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Chapter 5: The Globalization of IT Research

5.1 Overview

IT research has historically been, and still is, concentrated in a few countries. However, IT research is becoming more equally spread around the globe. This globalization is almost certainly unstoppable and may well accelerate. If current trends continue over the next twenty to thirty years, it is likely that IT research will spread to the far corners of the world, and China and India will emerge as centers of IT research rivaling the United States and Western Europe.

There is little hard data on the migration of IT research jobs. However, it appears that, to date, such migration has been limited and has on balance gravitated toward traditional centers of IT research rather than away from them. A much more significant phenomenon has been the migration of IT researchers themselves from one country to another. This migration has been overwhelmingly to the traditional centers of research. The migration of both jobs and researchers to traditional centers of IT research is lessening. The direction of job migration may well reverse.

Globalization presents challenges to the traditional centers of IT research. If they become complacent, or even merely inattentive, they may well dwindle in significance with strong negative consequences for their local economies. However, the globalization of IT research is happening in the context of a general increase in the amount of IT research. It is not a zero sum game where increased opportunities in one place inevitably result in decreased opportunities in other places. If they take strong action, it is entirely possible that the traditional centers of IT research will continue to flourish even as additional centers emerge.

The Concentration of IT Research

According to data collected by the Thomson ISI science citation index for the years 1999-2003 (see Figure 1), about a third of computer science papers come from the United States alone. A few additional traditional centers of concentration in IT research (Australia, Canada, France, Germany, Israel, Italy, the Netherlands, Sweden, Switzerland, and the United Kingdom) account for another third.

Much, but not all, of the large share of the world's IT research in these eleven countries is explained by the large part of the world's Gross Domestic Product (GDP) that is concentrated in these same countries. Figure 1 plots the percentage of the world's computer science publications against the percentage of the world's Purchasing Power Parity (PPP) adjusted Gross Domestic Product (GDP) for all those countries that produce more than 1% of one or the other. There is a basic correspondence between PPP GDP and computer science publication. However, the share of computer science publications by scientists in the traditional centers of concentration of IT research is more than 60% greater than their share of world PPP GDP (65% vs. 40%).

IT research was even more concentrated in the past than it is today. The initial bloom of IT research occurred in only a few select locations in the United States and a couple other countries in the aftermath of the Second World War. This small group of research centers expanded shortly after to the full list of traditional research centers given previously. Over the later 20th century, the list of IT research centers has continued to grow, but relatively slowly. For example, in Europe, Spain, Greece, and Belgium have joined the list, and in East Asia, Japan, South Korea, Taiwan, and Singapore have become significant research

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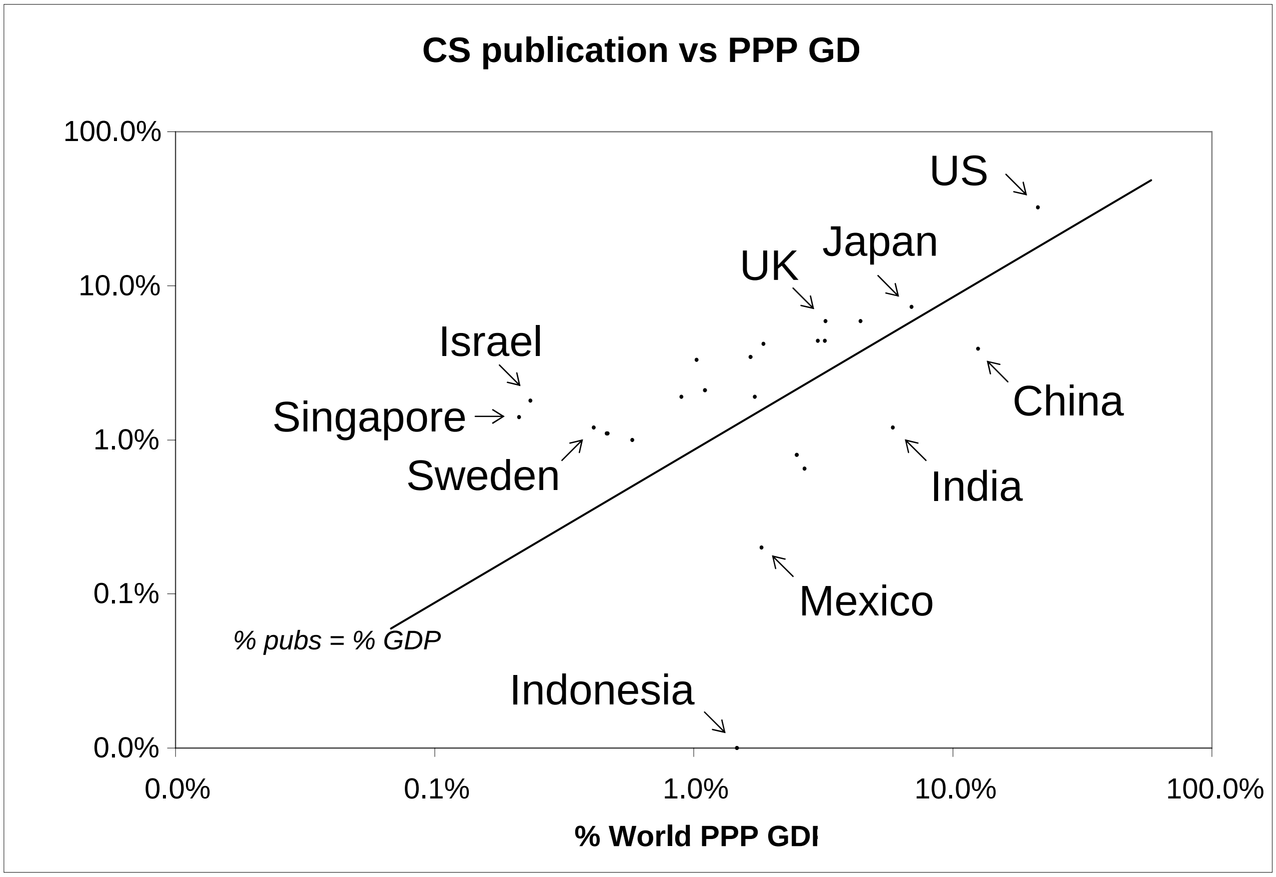
centers. With these additions, the centers of IT research listed produce about 85% of all IT publications.

Figure 5-1: The Globalization of IT Research



The line shows where a country would be if its share of CS publications were equal to its share of PPP GDP. The data underlying this graph are shown in Table 5-3.

China and India are moving toward becoming centers of IT research, but they are not there yet. Some other countries with significant GDP such as Brazil, Indonesia, Mexico, and Russia produce very little IT research. These six countries combined produce 27% of world PPP GDP but only 7% of computer science papers.

Particularly in the United States, the initial surge of IT research was driven by ample government funding and a significant migration of scientific talent from the rest of the world. The continued importance of government funding is illustrated by the fact that countries such as Israel, Singapore, and Sweden that have particularly high per capita government funding for IT research also have particularly high levels of computer science publication in comparison to PPP GDP. In addition, as shown in the data presented in this chapter, there has been a general migration of scientists from countries that do not support graduate education and research to countries that do.

Due to strong efforts to foster research on the part of a number of national and local governments outside the traditional centers of research, IT research is slowly but steadily becoming more global. This has been accompanied by a significant increase in the numbers of PhDs outside the traditional centers of concentration and a reduction in the migration of researchers to these centers. In the long run, there is no obvious reason why IT research should be any more concentrated than world economic activity in general.

What Globalization Means for the World as a Whole

Globalization allows more and better people to participate in IT research. The growing availability of educational opportunities around the world means that more people with research potential are able to realize this potential, increasing the size of the IT researcher pool and the quality of the best researchers. A freer worldwide market in research means that potential funding for IT research can more easily be targeted to those that can most effectively and efficiently create research results. Both of these trends increase the amount of scientific advancement that can be obtained from a given level of resources. There is little doubt that this is good for the field of IT and for the world as a whole; however, while we gain as a group, there can be individual losers.

What Globalization Means for Individual Locations

Research, in general, and IT research, in particular, is one important foundation for high value-added economic activity and is actively sought by more and more locations. This chapter uses the word location instead of country to highlight the fact that issues of change in IT research activity are not tied to countries so much as to particular regions within countries. For example, inside the countries that are the traditional leaders in IT research, there has long been competition between established research locations and new locations wishing to achieve that status. This competition is little different and no less intense than the global competition that is now emerging.

Becoming (or maintaining one's status as) a center of research in any field requires consistent long-term effort. The required measures include building basic economic infrastructure, providing first-rate education through the doctorate degree level to train high quality researchers and attract first-rate students who stay in the location, and providing ample direct government funding for research as demonstrated by the data presented in this chapter.

Every location must realize that it is competing in a truly global marketplace. This presents opportunities for locations that are not yet centers of research and challenges to those that are. It is likely that the traditional centers of concentration of IT research will remain important centers of research because as significant research centers, these locations will naturally attract research funding and research talent. However, these centers must take continued active measures to foster research. They cannot be complacent and assume that merely being a center of concentration of IT research is, by itself, a guarantee of indefinite success.

