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Determinants of Technological Progress: Recent Trends and Prospects

As discussed in the previous chapter, the pace at which technologies spread between and within countries has picked up. As a result, most developing countries are narrowing the technological divide that separates them from high-income countries. Nevertheless, the technology gap remains large; for many, including several low-income countries, it is widening rather than closing, in part because of the slowness with which technologies spread within countries. For virtually all developing countries, the domestic pace of technological progress is determined mainly by the speed with which already existing technologies are adopted, adapted, and successfully applied domestically, and done so throughout the economy, not just in the main cities.

This chapter explores some of the major determinants of this kind of within-country diffusion of technology. It adopts an analytical framework that distinguishes between the factors that dictate the extent to which an economy is exposed to external technologies on the one hand and the efficiency with which it absorbs them on the other hand. Among the most important channels through which low- and middle-income countries are exposed to foreign technologies are trade; foreign direct investment (FDI); and contacts with highly skilled diaspora members (nationals working abroad) and with other information networks, including those of academia and the media. Maintaining an open environment to such flows is critical for accessing technology at least cost. However, no matter how compellingly useful a technology may be, the process by which it spreads within a country can be lengthy.

The speed with which a country absorbs and adopts technology depends on many factors, including the extent to which a country has a technologically literate workforce and a highly skilled elite; promotes an investment climate that encourages investment and permits the creation and expansion of firms using higher-technology processes; permits access to capital; and has adequate public sector institutions to promote the diffusion of critical technologies where private demand or market forces are inadequate.

The process of technology absorption is also subject to virtuous circles. Scale economies in technologically sophisticated sectors and in learning by doing tend to make the acquisition of technology a nonlinear process, characterized initially by slow penetration until some threshold is reached, followed by a period of rapid acceleration, and finally by a period of slower diffusion as saturation is achieved. As a consequence, while gaps in technological achievement create opportunities for accelerated growth and convergence in lagging economies, they can also lead to divergence if the conditions for technology adoption in lagging countries are insufficient. Many technologies operate synergistically to reinforce the demand for each other and the effectiveness and capacity of supply.

Although the process of technological diffusion has a clear logic, the process is by no means mechanical. It occurs through interactions among individuals, entrepreneurs, firms, and governments. The role of government is both direct, as a supplier of many technological services, and indirect. In particular, the efficiency with which firms can diffuse technology within the domestic economy depends on the overall political and economic context, the level and distribution of human capital, the quality of the macroeconomic environment, and the rules and regulations governing the conduct of business, all of which are heavily influenced by governments.

This chapter discusses the principal channels through which developing countries are exposed to advanced technology, analyzes the main determinants of domestic absorptive capacity, and indicates likely future trends in technological diffusion. The following six main messages emerge from this analysis.

> *The principal channels by which developing countries are exposed to external technology—which include trade, FDI, and a highly skilled diaspora—have increased substantially over the past several decades.* The share of imported high-tech products in gross domestic product (GDP) has risen by more than half in both low- and middle-income regions since the mid-1990s, that of imports of capital goods by 37 percent, that of imports of intermediate goods by 26 percent, and that of FDI inflows by sixfold since the 1980s. Finally, the size and sophistication of global diasporas has increased markedly, along with substantial improvements in the technology by which migrants can transmit their know-how and interact with their home economies.
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> *The ability to absorb foreign technology, which depends on domestic policies and institutions, has also improved in many developing countries.* Reflecting rising school enrollment, literacy rates in low-income countries have increased from less than 50 percent in 1990 to more than 62 percent, and among youth they now exceed 74 percent. In addition, the macroeconomic, governance, and investment climate that innovative firms and entrepreneurs need to operate is improving. More countries are operating in a context of close to stable prices (median inflation in low-income countries declined from 9.2 to 4.2 percent between 1990 and 2006) and flexible exchange rate regimes, while government finances are better balanced.
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> *Technological diffusion among middle-income countries has benefited from the reorientation of global production processes.* Advances in communications and transport technology have given rise to the growth of global production networks, facilitating increased trade and technological advances in many developing countries, particularly middle-income developing countries. Until recently, low wages and a solid, if low, level of basic technological literacy have been sufficient to capture a significant role in global networks in many countries. As wages rise, however, these countries will need to make substantial additional investments in human capital to maintain their share of global production and continue the technological convergence of the past few years. They will also need to adopt a more proactive approach to developing local competencies and to using research and development (R&D) and outreach programs to bolster the diffusion process.
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> *For low-income countries, poor technological adaptive capacity and limited dissemination of often simple technologies to the countryside are severely constraining technological progress.* Despite progress in basic technological literacy, extremely low levels of income, weak governance structures, and, in some cases, ongoing conflict continue to stymie the ability of low-income, and

