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The Globalization of the Software Industry: Perspectives and Opportunities for Developed and Developing Countries

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Executive Summary

The spectacular growth of the software industry in some non-G7 economies has aroused both interest and concern. This paper addresses two sets of interrelated issues. First, we explore the determinants of success in software in emerging economies. We then touch on the broader issue of the lessons, if any, that can be applied to economic development more generally.

From the U.S. perspective, we think that the interesting debate is not the current one about the impact of outsourcing on jobs, but instead the one about whether offshoring of software is a long-term threat to American technological leadership. We conclude that policymakers in the United States should not fear the growth of new software-producing regions. Instead, the U.S. economy will broadly benefit from their growth. U.S. technological leadership rests in part on the continued position of the United States as the primary destination for highly trained and skilled scientists and engineers from the world over. Though this leadership position is likely to persist for some time, the increasing attractiveness of foreign emerging-economy destinations is a long-term concern for continued U.S. technological leadership.

I. Introduction

One rather unexpected phenomenon of the 1990s has been the spectacular growth of the software industry in some non-G7 economies. The first element of surprise is that these countries are not where one would expect to see the growth of what is commonly thought of as a high-tech industry. The second element is that the 1990s have shown not just growth of the industry but remarkable growth. In India, for example, software production was almost nonexistent in the early 1980s. Today, the software industry employs more than 250,000 employees, sustaining annual growth rates of 30 to 40 percent in revenues and employment over more than ten years. Although less remarkable than

India, countries like Ireland and Israel have also had double-digit growth.

This paper addresses two sets of interrelated issues. First, we explore the determinants of these successful stories. We then touch on the broader issue of the lessons, if any, that can be learned for economic development more generally. Second, the Indian, Irish, and Israeli software industries export a substantial fraction of their output (and services) to advanced economies—particularly the United States. A heated debate exists in the United States regarding the desirability of outsourcing, and the debate follows the familiar free trade versus jobs line. Rather than join this debate, we prefer to focus on a related one that is arguably of greater long-term significance. We ask specifically whether the growth of the software industry in emerging economies is beneficial for the United States, and what that growth means for the technological leadership of the United States in the long term.

In the next section, we discuss the growth of the software industry in five newcomer regions—India, Ireland, Israel, Brazil, and China. This discussion is based on the results of a two-year international project that led to our forthcoming volume (Arora and Gambardella 2005). The five comparisons provide an interesting basis for our discussion because the growth of India, Ireland, and Israel has been fueled by exports, but China and Brazil have grown largely thanks to their domestic market. From the evidence collected for these countries, we then discuss in Section III some of the reasons why they have been successful in software. In Section IV, we discuss some of the implications of this growing international division of labor for the U.S. economy. Section V takes the Indian point of view. One effect in particular must be assessed more carefully: the large outflow of human capital from India. We discuss the pros and cons of these flows for both India and the United States. Section VI discusses whether the patterns in the growth of software in our five countries can provide lessons for other emerging economies, in software or in the information technology (IT) industries more generally. Section VII summarizes some of the policy implications of our analysis; Section VIII concludes by providing some broad considerations on the topic.

II. The Software Industry in Brazil, China, India, Ireland, and Israel

During the 1990s, India, Ireland, and Israel emerged as significant software exporters. In the same period, Brazil and China also developed

Table 1.1
The software industry in Brazil, China, India, Ireland, and Israel compared to the United States, Japan, and Germany (2002 or latest available figures)

Countries	Sales ($ billion)	Employment (000)	Sales/employment (000)	Software sales/GDP (%)	Software development index[c]
Brazil[a]	7.7	160[b]	45.5[b]	1.5	0.22
China	13.3	190[b]	37.6[b]	1.1	0.23
India	12.5	250	50.0	2.5	0.96
Ireland (MNE)	12.3	15.3	803.9	10.1	0.34
Ireland (Domestic)	1.6	12.6	127.0	1.3	0.04
Israel[a]	4.1	15	273.3	3.7	0.17
United States	200	1,024	195.3	2.0	0.05
Japan[b]	85	534	159.2	2.0	0.08
Germany[a]	39.8	300	132.7	2.2	0.09

Data compiled from various sources.
[a] 2001.
[b] 2000.
[c] The software development index is the ratio between software sales over GDP (in %) and the GDP per capita of the country (in 000 $US) (See also Botelho et al. 2005.)

an extensive software sector relying largely on the domestic market and are now attempting to move to exports.[1] Table 1.1 shows that in 2002, the Indian and Chinese industries were of comparable size ($12.5 and $13.3 billion, respectively), while the 2001 sales of Brazil and Israel were $7.7 and $4.1 billion, respectively. The Irish industry reached $13.9 billion in total sales in 2002, of which $12.3 billion is attributed to multinational companies (MNCs) and $1.6 billion to the indigenous sector.[2]

The employment differences among our five countries are more marked than those in sales. In March 2003, the Indian software industry employed about 250,000 people.[3] The 2000 figures for China and Brazil are about 160,000 and 190,000, respectively. As noted, 2002 employment in the Irish software industry was about 28,000 (15,300 and 12,600, respectively, for MNCs and indigenous firms), while 2001 employment in the Israeli industry was about 15,000. To put these figures in perspective, employment in the U.S. software industry was slightly above 1 million, with sales of around $200 billion; the comparable figures for Japan were 534,000 and $85 billion.[4] Germany, the third largest software producer, employed around 300,000 and had sales around $40 billion.[5] The sales and employment figures produce notable differences in the sales per employee, with Israel having the highest sales per employee, followed by Ireland, whose figures are only slightly lower than the figures for Germany. The revenue per employee of the Indian industry in 2002 was about $50,000, which is comparable to figures for China and Brazil.

The picture that emerges from these figures is consistent with the stylized facts. The Israeli software industry is largely product- and research-and-development-oriented. The software industry in Brazil, China, and India is of a lower value added; it is heavily service-oriented in India. Ireland is in between, with a handful of product-oriented firms, and several small consultancies and niche firms.

Table 1.1 also shows that in Brazil and China, software sales are between 1 and 1.5 percent of gross domestic product (GDP), only slightly smaller than the corresponding figures for richer countries such as the United States, Japan, and Germany.[6] The software share of GDP is higher in Israel (3.7 percent) and India (2.5 percent). The shares for India and China have also increased substantially in recent years, while they have remained more stable for the other countries. In 2001, the GDP share of software was only 0.6 percent in China and 1.7 percent in India. Thus, in these two economies, software has continued to grow faster than GDP in 2001–2002, despite the general slowdown in the IT sector worldwide. In all five countries, software ranks high when compared to their overall level of development, as measured by the ratio between the software share of GDP and the GDP per capita (Botelho et al. 2005). In all five emerging countries, these ratios are far higher than those in the United States, Germany, and Japan, suggesting a specialization in software. The level of the index is particularly impressive for India (about ten to twenty times higher than the levels in the United States, Japan, and Germany).