What Globalization Means for Individual Researchers

Globalization provides improved opportunities for people who live outside the traditional centers of concentration of IT research. It also provides improved opportunities for the best researchers due to increased global competition for their services. However, it limits the opportunities of the least skilled researchers in the traditional centers of concentration, for whom global competition may mean declining wages or even the loss of jobs.

Every researcher must realize that he or she is competing in a truly global marketplace. There are many people worldwide who could be good IT researchers. Among those who are already researchers, huge differences in skill exist, and this translates into large productivity differentials. Those with talent who pay attention to maintaining a high skill level should see opportunities from globalization, but they must realize that they can no longer fall back on merely living in a traditional center of concentration of IT research as a guarantee of indefinite success. Because of the higher quality and productivity that results, talent and skill level will eventually win out wherever it is to be found globally.

Worldwide Changes in the Balance of Supply and Demand for IT Research

The globalization of IT research will inevitably reduce the dominance of the traditional centers of concentration in relative terms. However, IT research is not a zero sum game.

The most important question for individual locations and researchers is not whether they will prosper in comparison to others, but whether they will prosper in comparison to their own past history. If a given location has a vibrant and growing IT research community, it matters little if other locations are growing more rapidly. Similarly, if a given researcher has a career that is growing in interest and pay, it does not matter much if the prospects of other researchers are increasing more rapidly.

This chapter is primarily about changes in the balances between locations. If the demand for IT research and the supply of IT researchers were static, then this would be a primary determiner of the future prospects of locations and the researchers in them. However, the situation is far from static.

Both the demand for IT research and the supply of IT researchers are increasing rapidly. The most important question of all is whether the demand or the supply is increasing more rapidly. Changes in the worldwide balance of supply and demand for IT research is a more important factor for predicting the future than changes in the balance between locations. Unfortunately, forecasting the future balance of supply and demand comes down to forecasting the difference between two large, rapidly growing, and hard to forecast numbers—a very difficult task.

The goal of IT research is the automation of information and knowledge manipulation tasks, and as such, it is arguably one of the most fundamental of all disciplines, contributing to every area of science, engineering, and the economy. There is therefore every reason to believe that the overall demand for IT research will be very strong—quite possibly strong enough to grow faster than the worldwide supply of quality researchers.

Why IT Research Is a Separate Section in This Report

Discussion of research is in a separate section of this report because it is a self-contained microcosm with product flows that are quite different from IT in general. In addition, the indicators of what is happening in worldwide research, such as the publication of research papers and the numbers of PhDs, are different from the indicators of IT development activities. However, developments in the globalization of research may well be fundamental harbingers of changes to the field as a whole.

The Lack of Direct Data

It would be advantageous to start with a clear definition of what IT research is and then collect a set of data that directly targets that definition. However, there is little available data that directly targets any definition of IT research. Rather, data typically lumps IT research with other kinds of research, advanced development, or both. For instance, much of the data from the National Science Board combines all of natural science and engineering together. Similarly, economic data on the IT industry typically lumps research expenditures with advanced development costs and often with other things as well.

As a result, we see little advantage in arguing for any particular definition of IT research. Instead, we present a range of data relating to IT research. No single piece of this data is authoritative in its presentation of what is happening in IT research. However, since every piece of data paints a qualitatively similar picture of steady globalization, we are confident that this picture substantially applies to any plausible definition of IT research.

5.2 Worldwide Distribution of IT Research

Insight into the distribution of IT research can be gained by looking at R&D expenditures, the publication rates of research papers and patents, the international ranking of universities, and the granting of doctoral degrees.

Overall R&D Expenditures

As shown in Figure 2 from the National Science Board's (NSB) Science and Engineering Indicators for 2004, worldwide research and development is concentrated in a few industrialized nations. Of the $603 billion in estimated R&D expenditures in the year 2000 for the thirty OECD countries, fully 85% is spent in only seven countries (Canada, France, Germany, Italy, Japan, United Kingdom, United States) and more than 40% in the United States alone.

Note that all the curves in Figure 2 are trending upward but that research is growing fastest in the countries that currently do the least research. Continuation of these trends will inevitably lead to a more equal distribution of research around the world.

Figure 3 from the NSB (2004) shows R&D expenditures as a percentage of GDP. Comparing the two figures reveals that most of the differences in R&D spending stem from differences in GDP. However, within the G-8 countries, non-defense research and development as a percent of GDP differs by a factor of three between the lowest and highest. It is interesting that these differences have been quite stable over the past twenty years. In comparison to Figure 3, China spends only 1% of its GDP on research, and some small high-tech powerhouses, including Israel and Sweden, spend in the range of 4% and more (see the NSB (2004, Table 4-17)).

These figures aggregate data on many kinds of research and development. Consider the following more detailed information about US government funding of research and development. The US National Science Foundation (NSF) (see James (2005) reports that US government R&D funding dropped from 1.25% of GDP in 1985 to only 0.75% of GDP in 2002. Over this time, research and development in the life sciences remained more or less flat at 0.41% of GDP, but funding for research on technology dropped precipitously, from 0.55% of GDP to 0.24%. As a result, while overall research and development is rising in the United States, the government is not emphasizing technology research nearly as much as in the past. This change of emphasis in the United States is likely to accelerate the globalization of IT research.

Overall Research Publication

The US National Science Foundation compiles statistics on the publication and citation of Science and Engineering (S&E) papers in general. Figure 4 from the NSB (2004) presents the output of S&E articles for various regions and countries.

The picture painted by Figure 4 is broadly similar to the one painted by Figure 2 but focused more on IT research. The principal S&E research contributors are Western Europe and the United States. There has been steady growth of Western Europe's research output that overtook the US output in numbers of publications in the mid-1990s. The research output from Emerging East Asia (Taiwan, South Korea, Singapore, and China) is small but growing rapidly. Given the economic vitality and the strong growth of S&E PhD degrees in this region, it is reasonable to expect East Asia to emerge as a strong new research region.

In addition to the publication of papers, NSF tracks the citations to these papers. This correlates with the quality and influence of the papers coming from various regions which is much more important than mere numbers. This data is summarized in Figure 5 from the NSB (2004).

Here the dominance of the United States is greater, but the same picture of slow and steady globalization emerges. Western Europe is steadily catching up with the United States. Papers from Japan are cited approximately half as many times on average as US papers, and to date papers from Emerging East Asia have even less influence. It will probably take a long time for Asia to catch up with the United States, but it is in the process of doing so.

Another way of assessing the influence of S&E research from various countries is by considering the number of citations in US S&E literature, shown in Table 1 from the NSB (2004). The absolute level of citations may not be all that meaningful because US researchers are more likely to read and cite articles written in English and because they are perhaps more likely to read articles from researchers located geographically close to the United States. However, the relative level compared to other countries should have meaning. The strong stability of the citation percentages of the countries shown suggests that the importance of the research in these countries has changed little on a relative basis between 1994 and 2001.

University Rankings

A large portion of research is carried out in universities, and much of the best research is performed at the best universities. Insight into the distribution of the highest quality research can be obtained from the distribution of the world's best universities. As demonstrated in Table 2, the distribution of the top 100 universities in the world has the same basic form as the distributions in Figure 5 and Table 1. (The data in Table 2 are based on a list of the world's best universities compiled by Shanghai Jiao Tong University in 2004.)

IT Research Publication

Table 3 shows the percentage of the world's computer science publications (as compiled by the Thomson ISI science citation index for the years 1999-2003) along with the percentage of the world's Purchasing Power Parity (PPP) adjusted Gross Domestic Product (GDP), for all those countries that produce more than 1% of either. The table uses PPP GDP rather than nominal GDP because the primary expenses of computer science research are salaries, and PPP GDP is more closely aligned with salary costs in a country.

Unsurprisingly, there is a strong correlation between computer science publications and PPP GDP. However, there are important deviations from this correlation. The principal centers of IT research (United States, Japan, United Kingdom, Germany, Italy, France, and Canada) generally produce considerably more computer science publications than would be expected from their PPP GDP alone. Some smaller countries including Taiwan, the Netherlands, Greece, Sweden, and Switzerland produce more than twice as many publications as would be expected from their PPP GDP. Singapore and Israel produce 7 and 8 times as much, respectively.

At the other end of the spectrum some countries with substantial PPP GDP (e.g., China, India, Russia, and Brazil) produce relatively few computer science publications. Mexico produces less than one ninth of what would be predicted by PPP GDP, and Indonesia produces almost no computer science publications at all.

From Table 3, it is clear that the correlation of computer science publication is not just with PPP GDP, it is also with leading-edge, high-value-added economies.

PhD Degrees Conferred

The number of S&E PhDs conferred is an indicator of a region's research effort because much of the world's IT research is done at universities by doctoral students. In addition, the number of computer science PhDs is a key factor supporting a region's future ability to perform research because highly trained researchers are the most important foundation for research. Figures 6 and 7 from the NSB (2004) show the rate of Natural Science and Engineering (NS&E) PhD degrees awarded for selected countries.