especially Sub-Saharan African, countries to obtain and absorb new technologies. Nevertheless, the potential for technological progress through the greater dissemination of relatively simple technologies is huge.

The absence or low quality of some basic technologies that governments historically provide hinders technological diffusion by the private sector. These basic technologies often represent essential complementary technologies whose absence can prevent the successful adoption of a new-to-the-market technology.

The relatively rapid dissemination of new communications technologies throughout the developing world, including in low-income countries, offers a ray of hope. These potentially transformational technologies are enabling, often for the first time, the kinds of arm's-length transactions that may be critical to firm development and the spread of technology in these countries. New technologies are frequently introduced and promoted by members of national diasporas, both directly through networks and indirectly through investments financed from remittances.

The rest of this chapter is devoted to exploring how developing countries absorb external technology. The next section presents an analytical framework for technological progress. This is followed by a discussion of how trade, FDI, and migration expose countries to new technologies and can promote internal diffusion of those technologies. The section also discusses trends in these flows and the potential magnitude of associated technological progress and how this may have changed over time. The chapter then turns to an analysis of the domestic factors that facilitate the absorption of new technologies. This section first examines how government policies, and the business environment in general, facilitate the creation and expansion of innovative firms. It then looks at how levels of human capital—from literacy rates to R&D capacity—affect countries' ability to absorb technology from abroad. The chapter concludes with a speculative view of the prospects for technological progress and some policy messages.

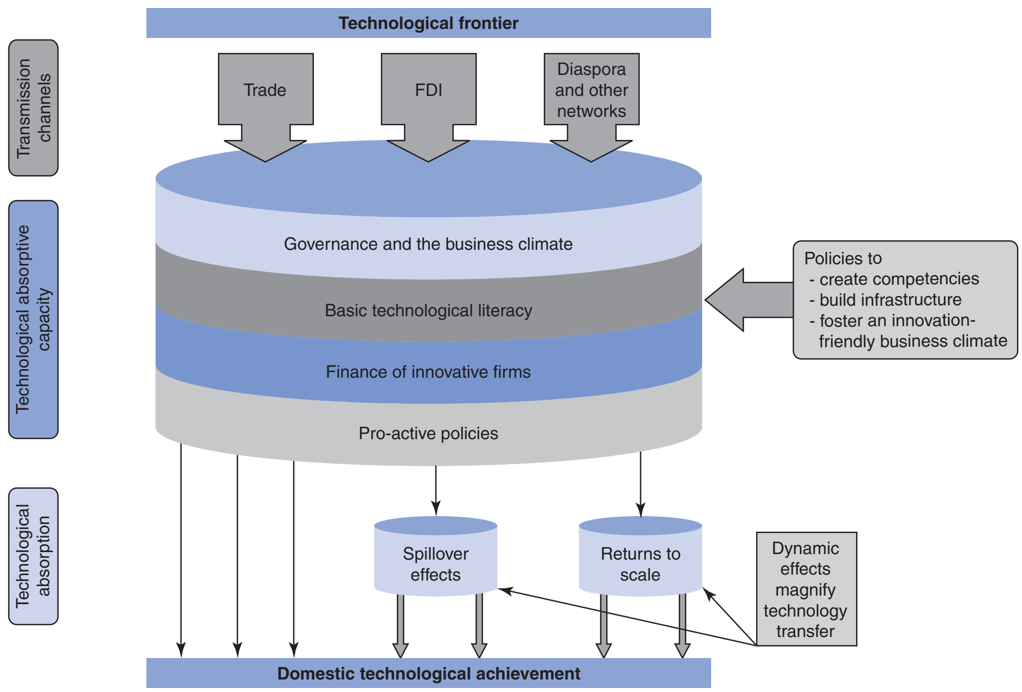
Drivers of technological progress: A framework