But the most impressive figures about the software industry in these emerging economies are their growth rates, which have ranged as high as 40 percent per year in the Indian case (table 1.2, column 2). The number of firms has also grown. In India, the membership of National Association of Software and Service Companies (NASSCOM) increased from around 100 in 1990 to 797 in 2000 (Athreye 2005). Similarly, the number of new Irish software firms increased from less than 300 in 1991 to 760 in 2000 (Sands 2005). Botelho et al. (2005) report that out of a sample of 685 Brazilian software firms in existence in 2001, a little less than one-third (210) were founded between 1996 and 2000, and a slightly larger fraction (221) were founded between 1991 and 1995.[7]

Table 1.2
Brazil, China, India, Ireland, and Israel: software industry growth and export shares

Countries	Average growth in the 1990s (%)	Exports as % of sales (2002 or latest available year)
Brazil	20	1–2
China	30–35	11
India	40	80
Ireland	20	85
Israel	20	70

Data compiled from various sources.

III. Potential Determinants of the Success Stories

Export-Led Versus Development-Led Export Model

One difference between the growth patterns of India, Ireland, and Israel (the 3Is) vis-à-vis China and Brazil is noticeable. As column 3 in table 1.2 shows, the export shares of the 3Is are far higher than for China and Brazil.[8] However, the export share in China has grown substantially, from about 5 percent in 1999–2000 (Tschang and Xue 2005) to 11 percent in 2002. In China, and perhaps in Brazil as well, exports are based on competencies nurtured and developed by serving the domestic market (see Botelho et al. 2005).

Even among the 3Is, we can see differences in the extent to which the underlying growth model is export-led versus development-led. As figure 1.1 shows, the export shares for the three are converging in the late 1990s, but the starting points differ greatly. In the Indian software industry, exports were a large share of sales from the early 1990s. In 1993, the first year for which Athreye (2005) reports export and total sales data, the share was 59 percent; in 1991, it was 41 percent for the domestic Irish industry and 20 percent for the Israeli industry. As Breznitz (2005) notes, the Israeli industry was catalyzed by domestic demand and became an international player only later. Although the leading Irish firms have been export-oriented from the beginning, the growth of the Irish industries owes a great deal to the activities of MNCs who located various software operations in Ireland.

The Indian software industry is perhaps the clearest example of export-led growth. The impetus for growth initially took the form of on-site projects, in which the Indian firms (and many U.S.-based firms as well) literally rented out software programmers to work at the

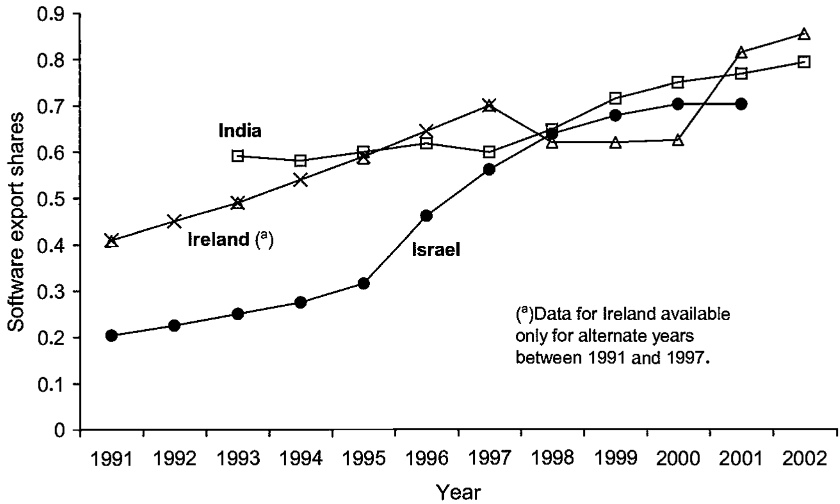

Figure 1.1
India, Ireland, and Israel: software industry export shares 1991–2002.
Source: Arora and Gambardella (2005).

client's site and under the client's management. India-based firms enjoyed a clear cost advantage over their U.S. rivals in the lower end of software services, and they did not compete directly with market leaders such as EDS, Computer Science Corporation, Anderson Consulting (now Accenture), and IBM. With booming demand, Indian firms had the opportunity to learn how to manage relatively large projects. Euro-conversion projects and projects involving the millenium change (Y2K) were well suited for the kind of competencies and skills that the Indian software industry had by then developed.

The domestic Irish industry shows a less pronounced initial dependence on exports. Sands (2005) argues that MNCs were an early source of demand for domestic software firms. As we also discuss in Arora, Gambardella, and Torrisi (2004), many successful Irish software firms started as programming houses for the subsidiaries of the MNCs in the information technology (IT) sector, or as software application developers for other non-IT firms, whether Irish or foreign-owned. Interviews with several Irish software firms indicated that they saw the MNCs both as a source of revenue and as providers of access to foreign markets.

Of the 3Is, Israel relied the least on the export market at the outset of its software industry, which makes this country the closest among the

3Is to the development-led export model. Breznitz (2005) argues that "the rapid expansion of defense research and development (R&D) and the fast accumulation of IT skills by both university graduates and graduates of the military technological units created both local demand for IT usage, the knowledge base to supply it, and a positive attitude toward this nascent industry." In addition, the Israeli software industry sits on the shoulders of a giant: The sizable Israeli IT hardware industry (55,000 employees in 2002), is a source of both demand and expertise.

The latter point is important. Apart from India, which was internationally focused from the outset, the software industry in all the other countries grew out of links with related sectors that were the sources of competencies and provided the underlying demand as well. For example, banking and telecommunications, along with customer electronics and retail automation, have been the principal sources of domestic demand in China. The government has been another big player, with national and regional governments often favoring domestic vendors for various PC-based software, from the operating system to applications software.[9] Domestic demand also explains why Brazil (rather than, for example, some of its neighbors) has become an important software producer. Brazil has an uncommonly high share of IT expenditures compared to its GDP. World Bank data cited by Botelho et al. (2005) indicate that in 2000, Brazil spent 8.3 percent of its GDP on IT, compared to 7.9 percent in the United States, 7.4 percent in Israel, 5.7 percent in China, and only 3.9 percent in India. The Brazil figure stands out when compared to its neighbors Mexico (3.2 percent) and Argentina (4.0 percent). Lead users such as banks have been central to the growth of the Brazilian software industry. Similarly, the telecom industry pushed the demand for communications software because of the growth in the demand for cell phones. Public-sector demand, exemplified by the installation of an electronic voting system, also helped (Botelho et al. 2005).

Human Capital and the Supply of Skills

One regularity among the 3Is is that they exhibited an excess supply of human capital in the 1980s and early 1990s, and specifically an excess supply of engineering and technology graduates. The 3Is are not the countries with the largest proportion or even number of science and engineering graduates. Rather, the excess supply was relative to the demand from manufacturing and related services. Simply put, the 3Is have produced more engineers than their hitherto lackluster industrial sector could absorb.[10] This fact is particularly relevant from about the mid-1970s up until the late 1980s. During this time, these countries grew only modestly while continuing to invest in science and engineering. Indeed, the average growth rate of GDP per capita for India between 1970 and 1990 was barely 2 percent per annum, while both Israel and Ireland managed to grow at 2.4 percent and 2.9 percent, respectively. In all three cases, however, this performance is lower than the performance of peer countries. It masks the large variation from one decade to another. In India, the 1970s were a period of very low growth, while the 1980s could be called the lost decade for both Israel and Ireland, a feature also reflected in the migration patterns to the United States (discussed in Section V below).[11]

In the more advanced countries and the rapidly growing Asian countries such as South Korea, Taiwan, and Singapore, science and engineering graduates faced a high opportunity cost of working in the software sector. Plentiful job opportunities in industry, in well-established firms with good opportunities, mean that fewer entrepreneurs set up software firms, and nascent software firms found it difficult to attract talented engineers.