Particularly striking in these graphs is the recent huge growth of NS&E PhDs in Asia, in general, and China, in particular. This contrasts with the United States and Germany, where strong growth in the 1980s has given way to decline, and also other countries, where there has been steady growth for many years. Changes in the number of PhD degrees suggest that research output will soon rise in East Asia, while stagnating at best in the United States and Germany.

These data are for NS&E PhDs as a whole. Looking more specifically at computer science PhDs, the data is not as comprehensive but suggests similar trends. According to the NSB (2004), there were 7,389 PhDs awarded in mathematics and computer science lumped together in 2000. Of these, 1,832 (24%) were in the United States, while 4,057 (55%) were in the European Union, with 956 in Germany, 800 in France, 760 in the United Kingdom, and 704 in Italy. This data is difficult to interpret because Europe has a higher proportion of mathematics doctorates than the United States, and the data set is missing information about countries in Asia. As a result, the US share of computer science PhDs may well be higher than the US share of NS&E PhDs as a whole.

Figure 8 is taken from the Computing Research Association (CRA) (2004) and shows that, while there has been a bit of an up-tick in the past year, the number of computer science PhDs in the United States has been basically trending downward for many years. Other data from the same survey shows increases in the number of students passing PhD qualifying exams, which suggests that the recent higher level of PhDs may continue. Nevertheless, Figure 8 still stands in marked contrast to the vast increase in graduate education in places such as China and India.

The Big Picture in Research Distribution

The previous data all indicate that the United States has the world's preeminent S&E research effort, followed at some distance by the United Kingdom, Germany, France, and Japan. Looking more specifically at IT research, some smaller countries such as Israel, Singapore, Taiwan, Greece, Sweden, Switzerland, Canada, and the Netherlands stand out as producing a large amount of research in comparison to their size.

The data showing trends over time all indicate that the preeminence of the United States and Europe is waning, and the gaps between countries are narrowing. It is not a question of whether these gaps will narrow significantly, but when. In particular, the data on PhD degrees conferred indicates a rapid narrowing.

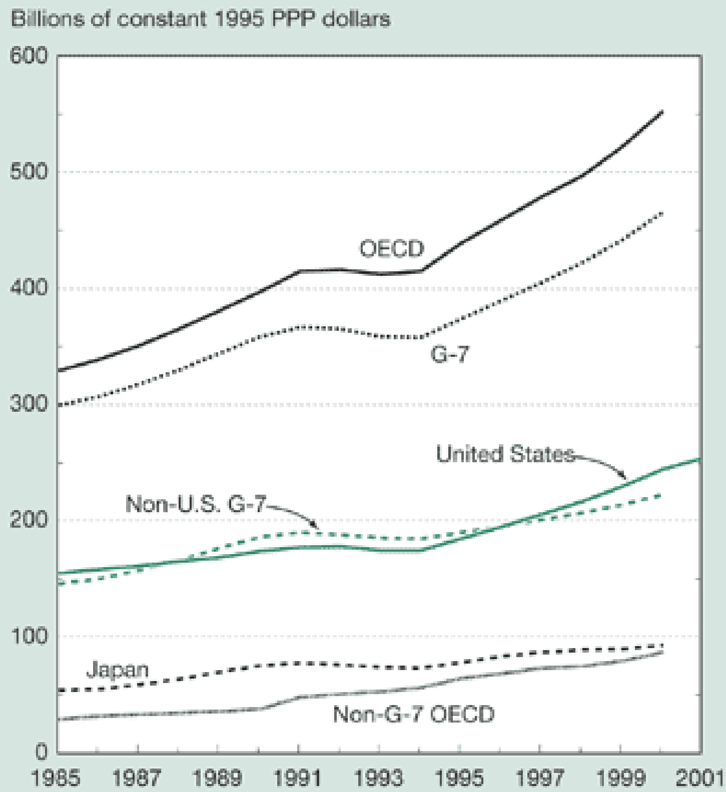
For example, if the trends in Figure 6 continue, the number of PhD degrees in China will equal current US levels in 15 years or so. The output (and particularly the impact) of science from China is not yet rising as quickly, but this is not surprising given the assumption that the number of PhD degrees awarded is a leading indicator of scientific output, and the increase in output has not yet fully responded to the major acceleration in Chinese PhD degrees that started ten years ago.

Unless something seriously derails current trends, it seems almost certain that China will be a research center rivaling the United States and Western Europe in importance within twenty to thirty years. The development of critical scientific infrastructure in India is a few years behind developments in China but moving down a similar road.

Figure 5-2

Figure 4-22

U.S., G-7, and OECD countries R&D expenditures: 1985–2001



OECD Organisation for Economic Co-operation and Development
PPP purchasing power parity

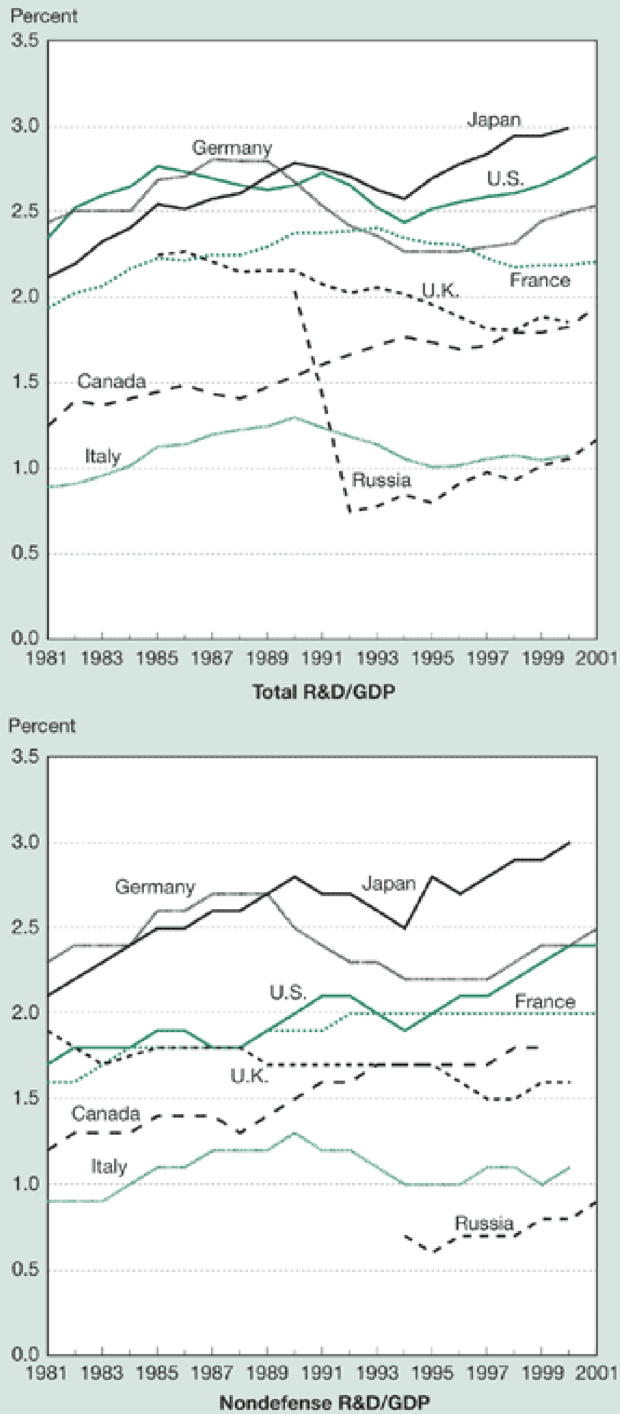
NOTE: Non-U.S. G-7 countries are Canada, France, Germany, Italy, Japan, and the United Kingdom.

SOURCE: OECD, *Main Science and Technology Indicators*, 2002. See appendix table 4-43.

Science & Engineering Indicators – 2004

Figure 5-3

R&D share of GDP, selected countries: 1981–2001

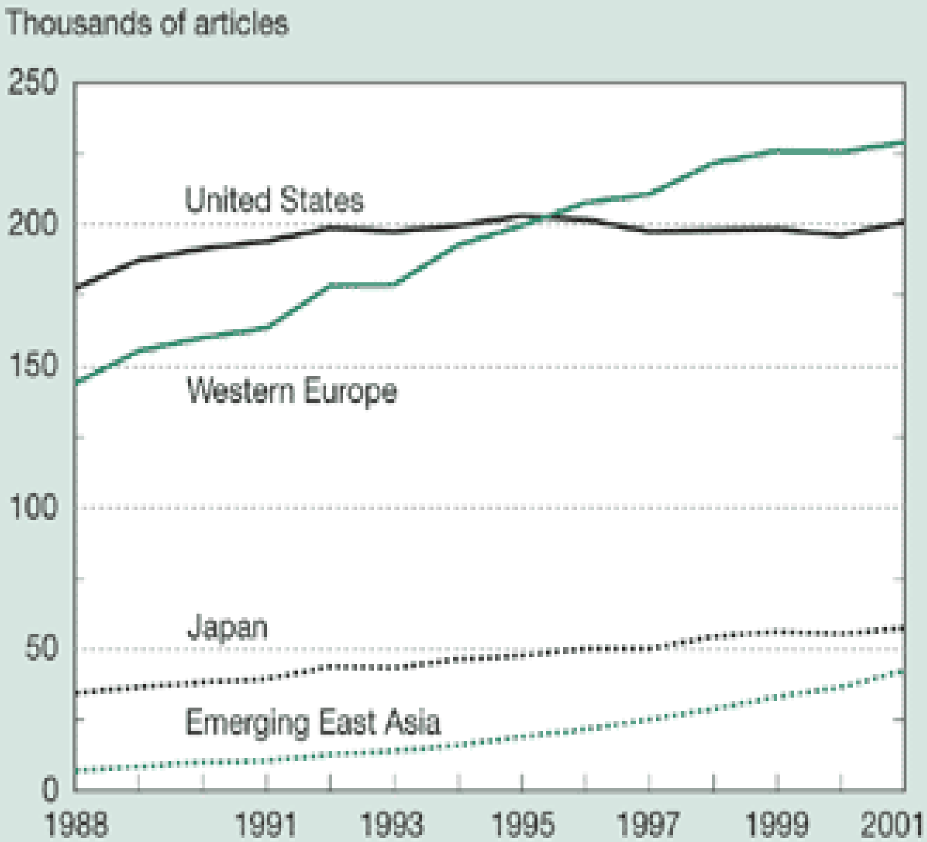


GDP gross domestic product
U.K. United Kingdom
U.S. United States

SOURCE: Organisation for Economic Co-operation and Development, *Main Science and Technology Indicators*, 2002.