The process by which countries adopt, adapt, and absorb external technologies is complicated. The overall framework followed in this chapter (depicted in figure 3.1) draws on previous work done at the World Bank, in particular, the 1998 *World Development Report* on the knowledge economy (World Bank 1998) and several regional and country-specific policy analyses of technology and technological competencies. In addition, it relies upon the academic literature on technology diffusion, including an excellent review article by Keller (2004); several articles by Coe and Helpman concerning the role of FDI; case studies of the process of technology diffusion by Chandra and Kolavalli (2006); empirical work on the technological influence of imports by Lumenga-Neso, Olarreaga, and Schiff (2005); and the discussion by Rodrik (2004) on the impact of market failures on innovation incentives.

Exposure to external flows interacts with domestic capacity to diffuse technology

For the purposes of analytical simplicity, the framework presents technological progress in developing countries as a process whereby an economy is exposed to higher-technology business processes, products, and services through foreign trade; FDI; and contacts with its diaspora and other communication channels, including academic and international organizations (the large arrows at the top of the figure). Exposure to new ideas and techniques is, however, not sufficient to ensure technological progress on the ground. The extent to which these flows are translated into technological progress depends on the technical absorptive capacity of the economy (represented by the ringed drum). This in turn depends on

Figure 3.1 Domestic absorptive capacity both conditions and attracts external flows



Source: World Bank.

the extent to which the business and macroeconomic climate fosters an environment in which firms—the main mechanism for technological diffusion within a country—are able to form, grow, and expand. Absorptive capacity also depends on the levels of basic technological literacy and advanced skills found in the country, which together dictate the country's capacity to implement technologies on the one hand and to do the research necessary to understand, implement, and adjust imported technologies on the other hand. Also important are government actions designed to help overcome market failures that might limit the financing of innovative activity, plus actions that focus technology policy on adapting and adopting those existing technologies for which there is a market and for which adequate domestic competencies exist. Critical here are outreach and dissemination policies, which need to serve as a two-way conduit, both informing the population about technological solutions and providing feedback to providers concerning the usability of and demand for proposed solutions. Taken together, these factors act as filters (the rings in the drum) that dictate how much of the potential technological flow is actually absorbed domestically.

The overall process is, of course, more complicated, with both technological flows and technological adaptive capacity influencing each other. For example, international trade is perhaps the most important vector for the transmission of technology, but the extent of a country's openness to trade depends significantly on the amount of FDI that has occurred, the existence of a vibrant and technologically literate diaspora, and the domestic business climate. Similarly, the quantity of FDI and its overall effectiveness depends on the quality and technological literacy of the labor force.

Increasing returns and spillover effects can magnify these effects . . .

Both domestic and external determinants of technological transfer are affected to varying degrees by increasing returns to scale and spillover effects that can magnify the absorptive impact of these flows. Access to foreign markets may allow domestic firms to grow and exploit economies of scale associated with some technologies, raising the overall wealth and technological sophistication of an economy. Meanwhile, the technological spillovers that can be expected from FDI, including demonstration effects and the transfer of business process and human capital to domestic firms through employee turnover, are likely to be greater the more qualified is the labor force. Both FDI and trade can contribute to cluster effects and networking externalities that increase the potential for spillovers and to technological diffusion from individual sectors and firms to the rest of the economy. Alternatively, economies of scale and agglomeration effects may prevent entry by new firms in some markets, cutting off otherwise promising opportunities for technological learning. In addition, imitators may limit entrepreneurs' ability to capture the returns to new-to-the-market innovations, thereby reducing incentives for technological progress.