Why the 3Is were abundant in technically skilled workers is not well understood, but there is no doubt that having such abundance was crucial for software success. Two issues must be considered here: the first has to do with the level of supply of the relevant human capital. The other issue is about the elasticity of the supply of graduates in the countries that we are studying. The education institutions in all five countries have responded with sizable increases in the number of graduates as the demand for their services rose over the 1990s.

Sanctioned engineering capacity in India increased from around 60,000 in 1987–1988 to around 340,000 in 2003, and IT capacity has increased from around 25,000 to nearly 250,000. It is likely, however, that the actual number of IT admissions increased more slowly and that the number of IT graduates increased even more slowly. NASSCOM figures indicate that in India, the number of IT graduates increased from 42,800 in 1997 to 71,000 in 2001. By comparison, the number of IT graduates in the United States increased from 37,000 in 1998 to 52,900 in 2000. During this period, the IT workforce (which does not directly correspond to IT degree holders) in the United States was probably eight- to tenfold larger than the IT workforce in India.

Table 1.3
Distributions of European Union structural funds 1989–1993 and 1994–1999 (%)

	Human resources		Infrastructure	
Country	1989–1993	1994–1999	1989–1993	1994–1999
Greece	25.6	24.6	40.9	45.9
Spain	24.2	28.4	54.0	40.4
Ireland	38.0	43.9	27.7	19.7
Portugal	26.1	29.4	29.2	29.7
Italy	21.6	21.4	38.7	29.8
Average for the 11 European Union countries	29.6	29.8	35.2	29.5

Source: First Report on Economic and Social Cohesion 1996 DG XVI EC Brussels, taken from Sands (2005).

Other countries report a similar pattern. Tschang and Xue (2005) report that in China, the number of IT graduates increased from 29,000 to 41,000 in 1999–2001. Botelho et al. (2005) note that the 18,000 IT graduates in Brazil in 2000 is a greater per-capita number than the numbers in China and India. The latest Organization for Economic Cooperation & Development (OECD) figures show that Ireland, with 34,000 graduates per year, now has the third highest share of adult population with tertiary degrees (30 percent of which are in science and technology), after Canada and the United States.

Such increases were the results of a mix of private and public efforts, with the mix varying across countries. In Ireland, Israel, and China, the bulk of the efforts were probably in the public sector. Table 1.3 shows that Ireland differs markedly from comparable European countries such as Greece and Portugal in investing a much larger share of European Union (EU) funds in human rather than physical capital.

In India, a substantial fraction of additional engineering capacity created during the 1990s was created in the private sector. Figure 1.2 (based on data from the All India Council on Technical Education) shows that the nearly 80 percent of the sanctioned intake capacity for engineering students at the undergraduate level in 2003 (about 340,000) was in privately financed colleges (those that did not receive grants from the government). The role of privately financed colleges, the vast majority of which were created in the 1990s, is even more marked if one looks only at IT-related engineering programs. Such a rapid expansion of engineering training capacity has raised valid

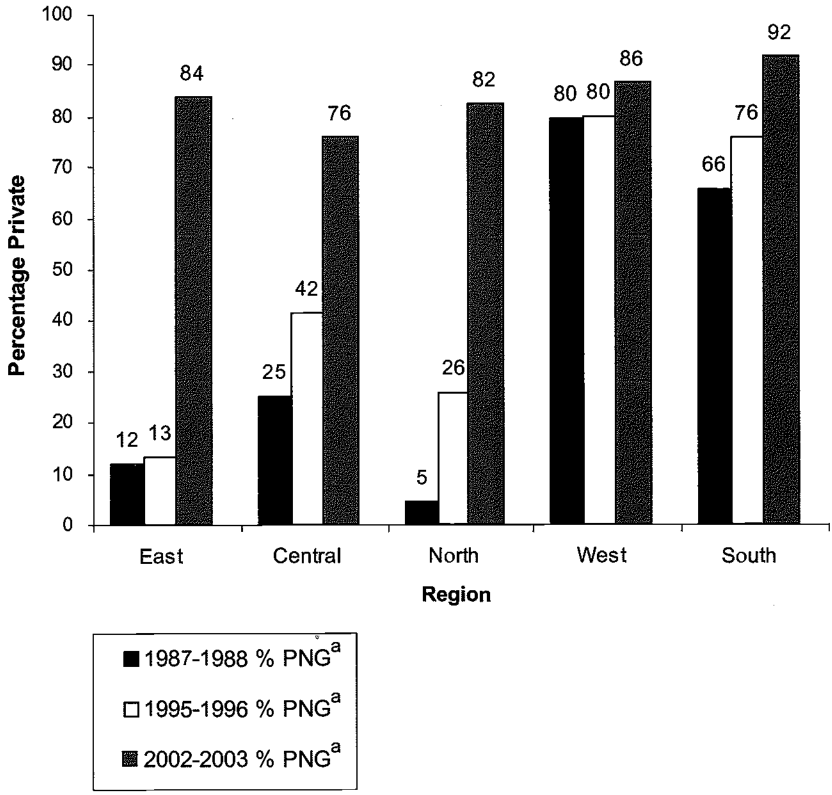

Figure 1.2
Share of privately financed colleges in Indian information technology capacity, by region and year.
[a] PNG refers to "private not granted," which are privately financed colleges.
Source: Based on data from the All India Council on Technical Education (AICTE). More details are available on request.

concerns about the quality of the education and various other social costs. Nonetheless, this supply response does indicate a flexibility that is rare in more advanced countries and also points to the perceived returns on human capital.

The Diaspora

One peculiar but crucial element of the picture has been the role of human capital flows. In addition to the human capital embedded in exports, the 3Is (and also China and Brazil) have directly supplied human capital, particularly to the United States. As a result, all the countries have a substantial diaspora in the United States. Unlike the embedded variety, the direct exports have different fiscal and economic welfare implications.

A recent set of estimates provided by Carrington and Detragiache (1998) indicate that the stock of highly skilled (more than thirteen years of schooling) immigrants in the United States from China, India, and Brazil were about 400,000, 300,000, and 60,000, respectively.[12] Kapur and McHale (2005) show that China ranks second only to India in the number of H-1B visa petitions approved by the U.S. Immigration and Naturalization Service (INS). Indians alone account for more than 42 percent of all the H-1B visas approved in this period, over half of which went for computer-related occupations. Independent estimates of the U.S. IT workforce indicates that more than 15 percent of this workforce is from Asia, of which slightly less than one-third are from India. Thus, Indian-born workers account for about 5 percent of the IT (mostly software) workforce of about 3.2 million (IT Workforce Update 2003).

