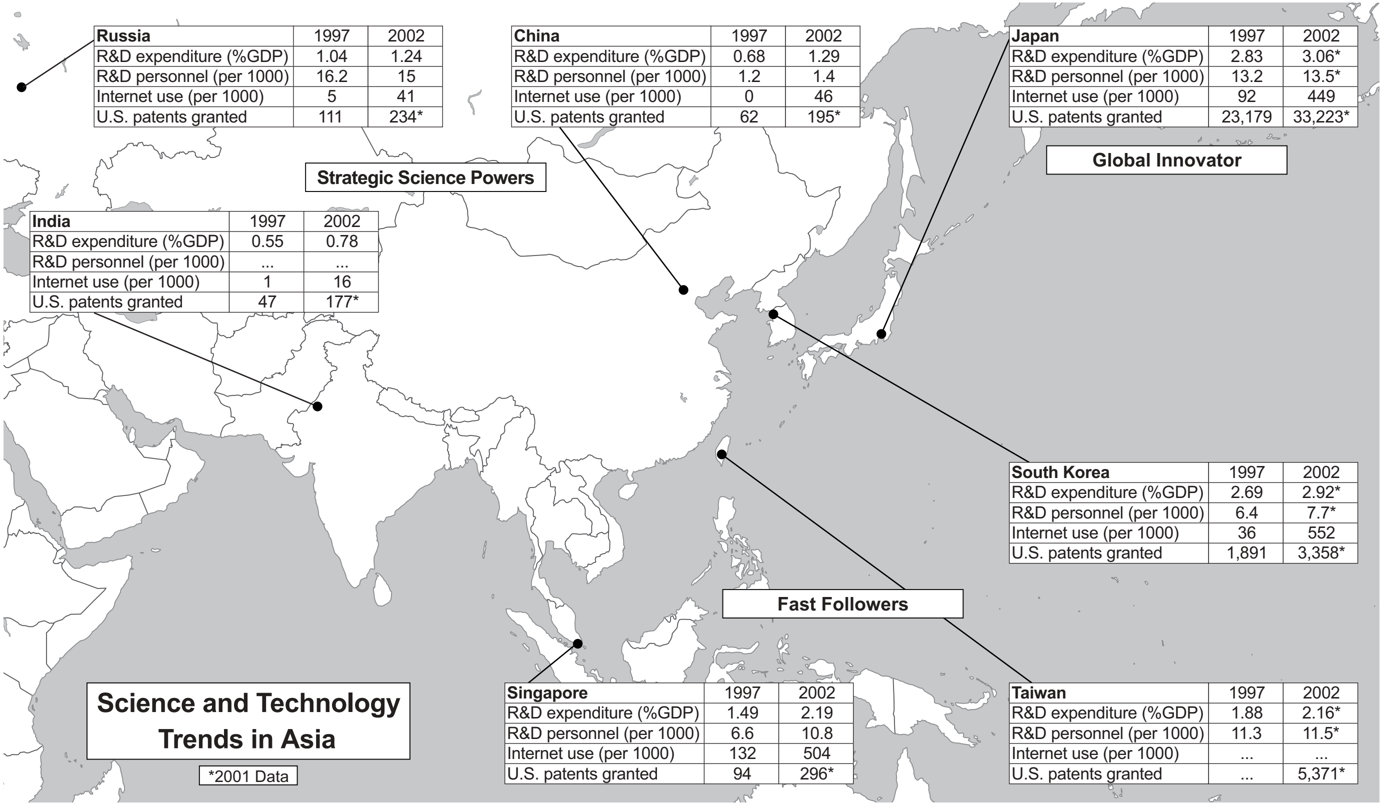
[41] At a recent international meeting in Shanghai, for instance, Zhou Guangzhao, the former president of the Chinese Academy of Sciences, member of the National People’s Congress, and former key physicist in China’s nuclear weapons program, explored the social relations of science as they affect everything from terrorism to environmental degradation, arguing that scientists and national research programs can no longer be insensitive to the profound ethical issues and social consequences of modern science and technology. Unpublished remarks made at the Fifth Shanghai Roundtable on Ecology of Science sponsored by the Shanghai Institute of Advanced Studies, May 2004.