. . . but a lack of financing can stymie innovation

Affordability issues can influence both the size of initial inflows and a country's technological absorptive capacity. Even if profitable investments in technology are available and the domestic environment encourages the absorption of new technologies, low incomes may make new technologies unaffordable to individuals and firms in developing countries. At the extreme, individuals near subsistence levels may be unwilling to risk adopting a new-to-the-market technique, may be unable to generate adequate savings to invest in a new technology, or may lack the collateral required to borrow. Thus poverty is a major cause, as well as a result, of low levels of technology.

Affordability is also an issue at the macro level. Low incomes constrain government finance, limiting the government's capacity to put into place both the level of physical infrastructure and the investments necessary to develop a level of domestic human capital capable of supporting and exploiting even simple technologies.

Policy should not impede innovative firms

Finally, firms, entrepreneurship, and government action that actively supports the diffusion of economically relevant and profitable technologies are the grassroots mechanisms by which technologies diffuse within countries. Firms must be able, and entrepreneurs permitted, to profit from the exploitation of new-to-the-market-technologies if those technologies and products are to diffuse. This means that policy must be welcoming of such profits and that both R&D and dissemination efforts not only need to focus on creating or adapting products and ideas (domestic or foreign) to the local market, but also must give priority to assisting firms to exploit them.

External transmission channels

This section presents data and describes recent trends concerning the external channels through which developing countries are exposed to foreign technologies. Where relevant, it also draws on the literature to comment on how specific elements in a country's technological absorptive capacity (discussed in more detail later in this chapter) interact with these external flows to determine the extent to which these channels translate into technological achievement.

Trade

Trade is one of the most important mechanisms by which embodied technological knowledge (in the form of both capital and intermediate goods and services) is transferred across countries. Imports of technologically sophisticated goods help developing countries raise the quality of their own products and the efficiency with which they are produced. Countries can also absorb new technology by exporting to customers who implicitly or explicitly provide guidance in meeting the specifications required for access to global markets. For developing countries with low R&D intensity, trade openness and exposure to foreign competition provide powerful inducements to adopt more advanced technology in both exporting and import-competing firms and are likely to produce large technology spillovers and productivity gains (Schiff and Wang 2006a).

However, the extent to which exposure to foreign technologies is reflected in the export and import patterns of individual countries depends on, among other things, the absorptive capacity of individual countries. As Soubbotina (2006) discusses, countries with relatively weak domestic scientific capacities tend to follow a more passive approach to technology absorption that is characterized by limited efforts to leverage the technology imported by foreign firms operating on their soil. For these countries, most technology transfers take place either through imports of high-tech goods, or perhaps through an apparently high-tech export sector that is, in reality, dominated by assembly operations associated with elevated imports of high-tech goods. Where sophisticated domestic capacities coexist with a significant degree of basic technological literacy in the population, technology diffusion is enhanced and, in general, the technological content of exports is higher.

Following Soubbotina (2006) classifications, "traditionalist slow learners," such as Bangladesh and Burkina Faso, which have low levels of technological competency and technological literacy, tend to rely to a large extent on imports of machinery and equipment. Other countries, such as Malaysia, Mexico, and the Philippines, appear to follow a "passive FDI-dependent" learning style. For these countries, the share of high- and medium-tech goods in their manufactured exports is higher than these goods' share in manufacturing value added, reflecting the dependence of their high-tech exports on imports of technologically sophisticated components and the relatively low technological complexity of domestic manufacturing operations. By contrast, "active FDI-dependent" countries, such as Chile and Hungary, strike a better balance between the share of high-tech goods and services in overall exports and domestic value added, reflecting greater domestic technological competencies. For the Russian Federation and some of the other countries that belonged to the former Soviet Union, a strong technological base and relatively low import shares of high-tech goods reflect their more advanced learning style, which places greater emphasis on domestically developed technologies. Nevertheless, these technologies mainly feed into products that serve the local market, because both high costs and quality concerns keep these sectors from being internationally competitive.