The diaspora can provide links, act as reputational intermediaries, and bring back valuable skills and expertise when its members return home. Despite much talk of IT professionals returning to India and China, only in Ireland has the return of skilled emigrants clearly increased the domestic supply of skilled people (Kapur and McHale 2005). Similarly, Sands's (2005) survey of fifty-eight Irish software entrepreneurs indicates that 66 percent of the founders of the Irish software firms in her sample had worked abroad, 55 percent had worked for multinational companies, and 74 percent of her companies had one founder who worked abroad; her findings are largely consistent with earlier findings (O'Gorman et al. 1997).

The Israeli case is similar to India. There is little evidence of systematic returns to Israel of Israelis who emigrated to the United States. At the same time, no evidence points to a major skill shortage in Israel. The number of U.S. Ph.D.s awarded to Israeli nationals has remained stable since the early 1990s. At the same time, the number of Ph.D. students who plan to stay in the United States has increased slightly from 51 percent to 57 percent.

Despite the many potential benefits of a diaspora, the outflow of skilled engineers, scientists, and doctors does represent a net loss of talent and of the considerable investment in training the emigrants. The broad question about the net effects of the international mobility of skilled people on the home country is a complex one and well beyond the scope of this paper. Kapur and McHale (2005) conclude, however, that the benefits from the diaspora outweigh the costs to the 3Is for the development of the software industry. In other words, setting aside the question about whether the brain drain represented by the diaspora was beneficial or not, the software industries of India, Ireland, and Israel certainly benefited from the diaspora. Given the domestic market orientation of the software industry in China and Brazil, the trade-off has likely been less favorable.

Multinational Firms

One potential success factor that is often highlighted (even though it is sometimes controversial) in analyses like ours is the role of the multinational companies (MNCs). MNCs have been a sizable presence in the software industries of our countries. At the risk of some exaggeration, one can say that MNCs went to Israel to do R&D, to India for inexpensive skilled workers, and to Ireland to leverage tax incentives and access the European market.[13]

Giarratana, Torrisi, and Pagano (2005) show evidence of these different patterns. They show that in Ireland, the entry of the IT MNCs precedes the rise of the domestic software industry. About 57 percent of the MNCs in the Information and Communications Technology (ICT) present in Ireland today entered the country before 1990, compared to 44 percent in India and 37 percent in Israel. The difference between Ireland and the other two I's is even more marked if one looks only at the software MNCs. The shares are 55 percent for Ireland, and they drop to 18 percent and 16 percent for India and Israel, respectively. Giarratana, Torrisi, and Pagano (2005) find that while in Ireland the MNCs have contributed to the initial push of the industry, Israel today has a more active set of alliances and similar links between MNCs and domestic software companies. Giarratana, Torrisi, and Pagano also find that two-thirds of the existing ICT Irish patents assigned to local MNCs were granted before 1994, compared to 37 percent for Israel and 32 percent for India, which suggests that the MNCs have begun to invest in R&D more recently in Ireland and India as compared to Israel.[14] This finding is consistent with the view that in Ireland, the MNCs played an important role in nurturing the rise of the domestic firms when the industry started. By contrast, in Israel and in India, a co-evolution of the entry of MNCs may have occurred while the industry grew in the 1990s.

The available evidence also suggests that the MNCs, especially Siemens and Ericsson, are contributing to the formation of domestic competencies in Brazil (Botelho et al. 2005). As in Brazil, the list of the top ten to fifteen software companies in China include MNCs like IBM, Microsoft, Oracle, and SAP. These firms play a major role in the national industry, especially as suppliers of their packaged products, but their role in developing local competencies is less well understood.

IV. Has the Growth of the Indian Software Industry Been Good for the United States?

To understand the impact of the rise of the emerging Indian software industry, one must understand the nature of software engineering. Specifically, software engineering work can be decomposed into separate elements, and these do not have to be elements performed, at least at a technical level, by engineers with the same firm or even in a specific location. This basic insight about the nature of software technology results in two important observations. First, while export-oriented software has grown rapidly in these countries, the bulk of export-oriented activities has involved software activities that are (1) complementary to value-added activities done in the United States and (2) at a lower level of the value chain (for example, maintenance rather than initial product development). Second, though early attempts to establish an international division of labor in software have focused on software products and services that are likely to be easily decomposable, the next generation of contracts is much more likely to involve a higher level of integration between firms and locations. As a result, it should not be surprising if Indian software firms start to establish facilities in the United States, and that leading U.S. firms begin to locate at least some high-level engineering work in emerging economy establishments. The remainder of this section develops our basic insight about product modularity more carefully, and then draws out the implication for the impact of these factors on economic development in the United States and emerging economies. Because outsourcing to India is the most significant in terms of employment, we focus on the Indian case to illustrate our argument.

We shall not enter the debate on whether the current job losses due to growth in software production overseas will be quickly made up by the creation of new opportunities at home. In our view, this debate echoes earlier debates that appear to pit free trade against job losses in existing industries. The conclusion of most mainstream economists, with which we broadly agree, is that although free trade creates winners and losers, the gains are greater than the losses, and thus, if the winners can compensate the losers, free trade ought to be supported. In this instance we think that policies such as retraining, that ameliorate the impact of such job losses, are beneficial.[15] It is also worth pointing out that the total Indian software workforce engaged in exports (estimated to be less than 400,000) is still a small fraction of the more than 3.2 million software professionals in the United States. Indeed, it is conceivable that the business cycle and technical progress in software technologies, which are making possible the automation of several tasks (such as some aspects of network and database administration) and testing and code reuse, are more potent in this context than the growth of the Indian software sector.

Thus, our focus is on a related question. Suppose that free trade is superior because the United States is relinquishing activities that are becoming commodities, and the United States no longer enjoys a comparative advantage. Some observers have speculated that this process will lead the Indian software industry to become more sophisticated and productive, so that the current set of activities in which the United States currently dominates, namely, those intensive in design and innovation, will also be lost. A more extreme version of this view is that R&D follows manufacturing, so that the offshoring of manufacturing will quickly lead to R&D activities also moving offshore. Might therefore the offshoring of software coding and maintenance cause manufacturing to be followed soon by the more design-intensive activities as well? The answer is simple. Such a succession is neither quick nor is it inevitable. Indeed, strong reasons support the belief that the United States will remain the center of software innovation for the foreseeable future.

Though it is not easy to find the analog of production in software, one can roughly divide software-related activities into design, coding, and maintenance. Subject to the usual caveats when one draws such sharp contrasts, one can think of coding and maintenance as analogous to production. Much (though not all) of the software-related activity carried out in the emerging economies is of the sort that complements the activities carried out by software firms, substituting for the most part activities carried out by the user sectors. For instance, NASSCOM figures indicate that the three largest industry verticals in terms of the share of export revenues for the Indian software industry are banking, finance, and insurance (35 percent); manufacturing (12 percent), and telecom (12 percent).[16] Though at variance with the common perception that the software industry in India is the result of outsourcing by U.S. software firms, the result should not be surprising. Software is a general-purpose technology, with the result that user sectors account for a substantial portion of software production. For instance, the latest available data from the Bureau of Economic Analysis (BEA) shows that of the 3.2 million IT workers (including programmers, network administrators, and Information Security (IS) managers), only about 1 million worked in the software industry itself. Thus, nearly two-thirds work in the rest of the economy, especially insurance, banking, and finance.