Figure 5-4

Output of S&E articles by selected countries/ regions: 1988–2001



NOTE: Emerging East Asia consists of China, Singapore, South Korea, and Taiwan.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc., and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-35.

Science & Engineering Indicators – 2004

Table 5-1: Countries whose S&E articles were cited most in U.S. S&E articles: 1994 and 2001

		1994			2001	
Rank		***Country***	***Percent***		***Country***	***Percent***
1		United Kingdom	17.8		United Kingdom	16.0
2		Japan	12.4		Germany	12.7
3		Germany	11.9		Japan	11.9
4		Canada	10.4		Canada	8.9
5		France	9.2		France	8.7
6		Netherlands	4.5		Italy	5.1
7		Italy	4.2		Netherlands	4.5
8		Switzerland	3.9		Australia	3.9
9		Sweden	3.7		Switzerland	3.8
10		Australia	3.7		Sweden	3.2

NOTE: Countries ranked by share of foreign S&E literature cited in U.S.-authored scientific articles.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Sciences Citation Index; CHI Research, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

Table 5.2: University ranking. Data taken from Institute for Higher Education, Shanghai Jiao Tong University, 2004, Academic Ranking of World Universities.

Number of top-100 universities in countries					
	In 1st 25	In 2nd 25	In 3rd 25	In 4th 25	In top 100
US	18	17	10	6	51
UK	4	1	2	4	11
Germany		1	2	4	7
Japan	2	1	2	1	6
France		2		2	4
Sweden		1	1	2	4
Canada	1		1	1	3

Switzerland		1	1	1	3
Netherlands		1	1		2
Australia			1	1	2
Denmark			1		1
Finland			1		1
Norway			1		1
Russia			1		1
Austria				1	1
Israel				1	1
Italy				1	1

Source: http://ed.sjtu.edu.cn/ranking.htm

Table 5.3:. The %CS publications numbers are from the Thomson ISI science citation index for the years 99-03. The Purchasing Power Parity GDP numbers are from the US CIA world handbook 2004, see http://www.indexmundi.com/. (This data is graphed in Figure 5.1.)

Country	**% CS pubs**	**% PPP GDP**
United States	32.3%	21.3%
Japan	7.3%	6.9%
United Kingdom	5.9%	3.2%
Germany	5.9%	4.4%
Italy	4.4%	3.0%
France	4.4%	3.2%
Canada	4.2%	1.9%
China	3.9%	12.5%
South Korea	3.4%	1.7%
Taiwan	3.3%	1.0%
Australia	2.1%	1.1%
Netherlands	1.9%	0.9%
Spain	1.9%	1.7%
Israel	1.8%	0.2%
Singapore	1.4%	0.2%
Greece	1.2%	0.4%

India	1.2%	5.9%
Sweden	1.1%	0.5%
Switzerland	1.1%	0.5%
Belgium	1.0%	0.6%
Russia	0.8%	2.5%
Brazil	0.7%	2.7%
Mexico	0.2%	1.8%
Indonesia	0.0%	1.5%

Figure 5-5

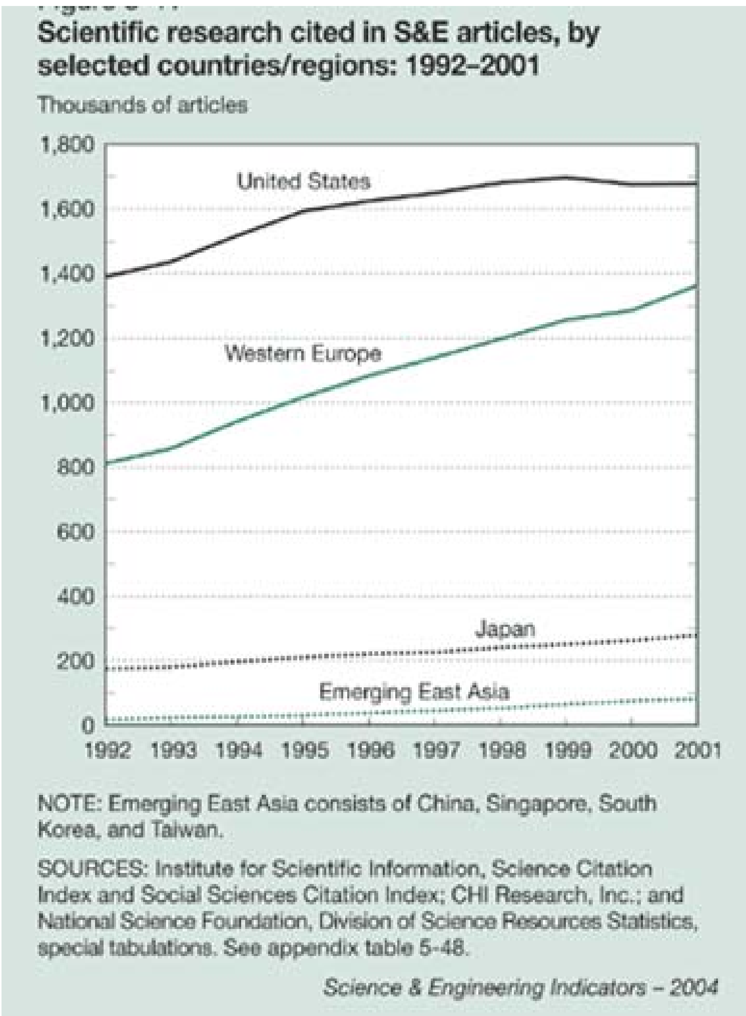
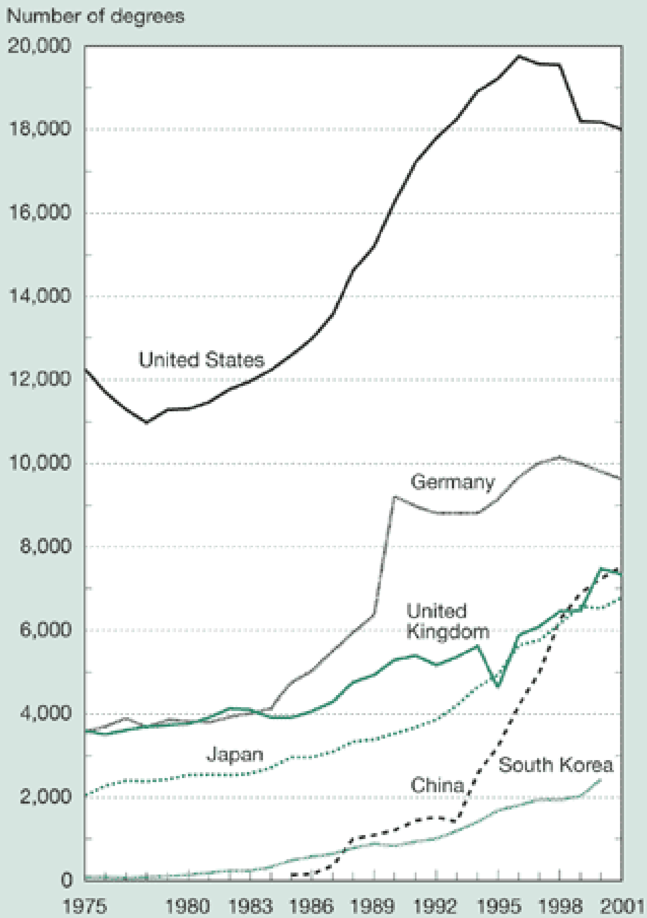


Figure 5-6

NS&E doctoral degrees, by selected countries: 1975–2001



NS&E natural sciences and engineering

NOTE: NS&E includes natural (physical, biological, earth, atmospheric, and ocean sciences), agricultural, and computer sciences; mathematics; and engineering.