The potential for technology transfer through imports has risen

Imports improve domestic technology because embodied technology both allows firms to employ more efficient production processes and affords the possibility that firms can copy more advanced products and processes. At the same time, competition from technologically superior imports may boost domestic productivity.[1] Developing countries that have a large share of imports from high-income countries with large R&D expenditures have significantly higher productivity than developing countries that import from advanced countries with lower R&D expenditures (Coe, Helpman, and Hoffmaister 1997).[2] There also is evidence for a positive relationship between access to imported intermediate goods and performance (Handoussa, Nishimizu, and Page 1986). More recent literature highlights the indirect benefits for developing countries from North–North trade in R&D. The exchange of high-tech goods and services among high-income economies contributes to an increase in the global stock of knowledge and eventually becomes available to developing countries through North–South trade. Finally, technology diffusion, like trade, tends to be regional, with the largest transfers coming from natural trading partners, for example, Jordan benefits more from the European Union and Mexico benefits from Canada and the United States (Schiff and Wang 2006b).

However, the extent to which imported technology boosts the sophistication of domestic technological activity either directly or indirectly through spillovers depends on the quality of a country's technological absorptive capacity. Thus while using an imported capital good can lift the technological content of activity in a country, to the extent that importers pay competitive prices for the technology, there may be no net gain to the country (Eaton and Kortum 2001). Moreover, the business climate may be too weak or the technological literacy of the local labor force may be too low to successfully adapt the machinery to local conditions (Dahlman, Ross-Larson, and Westphal 1987; Rosenberg 1976). As a result, the country may not realize the potential productivity improvements available from imported technology (Pack 2006).

Developing countries' high-tech imports have increased

To the extent that a developing country can make use of or imitate sophisticated goods, its level of technological achievement should increase in line with the quality and technological sophistication of imported goods. Since the mid-1990s, the share of imported high-tech products in GDP has increased by more than 50 percent in low-income countries and by 70 percent in middle-income countries (table 3.1).[3] Among developing regions, East Asia and the Pacific has the highest share of high-tech imports in GDP (8.4 percent), with the highest share being for Malaysia (37 percent) and the Philippines (18 percent), but Europe and Central Asia has experienced the largest increase, reflecting the transition of many of the region's countries to market economies and their improved access to high-tech products following the relaxation of Cold War export restrictions. Among regions dominated by middle-income countries, high-tech imports represent 3.8 percent of GDP in Latin America and the Caribbean and 3.6 percent of GDP in the Middle East and North Africa, less than in Sub-Saharan Africa (4.5 percent).

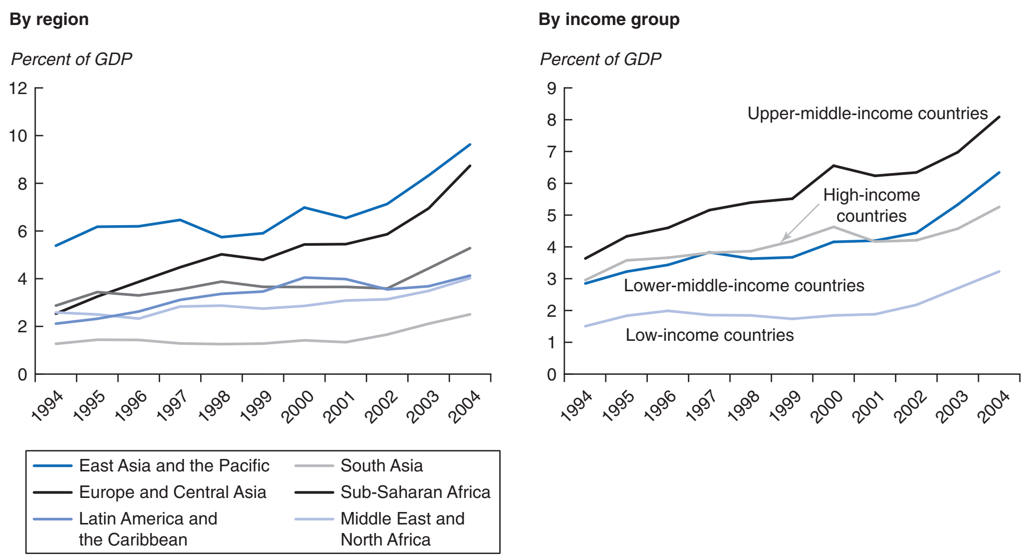
Low-income countries have also improved their exposure to high-technology embedded in foreign products. After hovering around