In this sense, much of what is being offshored to India is the production of software, rather than its design. We have already noted the low revenue per employee in the Indian software industry, approximately 25 percent of that in the U.S. industry. Other evidence points in the same direction as well. Arora et al. (2001) cite evidence from interviews with Indian software firms between 1997 and 1999 and find that porting existing applications from mainframe to client server, maintenance, and enhancement of existing applications are examples of typical activities. The typical projects were small and technically undemanding, and responses to a survey of Indian software firms indicated that the most important project in 1998 had a median size of 150 labor-months. Since then, the activities have become more sophisticated and larger in scale (Athreye 2005). However, requirements analysis and design, not to mention creation of new products and solutions, is still mostly the province of the United States.

If India is taking up mostly production and maintenance jobs while leaving the more innovative segments of the industry to the United States, we then have to understand the implications of the physical separation of these two activities. Note first that in many industries, the locus of production and the locus of invention are physically separated, particularly when the body of knowledge underlying the invention process has a strong scientific basis. Building on earlier work by Lamoreaux and Sokoloff (1996, 1997), Sutthiphisal (2003) studied the location of production and invention in three different industries during the second industrial revolution, (that is, the textile, shoe, and electric industries). She finds that, in general, the locus of invention did not shift with the locus of production as the latter moved to other locations. She also finds that the link between location of production and invention is weaker in the more science-based electric industry. Using data from a century later, Mariani (2001) studies the location of

R&D and production facilities by the Japanese MNCs in Europe. She finds that in low and medium R&D industries, R&D labs are more likely to be located close to production facilities than they are in more R&D-intensive industries.

A physical separation between the design-intensive and production activities comes with costs, including transaction and contracting costs, and communication and management costs. Physical separation may reduce the potential learning from production (Arrow 1962, Enos 1962) or from the feedback and links emphasized by Kline and Rosenberg (1986). Nonetheless, the lower cost of labor and the ability to work around the clock are important offsetting features. Perhaps the least appreciated benefit is the greater project management and delivery abilities of Indian software firms, abilities they have acquired over the last decade. Competition among Indian firms has meant that the benefits have accrued largely to the customers of Indian software firms, that is, to American firms. This point is obvious when stated because it is a benefit of free trade. Less obvious is the implication that firms from countries such as Japan, Germany, and France benefit far less. Because the principal competition for U.S. firms is still from these countries, important strategic benefits also accrue. Simply put, by outsourcing, U.S. firms are gaining important advantages over European and Japanese competitors in terms of lower costs, greater flexibility, and shorter product development cycles.

With globalization of production, it is perhaps inevitable that competing regions and countries will be able to learn and improve their productivity and challenge the leader. The leader must make sustained investments in innovation. Evidence about these patterns is offered by the long-term history of the U.S. chemical industry. The U.S. chemical industry grew through technology borrowed mainly from Germany and the United Kingdom. World War II and the shift from coal- to oil-based feedstocks marked the rise of the United States as the technology leader, albeit some time after it had emerged as the leading chemical-producing nation. Over time, chemical production has grown elsewhere, particularly in economies such as Taiwan and Korea, and since the 1980s, in China, India, and the Middle East. As we discuss in Arora and Gambardella (1998), since the 1950s, the U.S. chemical industry has developed an independent sector of specialized engineering firms (SEFs) that supplied new process technologies via licenses and chemical process engineering services to the rest of the world. In so doing, they nurtured the international competitors of the U.S. chemical firms as much as they nurtured the U.S. chemical companies.[17]

Can the United States specialize and keep its comparative advantage in the higher end industrial activities? The starting point for this discussion is to note that two key resources are required to remain the center of innovation in software: access to talented designers, software engineers, and programmers; and proximity to several large and technically sophisticated users. The United States dominates on both counts.

As noted in Section II, emerging software-producing regions are leveraging their abundance of relatively underused human capital, especially engineers and IT professionals. The United States also produces abundant human capital, but that is not all. The very same processes of globalization that have led to the growth of software overseas have also worked to attract the best and brightest to the United States. Thanks to the size and the openness of its culture and economy, the United States has had no difficulty in attracting talent, providing it with a strong advantage over potential competitors such as Japan or Western Europe.

Even more prominent is the relationship with users. New software applications depend largely on knowledge about demand and about the use of the applications. This dependence is apparent, for example, in telecommunications and semiconductors, where the software needed to design the chip is part of the product itself. More generally, a substantial fraction of software is used for running businesses and business processes. Hence, proximity to business activities is crucial for innovation in this industry, which consists of solutions to emerging business problems, often specific to particular industrial sectors such as banking, finance, and retail, as well as telecommunications and manufacturing. Indeed, the development of new commercial applications or solutions is a special comparative advantage of the United States. India's economy is growing and we expect that sophisticated domestic demand for software will eventually rise in India. At present, however, the U.S. lead is overwhelming.

As was true of human capital, globalization may reinforce this lead because we find that innovative companies from Israel, Ireland, and even India, are likely to move their operations to the United States to be closer to their users. Sometimes venture capitalists also push for such move. Although firms do not have to be based in the United States to tap its equity markets, a strong presence in the United States does help a great deal. Similarly, other intermediating institutions such as legal services and large and functioning labor markets are other important sources of advantage that the United States enjoys, and these are not likely to be eroded soon.

Countertendencies are also at work. If Indians have a preference for staying in their home country, the cost of scientists and engineers will be lower in India, so that the cost of R&D activities that are human capital–intensive and relatively less intensive in physical infrastructure will be lower. Anecdotal evidence suggests that India is viewed as an attractive location for certain types of R&D activities, although anecdotal evidence also suggests that U.S. firms are not locating mission-critical activities in India, nor are they moving activities at the technological frontier.

V. Is the Globalization of Software Beneficial for India?

The other natural twist to the question that we asked in the previous section is whether the growth of software, and particularly its globalization, has had net benefits for India.[18] In addition to the standard benefits from specialization according to comparative advantage, one must also reckon the benefits from increasing returns to scale and from possible productivity increases as Indian firms learn and gain experience. In this respect, it was a crucial strategy for India to specialize in activities that were complementary with the international industry. If India had instead moved up quickly to higher-value-added products, as many had suggested (perhaps because of the common belief that moving up the value chain is the only way to sustain an industry), it would most likely have conflicted with the United States. Ireland and Israel did face this problem, especially during the downturn of the international IT demand after 2000. Because software *product* development was more important in these countries than it was in India, it was natural that the reduced international demand for IT had a bigger impact on them. Indeed, as we showed in Arora and Gambardella (2005), the performance of the Irish and Israeli software industries faltered in 2001–2002, with reduced profitability and employment for the first time since the early 1990s. By contrast, the growth of the Indian software industry slowed, but only to about 20 percent per year in this period.

To summarize, because of the opportunities created by the international demand, India has had obvious benefits from its rising software skills. First and foremost, the growth of software has contributed in a nontrivial way to the growth of the country as whole. The growth of the software industry has provided the basis for the growth of a new entrepreneurial model, which in turn has had spillovers for related activities, such as business services and even some type of R&D tasks.