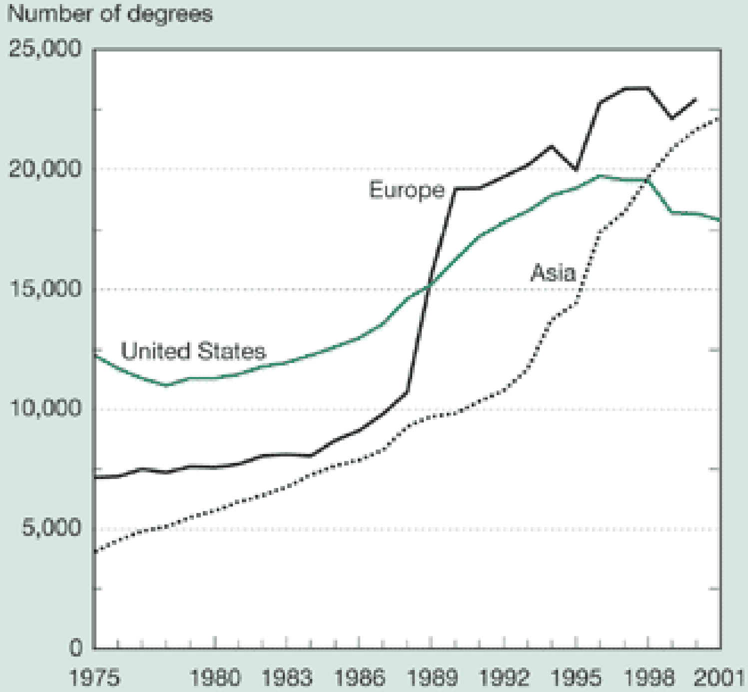
SOURCES: China—National Research Center for Science and Technology for Development, special tabulations; United States—National Science Foundation, Division of Science Resources Statistics, Survey of Earned Doctorates; Japan—Government of Japan, Monbusho Survey of Education; South Korea—Ministry of Education, *Statistical Yearbook of Education,* and Organisation for Economic Co-operation and Development, *Education at a Glance 2002;* United Kingdom—Higher Education Statistics Agency; and Germany—Federal Statistical Office, *Prüfungen an Hochschulen.* See appendix tables 2-38 and 2-39.

Science & Engineering Indicators – 2004

Figure 5-7

Figure 2-38

NS&E doctoral degrees in United States, Europe, and Asia: 1975–2001



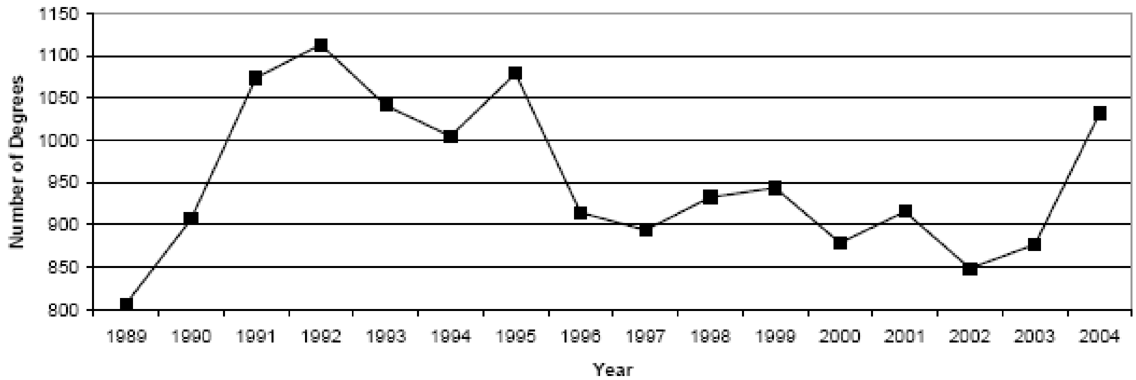
NS&E natural sciences and engineering

NOTES: NS&E includes natural (physical, biological, earth, atmospheric, and ocean sciences), agricultural, and computer sciences; mathematics; and engineering. Europe includes only France, Germany, and the United Kingdom. Asia includes only China, India, Japan, South Korea, and Taiwan. The jump in the European data in 1989 is due to the inclusion of French data, which were unavailable in this data series before 1989. French data are estimated for 2000.

SOURCES: France—National Ministry of Education and Research, *Rapport sur les Études Doctorales;* Germany— Federal Statistical Office, *Prüfungen an Hochschulen;* United Kingdom—Higher Education Statistics Agency, special tabulations; China—National Research Center for Science and Technology for Development; India—Department of Science and Technology, *Research and Development Statistics;* Japan—Government of Japan, Monbusho Survey of Education; South Korea—Ministry of Education, *Statistical Yearbook of Education;* and Organisation for Economic Co-operation and Development, *Education at a Glance 2002;* Taiwan—Ministry of Education, *Educational Statistics of the Republic of China;* and United States—National Science Foundation, Division of Science Resources Statistics, *Science and Engineering Doctorate Awards*. See appendix tables 2-26, 2-38, and 2-39.

Science & Engineering Indicators – 2004

Figure 5.8: PhD Production. 19 forward to fill the gap.bringFrom the 03-04 CRA Taulbee survey. [This figure could be extended back to 1980 by including data from earlier Taulbee surveys.]



5.3 Researcher Migration

The knowledge of scientists and engineers can be transferred across national borders easily through the physical movement of the scientists and engineers themselves. This movement can be for a short term or involve permanent migration. Since the beginning of IT research, the permanent in-migration of scientists and engineers from other countries has been a vitally important basis for the dominance of the traditional centers of research. The primary reason for this migration has been people moving in search of better job opportunities. This is aided and abetted by multinational corporations that vigorously recruit permanent employees from overseas.

Consider the movement of researchers to the United States as an example. The National Science Board (2004) reported that, in April 1999, at least 27% of S&E doctorate holders in the United States were foreign born, along with 20% of those with S&E master's degrees and 10% of S&E bachelor's degree holders. These individuals came from a wide range of countries around the world; however, India and China provided the greatest number of transplanted researchers, particularly for PhD-holding immigrants, 20% of whom come from China and 16% from India.

Mobility of Inventors

Manuel Trajtenberg (2004) of Tel Aviv University has done a study of the movement of inventors of US patents between countries during the period 1975 to 1999. He looked at the 650,000 people who are inventors on more than one patent and calculated statistics based on the country they were in when each patent was filed. There were only 20,767 inter-country moves recorded in the data. This means that 3% or less of these inventors are known to have moved. Nevertheless, interesting patterns are evident in their movements.

Figure 9 shows the number of moves per year for each 10,000 US patents filed. The mobility of inventors has increased steadily and markedly, rising eightfold in twentyfive years.

Figure 10 tabulates the countries these inventors moved between. The United States had by far the largest net immigration of these inventors. Trajtenberg (2004) argues that the total turnover of inventors to and from a country is even more significant than the net migration because the ebb and flow of people and their ideas is a vital stimulus to research progress. From this perspective, the United States is even more dominant, and it might be the case that a country such as the United Kingdom may gain more from its relatively high turnover than it loses from its net outflow of inventors.

Whether or not Trajtenberg's conjecture is true, the increasing mobility of inventors is a clear indicator of the increasing globalization of the market for scientific talent.

Students

A major factor in technical migration is students who relocate to study in universities and then remain in the countries where they obtain their degrees. The United States is the most common destination for such students, but a number of other highly developed countries (e.g., in Western Europe) are the targets of significant numbers of students as well. The great importance of this migration of technical talent on research in the United States is discussed in a recent report by the US National Academies (2005).

In 1997, 66% of the people in US universities who received PhDs in computer science held student visas (see the NSB (2004, Table 3-28). By 2001, this number had decreased slightly but was still 63%. These numbers are particularly important because many of these students stay permanently in the United States.

According to Michael Finn (2003) of the Oak Ridge Institute for Science and Education), 56% of 1996 US S&E doctoral degree recipients with temporary visas remained in the United States in 2001. The number of foreign students staying after obtaining their doctorates implies that approximately 3,500 foreign students remain from each annual cohort of new S&E doctorates in all fields. Stay rates differ by field of degree, ranging from 26% in economics to 70% in computer and electrical engineering.

As shown in Figure 11 from the NSB (2004), there has been a significant decline in foreign students coming to the United States in recent years. One can speculate that this is partly due to the restrictive visa atmosphere following the events of September 11, 2001. (The refusal rate for F-1 student visas has risen from 28% to 35%, and the application rate has fallen by 18%.) However, other forces are at work as well. This issue is discussed further in Chapter 8.

International competition for high-quality graduate students is increasing as both advanced and advancing countries seek more foreign talent. Job opportunities are also becoming more widespread in the world. As a result, students now have more choices of where to go to study, and they have more opportunity to stay in or near their home countries.

5.4 Research Job Migration

The question of exactly what is IT research job migration is fraught with complexity. The standard definition of job migration is that a job migrates from country X to country Y when a company C fires a worker in X that was making product used in X and then hires a worker in Y to produce the same product for use in X. In particular, it is not considered job migration if C hires workers in Y to produce product to be used in Y. It is difficult to apply this definition to research and there are questions surrounding this standard definition that are particularly pointed from the perspective of research.