Table 3.1 Trade in technology goods has increased in developing countries

	Imports of high-tech goods			Imports of capital goods			Share of high-tech exports in world high-tech exports		
	1994–96	2002–04	% change	1994–96	2002–04	% change	1994–96	2002–04	% change
	(% of GDP)			*(% of GDP)*			*(% of GDP)*		
Regions									
East Asia and the Pacific	5.9	8.4	42	11.6	12.8	10	9.9	19.0	93
Europe and Central Asia	3.2	7.2	125	7.1	14.7	107	1.0	2.7	163
Latin America and the Caribbean	2.4	3.8	61	5.4	7.2	32	2.1	3.4	61
Middle East and North Africa	2.5	3.6	44	6.3	8.9	42	0.1	0.2	29
South Asia	1.4	2.1	53	3.1	3.8	22	0.2	0.3	58
Sub-Saharan Africa	3.2	4.5	39	9.3	10.5	14	0.1	0.1	4
Income groups									
High-income countries	3.4	4.7	38	5.5	7.0	27	86.5	74.3	−14
Upper-middle-income countries	4.2	7.2	71	8.7	13.1	51	6.6	9.6	47
Lower-middle-income countries	3.2	5.4	70	6.9	9.2	33	6.7	15.7	137
Low-income countries	1.8	2.7	53	4.9	5.7	17	0.3	0.4	53

Source: World Bank calculations using Centre d'Etudes Prospectives et d'Informations Internationales' database, Banque Analytique de Commerce International.

Figure 3.2 Rising share of high-tech imports



Source: World Bank calculations using Centre d'Etudes Prospectives et d'Informations Internationales database, Banque Analytique de Commerce International.

1.8 percent between 1994 and 2001, the average share of high-tech imports in low-income countries' GDP began to rise in 2002, reaching 3.2 percent in 2004 (figure 3.2). Both South Asia and Sub-Saharan Africa have enjoyed significant increases, although the ratio of high-tech imports to GDP remains extremely low in South Asia, less than 3 percent of GDP. In most countries in Sub-Saharan Africa, the share of imported high-tech goods fluctuates between 2 and 5 percent of GDP from year to year. Mauritius and South Africa import the most high-tech goods relative to the size of their economies, between 6 and 8 percent of GDP in any given year, while Somalia imports the least, less than 1 percent of GDP.

Despite developing countries' increased exposure to foreign technology through trade, its distribution across regions within countries tends to be extremely uneven, with foreign trade concentrated in a few major cities or regions. For example, 70 percent of high-tech trade (both imports and exports) in China originates in four regions and is highly correlated with R&D intensity and foreign firms (OECD 2007). As a result, the benefits of exposure to trade also tend to be unevenly distributed.

Capital goods imports have also increased

Although imports of high-tech goods provide an indication of an economy's exposure to technology, this indicator does not distinguish between imports of technology for consumption and imports for production, nor does it indicate the extent to which these imports improve the technological content of a country's economic activities. Technological content depends importantly on the structure of the economy and the nature (assembly or high valued added transformation) of the work done with the imports (box 3.1).