Table 1.4
Selected foreign-born populations age 25 and over in the United States

	1990	2000	% change	% of 2000 population entering post-1990	Educational attainment (2000)		
					Primary %	Secondary %	Tertiary %
India	304	837	175	55	5	15	80
Brazil	54	154	186	49	9	36	55
China	405	847	109	66	20	26	54

Source: Kapur and McHale (2005). Original data from the March 2001 Current Population Survey of the United States.

Table 1.5
Selected foreign-born populations in the United States by year of entry

	Indian-born	Irish-born	Israeli-born
Before 1960	1%	32%	4%
1960–1969	3%	19%	1%
1970–1979	14%	8%	28%
1980–1989	24%	23%	35%
1990–1995	23%	13%	18%
1996–2001	36%	5%	14%

Source: Kapur and McHale (2005). Original data from the March 2001 Current Population Survey of the United States.

One feature provides pause for thought, namely, the observed patterns of international migration of human capital. As tables 1.4 and 1.5 show, the number of Indian-born residents in the United States increased nearly threefold between 1990 and 2000, with over 80 percent of the Indian-born residents having tertiary-level education. Brazilian- and Chinese-born residents have lower levels of tertiary education than do Indians, but it is still above 50 percent, and these levels have also increased rapidly in the last decade. To put these figures in perspective, around 50 percent of the native-born adult population in the United States has tertiary education, second only to Canada.

Such large-scale migration of human capital has conflicting welfare implications. To the extent that the increase in the U.S. labor supply curbs the U.S. wages, native-born workers have lower welfare than they would without international labor mobility. By contrast, the Indian workers gain because the salary of the emigrants increases, as does the salary of the workers who stay in India (or at least it does not fall as much as it might have given the large increases in the supply of Indian IT workers). The standard argument, however, also implies that because the migration follows more productive opportunities in the United States, the re-allocation of Indian workers to the United States implies a higher combined output of the two countries than if migration did not take place. Hence, proper redistribution policies, or the extent to which Indian workers ship some of their rents back to India (for example, links to Indian software companies, returnees, consumption of other Indian commodities), may in the end enhance the overall value for India as well.

Yet if externalities exist in software production (because of spillovers or scale economies) associated with the agglomeration of human capital, the picture could be different. Such externalities are plausible in activities like software. With externalities, it is possible that as more Indian IT engineers flow to Silicon Valley or other U.S. locations specializing in IT, the productivity of these workers may even increase, at least until congestion effects overwhelm them. The increase in productivity would then encourage more migration from India. In addition, if the Indian industry suffers from reduced spillovers or lower-scale economies because of the outflow of skilled workers, Indian software salaries may not rise fast enough to match U.S. salaries. This situation may imply persistence differences in salary that feed a continuous outward flow of software professionals from India to the United States.[19]

The available evidence suggests, however, that in fact Indian software salaries have increased faster than those in the United States. Athreye (2005) presents data that suggest U.S. salaries for various software occupations such as programmer, project leader, quality assurance specialist, and systems designer increased by about 21 percent between 1995 and 1999, and Indian salaries increased by nearly 45 percent.

In sum, while the migration of Indian talent to the United States can be a problem for India if externalities are involved in these activities, it is India's ability to sustain a continuous flow of human capital that may turn this situation into a major opportunity. As people move but are replaced by new workers, the flow of workers to the United States feeds its software industry with talented programmers and motivated entrepreneurs. Indeed, the main Indian (or Chinese) resource could easily be its academic system, which supplies human capital to the world.

VI. Software: A Model for Other Emerging Economies?

The spectacular growth of software in India, Ireland, and Israel raises the natural question, Are other developing countries taking up a similar opportunity? We believe that potential emulators will likely find it difficult to replicate two central features of the successful growth of the software industry in the 3Is: the excess supply of skills and the international connections.

Software is labor-intensive, but it does require skilled and trained labor. Indeed, the software industry makes little use of workers with modest education and training, in marked contrast to large-scale manufacturing operations. Most developing regions have abundant labor, but rarely abundant skilled labor. Not only could this feature hamper the growth of a software industry, such a growth may even increase inequality by greatly increasing demand for the small segment of the population that is highly skilled and educated and leave almost untouched the rest. Indeed, the growth of the software industry draws away skilled engineers from other sectors. This trend may not only increase inequality but may also reduce rather than increase total output if the growing middle-class incomes are primarily directed at imports (see Gambardella and Ulph 2003).

Several non-G7 countries have a substantial number of underemployed college graduates. However, few are English-speaking countries with a diaspora or other means of linking to their potential export markets. Therefore, it is unlikely that others can replicate a success of similar proportions, even more so because they would be playing catchup.

Nonetheless, software has thrived in a few regions in the world, but not at the rates that we have observed for our 3Is. As we discussed earlier, and in greater detail in Arora and Gambardella (2005), other successful examples in software include Finland and South Korea. To a lesser extent, Hungary and the Czech Republic are also showing some signs of vitality in this area. Broadly speaking, all these cases fit our model. They all have a relatively higher share of educated population compared to their level of development. At the same time, they do not have a wide and diversified industrial basis, which implies that the opportunity cost for these people to work in the software industry is not significant. Furthermore, domestic sources exist for the formation of software competencies, like the electronics industry in Korea, the telecom leader Nokia in Finland, or some investments in ICT and electronics foreign firms in Hungary and the Czech Republic.

More generally, one can list the exportable lessons for other emerging economies. First and foremost, our cases have underscored the importance of openness. Export markets can facilitate scales of operation and opportunities for learning that would not be possible otherwise. As we have emphasized, however, openness means more than free trade. It includes openness to MNCs. In Ireland, for instance, MNCs have been important as sources of demand and competencies, and in India, they appear to have helped in legitimizing India as a source of software. Doubtless, relying on export markets also makes one more vulnerable to the vagaries of the business cycle and policies in those markets, policies over which one can have little control. Openness also has other costs. Domestic firms may be squeezed out of learning opportunities, and experienced managers and engineers may be lured away to jobs in the developed countries, as in India or Israel. Such mobility of people, which is an important component of openness, can be turned into an advantage because ethnic links often underpin important trade links (Rauch 2001), and in a human capital–intensive industry such as software, such links are vital. If conditions are right, some of the emigrants may also return, as was the case in Ireland, bringing with them valuable skills and experience, both technical and managerial.

A second exportable lesson is that the upgrading to overcome the inevitable erosion of initial competitive advantage can take many forms. In particular, it does not have to take the form of moving up the technology ladder. For instance, many observers of the Indian software industry have noted that with the growth of the industry, the advantage of low wages would decline. Many even characterized the growth of the Indian software industry as unsustainable unless firms began to invest in R&D to undertake sophisticated product development. The prescription that emerged was that Indian firms would have to move rapidly from programming to higher-value activities such as design and product development (Heeks 1996, DaCosta 1998).[20] Such recommendations are often part of a broader mind-set, wherein progress in technology-intensive industries must necessarily take the form of moving up the technology ladder, to parallel (if not imitate) the activities undertaken in the rich countries. Indeed, policy makers in developing countries often point with pride to the technological accomplishments achieved in their countries, treating them as indicators of success. Considerable pride is based on the formation of national champions and the ability to undertake high-tech projects and produce technically sophisticated products, regardless of their commercial feasibility.