For one thing, unlike manufactured goods, there is little if any information about where companies that create research use it. One could say that this issue is not as relevant to research as to other kinds of economic activity, but it does not seem reasonable to say that it is totally irrelevant. If a company C opens a lab in China in order to experiment with human-computer interfaces supporting the Chinese language so that C can sell more product in China, is that job migration?

In addition, for much of the history of IT research, the research workforce has been growing in every place where IT research is done. Is it job migration if the workforce in one geographical location merely grows more slowly than it might have? Is it job migration if the only alternative to moving the job from country X to country Y would have been moving a person from country Y to country X to do the job? Here too, there does not appear to be anything other than anecdotal information about what is actually happening.

Figure 5.9: Moves from one country to another for inventors of multiple patents, normalized by the number of patents filed (moves per 10,000 filings).

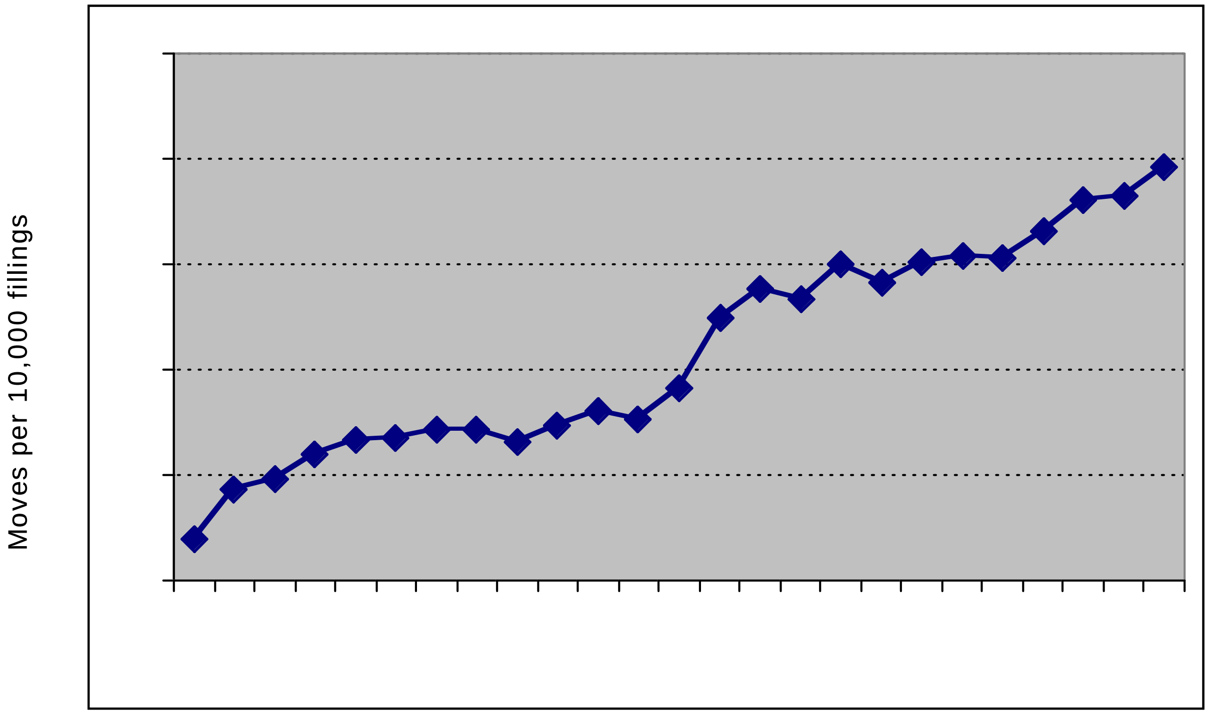
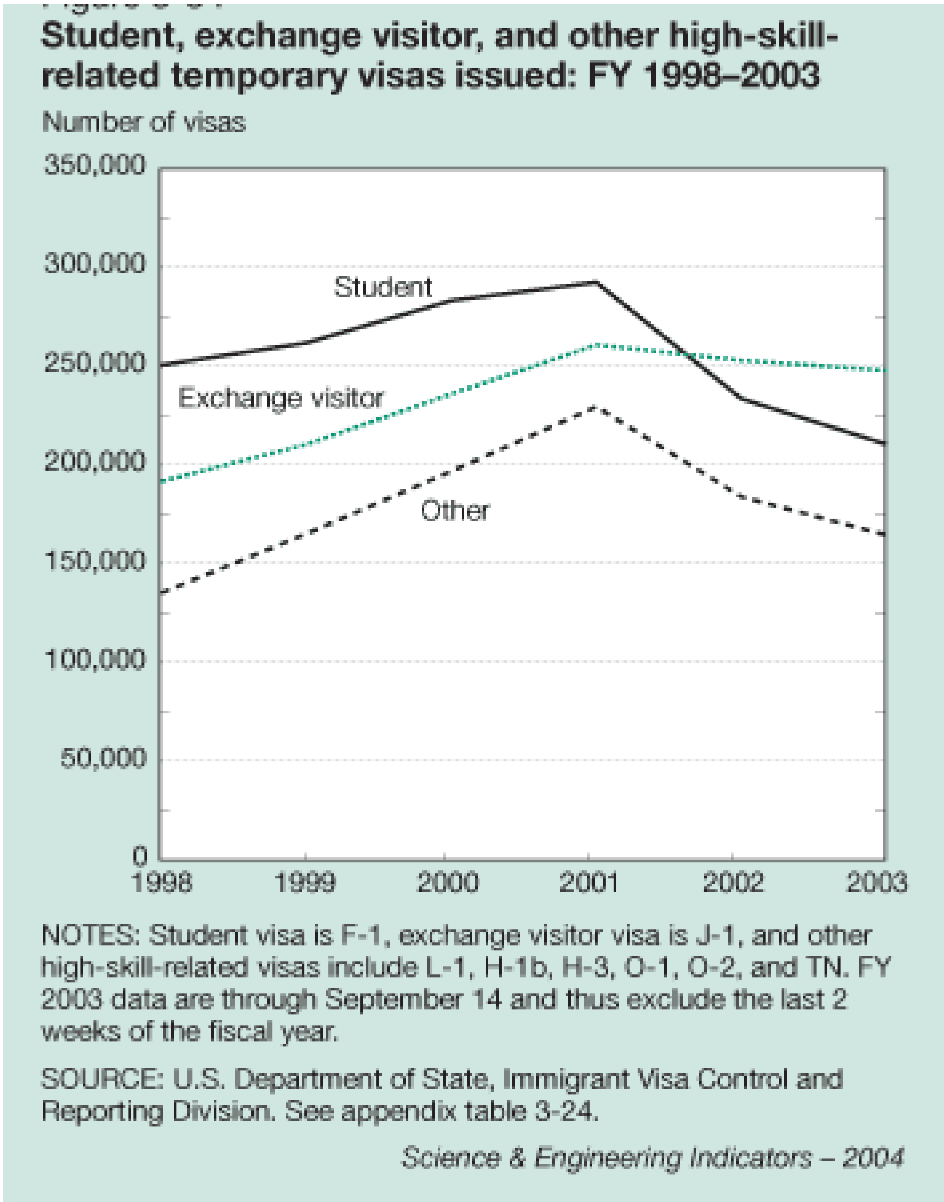


Figure 5.10: Total flows of inventors between countries.

Country	Moves in	Moves out	Net	Turnover
Canada	1392	1554	-162	**2,946**
Switzerland	702	693	9	**1,395**
Germany	1551	1701	-150	**3,252**
France	665	665	0	**1,330**
UK	2181	2809	-628	**4,990**
Israel	248	219	29	**467**
Italy	205	186	19	**391**
Japan	1114	1244	-130	**2,358**
Korea	371	270	101	**641**
Netherlands	453	527	-74	**980**
Taiwan	275	176	99	**451**
US	8041	7272	769	**15,313**

Figure 5.11



Student, exchange visitor, and other high-skill-related temporary visas issued: FY 1998–2003

NOTES: Student visa is F-1, exchange visitor visa is J-1, and other high-skill-related visas include L-1, H-1b, H-3, O-1, O-2, and TN. FY 2003 data are through September 14 and thus exclude the last 2 weeks of the fiscal year.

SOURCE: U.S. Department of State, Immigrant Visa Control and Reporting Division. See appendix table 3-24.

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Due to these difficulties, this section focuses primarily on where research is done rather than on whether jobs have migrated; however, Figure 12 from the NSB (2004) shows that the balance of trade in research is such that the United States exports more research than it imports. Figure 13 from the same report shows that most of the research investment flow into the United States comes from other traditional centers of research concentration and most of the investment outflow goes to these other centers.

These data do not directly address the question of job migration, but they suggest that, to the extent there has been job migration, it has probably been to the United States rather than from it. Since the United States is one of the most expensive places in the world to do research, this job migration is clearly not motivated by a search for low-cost labor.

Why Companies Do Research in Remote Locations

Before considering why companies do research in remote locations, it is important to note what kind of research companies do in their remote locations. There are numerous examples of companies that have moved their primary manufacturing, or even all their manufacturing, to distant places. However, there are very few examples of companies that have done that with research. In general, distant research labs are relatively small satellite operations focusing on specialized areas. That is to say, companies that have distant labs typically have much larger labs in their home areas that are the backbone of their research.