Imports of capital goods, such as machinery and equipment, which enable the production of higher quality and more technologically sophisticated goods, have a less ambiguous impact on a country's technological capacity. For countries operating within the technological frontier, a higher share of imported capital goods in GDP can reflect the presence of strong investment activity; a process of technological

Box 3.1 Technology imports: Different paths for different countries

Based on a breakdown of trade flows by technology level and by production stage, Lemoine and Ünal-Kesenci (2003) highlight the following divergent integration paths adopted by China, India, and Turkey, which all started from a relatively similar degree of industrial specialization about 10 years ago:

- *China* has become an assembly country, strongly integrated into the international segmentation-of-production processes in Asia. Most of China's imports of high-tech products are parts and components. These high-tech imports are predominantly incorporated into the production of exports and are not used to modernize domestic production capacities. Given its level of development, China's exports display an outstandingly strong high-tech content.
- *India* is characterized by limited participation in international division-of-production processes and by a low level of imports in high-tech products. These high-tech imports are evenly distributed among the different stages of production and the different sectors, while high-tech exports are concentrated in chemical industries.
- *Turkey's* high-tech imports consist mainly of capital goods and correspond to a classical form of technology transfer aimed at upgrading indigenous industrial capacities. Turkey's foreign trade is strongly structured by its traditional complementaries with Europe.

upgrading; and, over the longer term, a relatively sophisticated structure of production.[4] As a result, relatively technologically sophisticated middle-income countries import more capital goods (as a share of GDP) than less sophisticated low-income countries (table 3.1).

Overall, the share of capital goods in the GDP of developing countries has risen substantially over the past decade. Upper-middle-income countries saw a 51 percent increase in the share of these goods in GDP, while lower-middle-income countries have boosted their reliance on such goods by 33 percent. The former group of countries continues to have the largest share of capital goods in GDP, about 13 percent, more than double the share of low-income countries. As a consequence, the gap between low-income countries (especially the Least Developed Countries [UNCTAD 2007]) and other developing countries has widened. Europe and Central Asia saw the biggest regional increase in imports of capital goods, reflecting the substantial economic recovery in these countries following the recession that accompanied the transition to market economies. As was the case for high-tech imports, South Asia has the lowest level of imports of capital goods and has shown little improvement, presumably reflecting the relatively autarchic policies that governments in the region have followed until recently. By contrast, Sub-Saharan Africa imports substantially more capital goods, although the ratio of capital goods imports to GDP has increased less than in other developing regions since the mid-1990s, with the exception of East Asia and the Pacific. The story is particularly varied in Latin America, where some countries, such as Costa Rica and Mexico, increased their imports of capital goods following liberalization policies in the early 1990s, while others did not. The increase in the share of capital goods in GDP was particularly notable in Costa Rica, where it rose from about 7 percent in the mid-1990s to about 18 percent in 2002–04.

Exports of technological goods have also expanded

Participation in high-tech export markets has also been identified as a channel through which technology is diffused within developing countries. Many case studies suggest that exporting firms in developing countries benefit from implicit and explicit technological transfers that occur as a result of their interactions with foreign buyers. Benefits accrue because foreign buyers may have higher quality standards than domestic buyers. Foreign buyers may also assist with process improvements and provide information about and experience with foreign markets. Moreover, the additional demand that foreign markets provide may allow for the exploitation of economies of scale that justify more capital-intensive production (see, for example, Hobday 1995 and Rhee, Ross-Larson, and Pursell 1984 on the effects of learning by exporting in East Asia). Technology transfers through exports may be most important in production networks with clearly articulated supply chains (Gereffi 1999; Hobday 1995).[5] Spillovers may also be common in labor-intensive sectors where production processes are relatively simple and the relevant knowledge is widely available in industrial countries (Enos and Park 1987; Hou and Gee 1993).

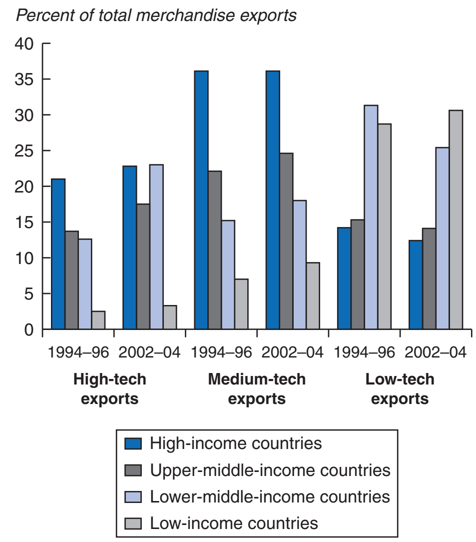
Unfortunately, these efficiency benefits from exporting are not confirmed by econometric studies (Keller 2004), which generally find that the positive relationship between exporting and productivity results largely from the self-selection of firms into the export market.[6]