The lessons from the Indian experience are the opposite. To be sure, in recent years the leading Indian firms have managed to take on a larger range of activities. But for the most part, developing new products or undertaking high-level design has not been the principal means of offsetting the wage advantage. Rather, Indian firms upgraded their ability to take on and manage larger projects. Instead of moving aggressively into product design, they focused on performing lower-end functions such as maintenance and support. This strategy also fits theoretical models of the advantages from international trade, such as the one by Gomory and Baumol (2000). In this respect, the lower-end activities undertaken by Indian firms involve a steady and predictable, although not as lucrative, stream of revenues because maintenance contracts are typically three to five years in duration. This focus leveraged the capabilities that Indian firms had developed, which was to manage projects with large teams of skilled people.

Conversely, most of the early forays of Indian software firms into product development did not pay off. We do observe other Indian software firms (mostly later entrants that do not have the same possibilities in software services) investing in developing products for targeted niche markets as a means of differentiating themselves. Some of these firms are likely to succeed. Even if they fail, however, it is unlikely to shake the foundations on which the Indian software industry has grown.

The Indian experience can be compared to the development-led export model of Brazil and China. Growth based on domestic demand can give rise to development processes that help firms move down their learning curve, even though the drawback of any strategy that relies too strongly on the domestic market is that too great a focus can be placed on the idiosyncratic needs of local users, as the Brazilian case suggested. The Chinese strategy, which is essentially one of import substitution, is even less promising in terms of the export markets in the West. It may prove of some value, however, in terms of the East Asian export markets of Japan and Korea.

Finally, our case studies highlight the importance of entrepreneurship. In each of the countries, firms have sprung up to exploit the opportunities opened up by the growth of demand for software. However, these firms have not formed in a vacuum. Frequently, related industries such as IT, telecom, and hardware have supplied the entrepreneurs and managers. In some cases, particularly in Ireland and India, nationals working and trained overseas have played an important role as well. For countries wishing to develop their own software industry, a key question is, Do they have the related industries to act as the nurseries for future software entrepreneurs and managers?

But our studies also provide a message of hope in this regard. For India and Ireland, and to a lesser extent for Israel, entrepreneurship in high-tech industries had hitherto been the exception, not the norm. These countries had mostly lacked a culture of risk taking that one takes for granted in the United States. Financial institutions and capital markets were not set up to promote entrepreneurship, and few role models were available. In India, commercial success had hitherto required preferential access to government permits and capital markets to exploit the protected India market. In Ireland, few believed that Irish scientists and engineers could develop and commercialize world-scale technology until companies like Iona or Baltimore proved them wrong. Quite simply, the elasticity of entrepreneurship has proven to be high. For policy makers in developing countries, this should be welcome news. What is required is not special programs to encourage entrepreneurship but a clear opportunity and an economic environment that minimizes legal barriers to entry and exit. For software, this welcome news must be tempered. Not only is the sustained boom of the 1990s unlikely to repeat itself in the near future, but even if such a boom arose, newcomers would have to contend with established incumbents.

VII. Implications for Policy

The previous three sections hold specific implications for effective policy in both the United States and the emerging economies. The implications for U.S. policy are twofold. On balance, the rise of software services in emerging economies is a boon for the U.S. economy. Calls for restricting outsourcing are likely to harm the competitiveness of U.S. firms and reduce efficiency. Because equity is often sacrificed at the altar of efficiency in economic analysis, however, we stress that policies for mitigating the impact on software professionals is not only fair but, more important, upgrading the technical skills of the U.S. workforce is important also for sustaining the U.S. technological leadership. The U.S. leadership in technology has been based in some measure on access to skilled and talented people from the world over.

In the short term, concerns over terrorism and anaemic job growth now threaten one of the most potent sources of U.S. advantage: its open economy and culture. Though such threats are perhaps not severe and the United States is likely to remain the primary destination for emigrants with training and drive (often educated at public expense in their home countries), policy must account for the growing attraction of other economies. In terms of the emerging economies, our stories have shown the benefits of organizing policy to encourage economic growth based on the development of these types of industries around an investment in human capital; openness to international trade, investment, and competition; and domestic economic liberalization.

The implications for technology policy are more diffuse. Israel and Ireland are instances where enlightened government policy did help the software industry. Even here, the evidence for the efficacy of targeted sector-specific policies is limited at best. Israel's software industry benefited from general support for R&D and human capital development, and from the earlier growth of the computer hardware and electronics industries. The benefits of government venture capital funding and incubators, and in particular, whether the benefits outweigh the costs, are difficult to assess. Ireland's welcome for foreign direct investment was aimed at boosting employment rather than promoting software. Software did benefit directly because these MNCs were initial sources of demand and sources of competencies. We speculate that the indirect effects, including the training of managers and of legitimizing Ireland as a place to develop software, will prove to be more important.

The Indian case shows that a weak and inefficient bureaucratic structure works best when it attempts not to do too much. It also shows the virtues of decentralization. Competition among Indian states to develop software has obviously kept political excesses in check and has focused government policy on addressing issues such as physical infrastructure instead of attempting to channel the industry into high-tech and high-value-added directions, or attempting to regulate entry and entrepreneurship. This situation is also an instance of the political economy of success: the success of the software industry has provided celebrity status for Indian software entrepreneurs and political clout for the industry, which the industry has used to push for sensible tax and capital market policies (Arora, Gambardella, and Torrisi 2004).

VIII. Conclusion

In the traditional neoclassical model, capital and labor are symmetric. Countries with relatively abundant labor supplies can just as easily specialize in labor-intensive sectors and adopt labor-intensive technologies as countries with abundant capital, who can specialize in capital-intensive sectors. As we all know, however, labor and capital have been anything but symmetrical. Poor countries have had to follow in the footsteps of richer countries, moving from agriculture to manufacturing, moving from labor-intensive to capital-intensive sectors. Might software, with its dependence on human capital but relatively low intensity in physical capital, offer a new way for labor-abundant countries? Can developing countries leverage their abundant labor endowments to target human capital–intensive service sectors for exports and growth, without having to invest the large amounts of capital that manufacturing requires?

It is true that software, particularly software services, do allow a country to participate in the high-tech sector with only a limited physical infrastructure. However, even a successful software industry is likely to account for a small share of GDP and employment. The software industries in the countries we have studied, except Ireland, account for at best 2 to 3 percent of their respective GDPs and an even smaller fraction of the total labor force, so that the direct impact on economic growth is likely to be small. Hence, we turn to examine the indirect effects.

One possible set of indirect effects works through the links to other sectors. Some authors have argued that software is to the knowledge-based economy what capital goods were to manufacturing—an input source whose importance for productivity and innovation was far greater than was reflected in revenues or share of GDP. Software does supply basic inputs to almost every industrial sector. Better software would therefore increase productivity across the board. Though attractive, this argument has a problem. Software is internationally traded and it is not clear why a country, particularly one not at the leading edge of technology, could not use software developed elsewhere. A domestic software sector that can tailor software to local requirements at lower costs may have some advantages. However, this must be weighed against the possible lower efficiency in developing software domestically. The net effect of all these factors is that having a domestic software industry provides at best a modest contribution to the overall growth of the economy, even when considering the potential effects on the large set of domestic user firms and industries.