Focusing on IT research in particular, there are anecdotal reports of recent start-up companies in California that have all of their technical operations, including research, in India. However, other than that, we are not aware of any company in the IT business that has a primary research lab (as opposed to a satellite lab) in a distant location nor are we aware of any company in the IT business that is thinking of opening such a lab. It seems entirely likely that there will be primary IT research facilities in places such as India and China, but that will be because these places will have major IT companies that chose to have primary IT research facilities in their home areas just as Japanese companies in the IT business chose to do decades ago.

It is useful to distinguish two quite different cases of companies opening labs or utilizing independent research labs in distant locations: (a) companies opening research labs in the traditional centers of IT research concentration and (b) companies opening labs in other locations. As noted previously, it appears that to date (a) has been more common than (b). However, it is hard to imagine that (b) will not also be important.

Dalton and Serapio (1993, 30) present an interview survey of senior R&D executives of Japanese electronics companies, which found the following to be important reasons to open research labs in the United States (in no particular order).

1. Keep abreast of technological developments.
2. Help the parent company decide what technology to acquire.
3. Cooperate with other US R&D labs.
4. Hire US scientists and engineers.
5. Assist the parent company in meeting US customer needs.

We think this list is entirely reasonable. Note that items 1-3 are central reasons for placing research in an existing center of concentration rather than somewhere else, and they are likely to be key reasons why such centers are self-perpetuating. Item 4 could be interpreted various ways, but, in this case, it can be assumed to focus on exploiting the talent pool in the center of concentration. (Given that US wages were higher than Japanese wages in 1999, It certainly was not an attempt to save on labor costs.) Item 5 is the only item unrelated to the fact that the United States is a center of IT research concentration.

Turning to case (b), here is a comparable list of reasons for investing in research outside the traditional centers of concentration.

1. Take advantage of local offers of cost sharing.
2. Meet local demands for research investment.
3. Hire local scientists and engineers.
4. Assist the parent company in meeting local customer needs.

As discussed in the following, items 1-2 are the result of locations working to attract research to their shores. Item 3 typically involves hiring lower cost labor. As a result, items 1-3 are all indicative of job migration. In contrast, item 4 is identical to the final reason in the list of reasons for case (a). To the extent that it is a dominant reason for the investment, the investment is not job migration in the standard sense.

It appears that research job migration from the traditional centers of concentration to places such as India and China is beginning to become a significant factor. In particular, quite a few R&D labs have been created recently in these countries. However, it is very difficult to pin down how much research job migration has actually occurred because it is very hard to determine how much of the work done in these new labs is actually research as opposed to advanced development.

An interesting model has emerged for staffing labs in places such as China and India where many of the employees are hired locally at wages determined by the economy of the host country, but the key lead research positions are filled with people brought in from outside. Typically these lead researchers are people who grew up in the host country but who were educated in the traditional centers of IT research concentration and gained key research experience there. (For example, the founding head of Microsoft's research lab in Beijing grew up in China, got his PhD at Carnegie Mellon University in 1988, and worked for ten years in the United States before being hired by Microsoft to start their new lab in 1998.) In addition to the natural cultural and familial attractions of returning to their countries of birth, these people are induced to return in part by offering them salaries that may be low by US standards but extremely high by the standards of the local economy.

Making research pay off for a company is difficult, and there is no doubt that this is made even more difficult when a lab is located far from the main operations of the company. However, for the most part, it appears that companies are satisfied with their overseas research operations. Perhaps the strongest indicator of this satisfaction is the longevity of many overseas labs. This is particularly true for case (a) discussed previously, where many labs have a long track record. Given that it typically takes a number of years before any newly-created lab has a real impact on the company that creates it, much remains to be seen about the labs being created now.

Why Locations Seek to Foster Research Activities

For a country to have companies that are at the forefront of innovation is generally seen as essential for robust economic growth in the long-term. To be at the forefront of innovation, a location must have access to cutting-edge research and have a workforce capable of utilizing it. Fostering research helps both of these prerequisites. It creates cutting-edge technology and it hones the skills of cutting-edge personnel.

The importance of research in and of itself is demonstrated by Figure 14 which shows nine industries, each worth at least a billion dollars, spawned by IT research. Research contributed to each of these fields in the early stages of their development. In these important cases, government funding was critical to funding the research and establishing the industry. (In some other important cases, industry provided the initial funding.) In the cases described in Figure 14, the initial research phase was followed by industrial research and culminated in a new industry in the sponsoring country. It is beyond the scope of this study to untangle the complex interplay between basic research, customer requirements, product development corporate research, and government. The main point is that research is a driver of major economic development, and government funding has historically played an important role in priming these developments.

Creating cutting-edge personnel is probably just as important as creating new technology. Even if a location would be happy just to import research to incorporate into products it makes rather than to import whole products from other areas, importing research is easier to talk about than to do.. To import and effectively use research, you have to have people that understand it fully. One of the best ways to do this is to have a research lab that is participating in the research area because researchers in the area are in an optimal position to find out about and understand what is happening at the research frontier of that area.

Typically, the goal of a location is not research job immigration but rather the positive benefits to be obtained from homegrown research used at home. The end goal is a vibrant local industry fueled by local research rather than being an exporter of research. When a location fosters research, it has an important goal focused on job creation. However, this goal is focused on the many jobs that can be created by a general increase in economic activity that is sparked by research rather than on the relatively few jobs that are involved in the research itself.

What Is Needed to Foster Research in a Country

Quality researchers and the money to hire them are critically important in fostering research. High-quality equipment along with a high-quality communication infrastructure is also required, but, in contrast to many other areas of science and engineering, IT equipment and infrastructure have relatively low cost. Moreover, battles in the marketplace during the dot-com boom led to a world-spanning broadband communication infrastructure that is widely (though not universally) available with costs driven rapidly down because of excess capacity. Without any connection to products or product development, it is hard to visualize good research except in the most academic sense. For example, much of the Xerox PARC work and the IBM work on relational database and RISC technologies, both seminal efforts, were driven by a desire to introduce new products. While equipment, communication infrastructure, and relation to product development are all important to research, we will focus here on the importance of personnel.

To host research, a location needs to produce, retain, and attract quality researchers. To produce quality researchers, a location must have first-class education through IT graduate school. To retain quality researchers, a location must have a good work and living environment, and good opportunities for researchers. To attract quality researchers to move to a location, the location must have a very good work and living environment, and very good opportunities for researchers.

The traditional centers of concentration of IT research have prospered in a self-reinforcing way by being among the world's best places for education, work and living environment, and researcher opportunity. Multiple reinforcing cycles perpetuate this. The presence of good research in universities both improves graduate education and attracts better students. These two factors act to produce better researchers. Researchers have a tendency to stay where they are educated. The more research there is in an area, the more opportunity there is for researchers. Research leads to increased economic activity, which improves work and living environments.

Locations that want to become centers of research concentration need to invest in improved education and infrastructure as well as direct support for research. In some cases they also need to induce foreign companies to open research centers, for example by offering tax incentives or by making it a requirement of doing business there.

As discussed in Newman et al. (2004), many countries are investing large sums in higher education. In addition to this expansion of homegrown universities, some US universities (particularly for-profit ones) are beginning operations in other countries. All told, in the world as a whole, the number of students studying in college and graduate school more than doubled from 40 million in 1975 to 80 million in 1995 and is continuing to grow rapidly.

An interesting aspect of IT research is that the largest traditional centers of concentration are all in English-speaking countries, so English is very much the common language of IT research. As a result, it is of benefit for a location seeking expanded IT research to speak English (at least for work in IT). For instance, some German universities are now teaching all their IT classes in English in order to provide better opportunities for their students.

There are long lead times in the various steps mentioned in this chapter, so the rate of change is slow. Patient application of resources is required over decades before the reinforcing cycles discussed can come into play. However, there is ample evidence that a location can make strong progress given sufficient time and effort. This can be seen, for example, in the experiences of many state university regions in the United States such as the Research Triangle in North Carolina.

Particularly notable are small countries (including Switzerland, Sweden, Israel, and Singapore) that have historically supported research to a high degree and reaped ample rewards from doing so. For instance, Sweden has consistently provided some of the world's highest per capita levels of government support for higher education (currently 0.8% of GDP, more than twice US levels) and research (1% of GDP, nearly twice US levels). This has yielded consistently high levels of research as demonstrated by per capita publication rates that are among the highest in the world (nearly twice US levels) and other criteria (see Vinnova (2004)).

There is ample anecdotal evidence showing the benefits that accrue to a location that fosters research. Given the large amounts of money and effort being expended by many countries, there is little doubt that they feel that this is very important. This may well be a prime area of competition between countries in the 21st century.