[42] See, especially, Mu-ping Poo, "Cultural Reflections," *Nature*, March 11, 2004, p. 204.
[43] C. P. Rajendran, letter to the editor, *Nature*, June 3, 2004, p. 501.
[44] On these challenges in Korea, see Mark Russell, "Suddenly, Science Moves to the Top of the Government's Agenda," *Science*, May 28, 2004, p. 1237.
[45] See U.S. National Science Foundation, *Science and Engineering Indicators, 2004*.
[46] See, for instance, Gregory T. Huang, "The World's Hottest Computer Lab," *Technology Review*, May 17, 2004.
[47] National Science Board, *Science and Engineering Indicators, 2004*, pp. O–17.
[48] For a recent discussion of the value to U.S. firms of royalties and fees from holding IPR, see National Science Board, *Science and Engineering Indicators, 2004*, pp. 6, 13–15. The balance of receipts vs. payments is especially favorable for U.S. firms in Asia.
[49] Compare with Kim and Hart, "The Global Political Economy of Wintelism."
[50] Ron Hira, "Implications of Offshore Outsourcing," p. 4.
[51] Hira, "Implications of Offshore Outsourcing ..."; see also William M. Bulkeley, "IBM Documents Given Rare Look at 'Offshoring'," *Wall Street Journal*, January 19, 2004.
[52] See, for instance, James Mulvenon, "The Digital Triangle: A New Defense-Industrial Paradigm?" unpublished paper presented at the Conference on China's Emerging Technological Trajectory in the 21st Century, Rensselaerville, NY, September 4–7, 2003.
[53] See, for instance, discussions on innovation on the Council on Competitiveness website.
[54] See, for instance, Jen Lin-Liu, "A Chinese University, Elite Once More," *Chronicle of Higher Education*, vol. 50, no. 44, p. A16.
[55] National Science Board, *Science and Engineering Indicators, 2004*, pp. O–8.
[56] National Science Board, *Science and Engineering Indicators, 2004*, pp. O–10.
[57] National Science Board, *Science and Engineering Indicators, 2004*, ch. 3, pp. 36–38.
[58] For recent discussions of how post-September 11 U.S. immigration policy is affecting science, see *Nature*, vol. 497, January 15, 2004, pp. 190–95; and *Science*, vol. 304, May 28, 2004, pp. 1278–82. The latter makes the case for the continuing competitiveness of the United States for the world's best minds, but may understate the serious problems which new visa procedures are creating for scientific cooperation and graduate training. For an analysis of how students from China's elite universities calculate the costs and benefits of applying for graduate study in the United States in light of the new visa problems, as opposed to entering improving graduate programs in China, see Jen Lin-Liu, "A Chinese University, Elite Once More."
[59] On May 12, 2004, representatives from over 20 American organizations in science, engineering and education issued a "Statement and Recommendations on Visa Problems Harming America's Scientific, Economic, and Security Interests," which called attention to, and voiced concerns over, the consequences of the state's new immigration policies.
[60] For a useful recent discussion, see Adam Segal, "Practical Engagement: Draw-

ing a Fine Line for U.S.-China Trade," *Washington Quarterly*, vol. 27, no. 3 (Summer 2004), pp. 157–73.

[61] A February 2004 General Accounting Office report found that visa delays were most severe for students and scientists from China, India, and Russia.

[62] The Santangelo Group, "Do Visa Delays Hurt U.S. Business?" June 2, 2004.




## Science and Technology Trends in Asia

*2001 Data

| Russia | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 1.04 | 1.24 |
| R&D personnel (per 1000) | 16.2 | 15 |
| Internet use (per 1000) | 5 | 41 |
| U.S. patents granted | 111 | 234* |

| China | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 0.68 | 1.29 |
| R&D personnel (per 1000) | 1.2 | 1.4 |
| Internet use (per 1000) | 0 | 46 |
| U.S. patents granted | 62 | 195* |

| Japan | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 2.83 | 3.06* |
| R&D personnel (per 1000) | 13.2 | 13.5* |
| Internet use (per 1000) | 92 | 449 |
| U.S. patents granted | 23,179 | 33,223* |

| India | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 0.55 | 0.78 |
| R&D personnel (per 1000) | ... | ... |
| Internet use (per 1000) | 1 | 16 |
| U.S. patents granted | 47 | 177* |

| South Korea | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 2.69 | 2.92* |
| R&D personnel (per 1000) | 6.4 | 7.7* |
| Internet use (per 1000) | 36 | 552 |
| U.S. patents granted | 1,891 | 3,358* |

| Singapore | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 1.49 | 2.19 |
| R&D personnel (per 1000) | 6.6 | 10.8 |
| Internet use (per 1000) | 132 | 504 |
| U.S. patents granted | 94 | 296* |

| Taiwan | 1997 | 2002 |
|---|---|---|
| R&D expenditure (%GDP) | 1.88 | 2.16* |
| R&D personnel (per 1000) | 11.3 | 11.5* |
| Internet use (per 1000) | ... | ... |
| U.S. patents granted | ... | 5,371* |