Success at an export-oriented industry also has spillovers for other industries in terms of enhanced reputation. China's initial success in producing and exporting light manufactures of all kinds has earned it the reputation of being a desirable location for all manufacturing. Conversely, years ago, Japanese automakers had to fight the reputation for shoddy quality that its early exports of light manufactures had earned. Today, India enjoys a reputation for service quality largely because of its software industry. It is no accident that it is the favored destination for other service exports, ranging from call centers to customer care, medical transcription, and high-end R&D services.

We believe more potent indirect effects work more subtly. Most of the successful software firms in the 3Is, in modeling themselves after their Silicon Valley counterparts, have also stressed shareholder value, and responsible and transparent corporate governance and accounting. Though American corporate governance is under attack, and with justification, it is likely superior to the practices of the traditional firms in many developing economies, which frequently resemble family fiefdoms more than shareholder-owned corporations. The software industry can act as an exemplar of a new business model that features flatter organizations, individual incentives, competition, and export orientation, particularly for other sectors that rely on skilled workers.

But perhaps most important of all, the success of an export-oriented software industry can show to potential entrepreneurs what is possible with talent, luck, and hard work. In Ireland, the success of the software industry provided others with the confidence that Irish high-tech firms can compete with any in the world. In India, software was almost the first instance where wealth was created honestly and legally, and more important, visibly so. Before the development of the software industry, wealth came either from breaking laws or at least bending them to one's convenience, using existing political and economic power. Partly as a result, commercial success had invited envy, cynicism, and even outright hostility, and only rarely admiration. While envy and hostility are not gone by any means, there is much more of admiration and, more important, a desire for imitation. Of course, entrepreneurs can succeed only if other conditions are also present. Some, such as international links and a supply of skills, are not easy to create. However, the task for any underdog region is probably easier today than at any other time in the past.

Policy makers in the United States should not view the growth of underdog regions with fear. Instead, the U.S. economy will broadly benefit from their growth. Over time, the growth of software and other high-technology industries in these economies may raise other challenges. U.S. technological leadership rests in part on the continued position of the United States as the primary destination for highly trained and skilled scientits and engineers from the world over. Though this position is likely to persist for some time, the increasing attractiveness of foreign emerging economy destinations is a long-term concern for continued U.S. technological leadership.

Notes

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1. While the 3Is stand somewhat separately because of a set of peculiar features (for example, the diaspora, English-speaking human capital, large export shares), the patterns observed for China and Brazil bear greater similarities with other non-G7 countries. For example, in South Korea too the software industry has relied mainly on the domestic market and on spillovers from leading industries like hardware and electronics.

2. The Irish MNC sales are most likely inflated by accounting devices guided by the substantial tax concessions offered by the country. Indeed, the MNCs in Ireland have employment levels comparable to that of the indigenous firms (15,300 and 12,600, respectively, in 2002), while their sales are over eight times as much. Because they mostly adjust their products for local markets in Ireland, not design them, this gap must arise mainly from accounting reasons, not superior value added.

3. This figure excludes what NASSCOM calls IT-enabled services, such as call centers and help desk operations, which employ 160,000. Another 260,000 software professionals are estimated to work in what NASSCOM calls user organizations.

4. Note that about two-thirds of all software occupations are not in the IT sectors. Thus, the true number of software workers in the United States is probably closer to 3 million (see also IT Workforce Update 2003).

5. It is likely that in these countries, the true size of software production is even higher because a large number of firms not in the software business, such telecommunications, banking and finance, and large retail and banking firms, produce significant amounts of software for their internal use.

6. The GDP shares of Brazil, China, and the domestic Irish software industry are indeed higher than other G7 countries, like the United Kingdom (1 percent) or Italy (0.8 percent), and they are comparable to the figure for all the G7 countries taken as a whole.

7. There are no specific figures for the creation of new software firms in China or Israel. However, the existing scattered accounts support the idea of high rates of entry into the software industry in both countries.

8. As shown in Sands (2005), the software MNCs in Ireland exported 95 percent of their sales in 2002, and this percentage has mostly been above 90 percent since 1991.

9. For example, Saxenian (2003) reports that the Beijing municipal government and the Guangdong provincial government recently required that all their departments used a Chinese-language office software package, WPS2000, rather than Microsoft Office 2000, in spite of its lower technical quality.

10. In the Israeli case, the economic crisis in the early 1980s and the growing military alliance with the United States after the 1973 war led to a significant downsizing in the defense industry. The most notable instance was the decision to stop the development of the latest fighter jet (the Lavi). The result was that thousands of highly trained and experienced engineers became available. Breznitz (2005) also notes that generous redundancy packages became seed capital for many of these would-be entrepreneurs.

11. A regression of the stock of scientists and engineers on per-capita GDP and other factors (not reported here) showed that the 3Is all had actual stocks that were higher than the predicted stocks of scientists and engineers.

12. Brazilian emigration of skilled workers, though lower in absolute volume, are comparable with India and China when expressed as a percentage of the stock of skilled population. The small absolute size of the stock of Brazilian immigrants in the United States has meant, however, that little is known about their role in the growth of the Brazilian software industry.

13. In time, they also established software development and R&D facilities in Ireland. Of course, India is too large a market to ignore for software products, and so firms like Oracle and Microsoft also came to sell in India.

14. Giarratana et al. (2005) confirm the stronger links between domestic and multinational ICT firms in Israel by using patent citation data. More cross-cites occur among the two types of firms in Israel than occur in the other two countries.

15. On the debate about the outcomes for the United States of the outsourcing game in software and IT more generally, see Mann (2003) and the McKinsey Global Industry report (MGI 2003).

16. http://www.nasscom.org/artdisplay.asp?cat_id=314 (last viewed on 2 May, 2004).

17. Even if the U.S. chemical suppliers were hurt by the international diffusion of technology, U.S. engineering firms and contractors have benefited. Indeed, the United States is still the world leader in the provision of chemical process technology and engineering services.

18. Once again, we focus on India for brevity and emphasis.

19. The problem would be even more severe with some sort of selection, that is, if those who move are the more productive workers who can take greater advantage of the opportunities that open up in more advanced nations. Indeed, Europe faces this problem today. The European brain drain to the United States does imply a possible deficit of highly skilled people. Yet a major difference between Europe and India is that India can

produce human capital at a substantially higher rate in large measure because of a much younger population, so India can sustain a net outward migration for much longer.

20. This recommendation was frequently, accompanied by a complementary recommendation for firms to focus on the domestic market, which would provide the initial demand for more sophisticated products and services. Arora et al. (2001) conclude that the competencies developed in the domestic Indian market were not helpful for exports. Athreye's study of CITIL (now i-Flex), a Citibank subsidiary, indicates that the Indian market could provide a fruitful learning base for products (in this case, a back-end banking product) that could be successfully exported. The study also makes clear, however, that this strategy depends on several conditions for its success. In this case, Citibank's internal use of the product (albeit in India and other developing country markets) provided important legitimization. CITIL's strategy was to focus initially on other developing country markets, particularly in the British Commonwealth, avoiding head-to-head competition with incumbent producers in developed countries, most of which were not large established firms. Only after succeeding in the export markets did CITIL enter the developed country markets.

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