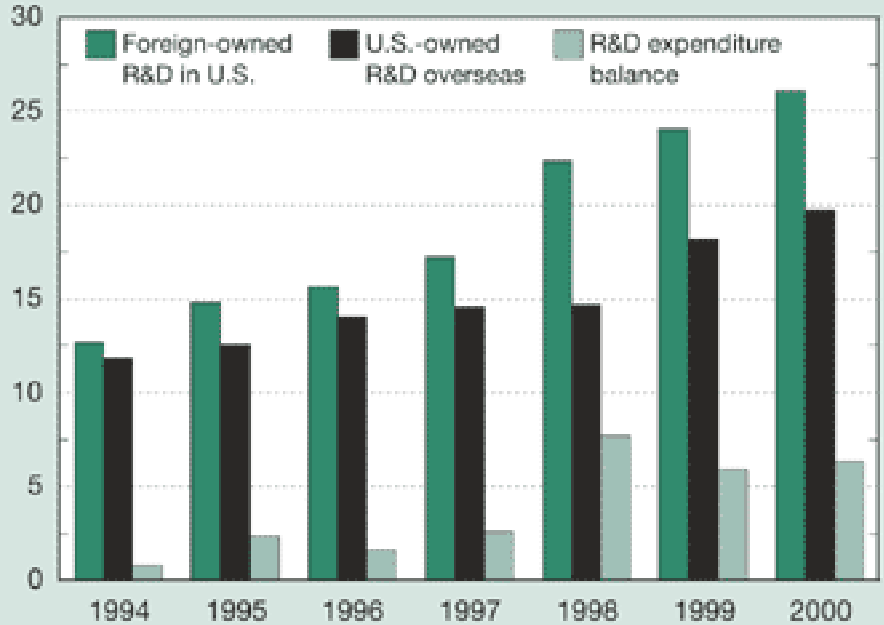
5.5 Conclusion

IT research is steadily, and almost certainly inevitably, becoming more global. This will bring strong advantages to those locations that are now entering the IT research main-stream. Because this is happening in the context of a general worldwide growth in IT research, these benefits will not necessarily come at the expense of the current centers of IT research. However, these current centers are faced with an important choice. They can continue to be strong supporters of IT research and compete vigorously in which case they should be able to continue as influential centers of IT research. However, if they choose to ignore the growing global competition, the world may pass them by and relegate them to second-class status.

Figure 5-12

Foreign-owned R&D in United States, U.S.-owned R&D overseas, and R&D expenditure balance: 1994–2000

Billions of current U.S. dollars



NOTE: R&D expenditure balance equals foreign-owned R&D in the United States minus U.S.-owned R&D overseas.

SOURCES: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States*, annual series; and U.S. Bureau of Economic Analysis, *U.S. Direct Investment Abroad*, annual series. See appendix tables 4-49 and 4-51.

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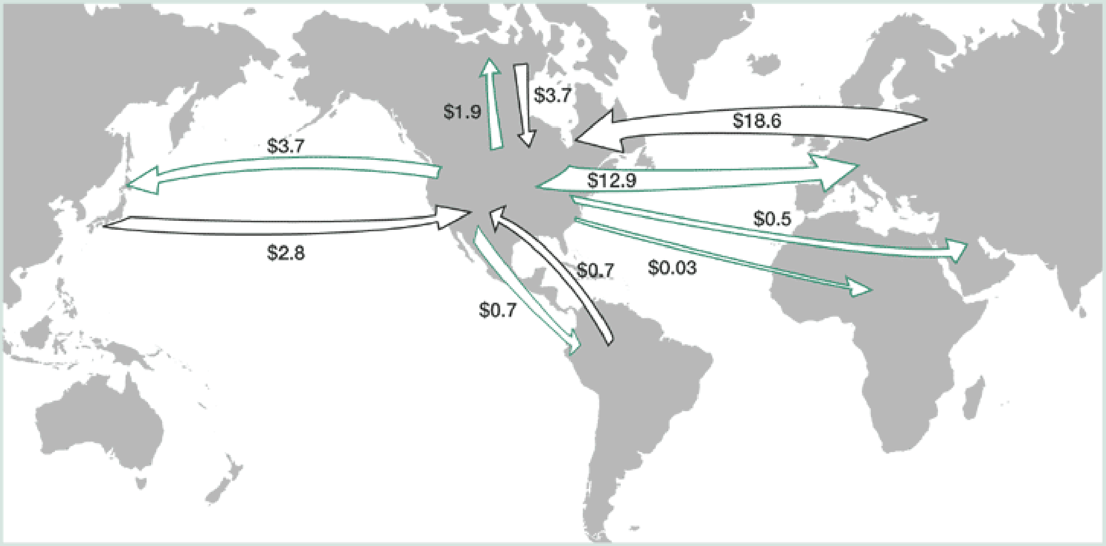
Figure 5-13

Figure 4-34

Foreign-owned R&D in United States and U.S.-owned R&D overseas, by investing/host region: 2000

(Billions of current U.S. dollars)



SOURCES: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States*, annual series; and U.S. Bureau of Economic Analysis, *U.S. Direct Investment Abroad,* annual series. See appendix tables 4-49 and 4-51.

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Figure 5-14

From *Evolving the High Performance Computing and Communications Initiative to Support the National Information Infrastructure*
Information about this publication can be found at **http://cstb.org/pub_hpcci**
Read it online: http://www.nap.edu/books/0309052777/html/index.html (Figure 1.2, page 20)

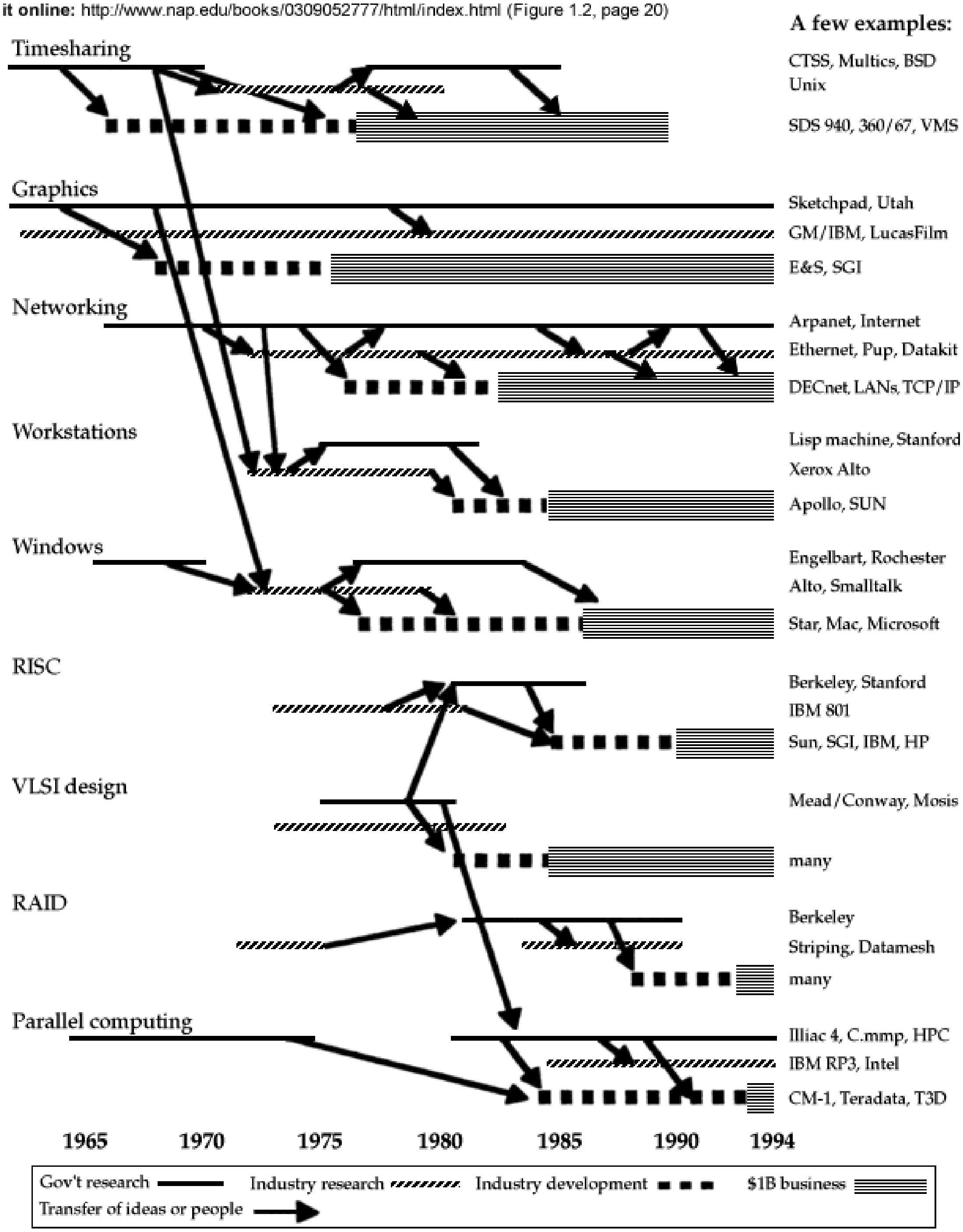

FIGURE 1.2 Government-sponsored computing research and development stimulates creation of innovative ideas and industries. Dates apply to horizontal bars, but not to arrows showing transfer of ideas and people. Table 1.1 is a companion to this figure.

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