Whatever the magnitude of spillovers from exports and of concerns surrounding the re-export nature of some high-tech exports, the export of technology products is nevertheless an important indicator of technological achievement. High-tech exports offer better prospects for future growth than lower-tech goods because their market has been expanding more rapidly and because they offer superior spillover potential by transmitting skills and generic knowledge that can be used in other activities (Guerrieri and Milana 1998). High-tech exports are also less vulnerable to easy entry by lower-wage competitors, substitution by technical change, and market shifts (Lall 2001).

Although high-income countries continue to dominate the world market for high-tech goods,[7] middle-income countries have substantially increased their market share since the mid-1990s. Lower-middle-income countries more than doubled their global share of high-tech exports, increasing them from 6.6 percent in the mid-1990s to 15.7 percent in 2002–04 (3.4 to 5.0 percent if China is excluded). Moreover, the share of higher-technology goods in the total merchandise exports of these countries has also been increasing (figure 3.3). Much of this increase reflected the transfer of manufacturing processes from high-income countries to developing countries, notably those in East Asia and the Pacific. China was a major beneficiary of this process, increasing its global market share of high-tech exports from about 3 percent to 11 percent, but so too were other countries. The Philippines, for example, increased its market share from 0.9 percent to about 2.0 percent. Upper-middle-income countries made less spectacular progress, increasing their global market share from 6.5 percent to 10.5 percent, although some countries, such as Costa Rica, the Czech Republic, and Hungary, were able to increase their high-tech markets significantly.[8] In Sub-Saharan Africa, South Africa is the largest exporter of high-tech products, but its share has remained small and stable at about 0.08 percent.

The relative performance of different middle-income regions reflects different levels

Figure 3.3 Exports of low-, medium-, and high-technology goods



Source: World Bank calculations using Centre d'Etudes Prospectives et d'Informations Internationales database, Banque Analytique de Commerce International.

of technological capabilities and learning styles. Since the early 1990s, Latin America has almost doubled its share of high-tech products in world markets and now has the second largest market share after East Asia and the Pacific. However, in contrast with Europe and Central Asia and the Middle East and North Africa, it has done so with relatively little input from imported technology (imports of high-tech and capital goods as a share of GDP in Latin America and the Caribbean are half the rate of Europe and Central Asia). Partly as a consequence, Europe and Central Asia has gained market share in high-tech goods much more quickly than Latin America, and based on recent performance, is poised to overtake that region soon.

Low-income countries remain marginal players in the world market for high-tech goods, and even though their global share of exports of medium-tech goods has doubled, between the mid-1990s and 2002–04, it remains low at 0.8 percent. The share of low-income countries in world exports of low-tech goods is more substantial and has increased from 3.5 percent to 5.2 percent. Among these countries, Vietnam has improved its global market share of low-tech products from 0.2 to 0.8 percent, a 250 percent increase. India remains the most important exporter of low-tech products in this income group with 2 percent of the world market, second after China among developing countries, which accounts for about 17 percent of the world's low-tech exports.

Overall exposure to foreign technologies has increased

Overall, the increased participation of developing countries in global trade has substantially increased their exposure to foreign technologies. For middle-income countries, this exposure and the attendant expansion of high-tech exports have likely yielded important side benefits that are reflected in the sustained acceleration in developing country growth rates over the past 15 years. While the increase in trade openness has been generalized, the extent to which countries have been able to translate that into improved export performance and an increase in the technological sophistication of their own exports has varied, with countries like those in Europe and Central Asia that have relatively well-educated populations and a strong institutional structure having extracted the greatest benefits. Among other countries, notably low-income countries, weak absorptive capacity may be restricting the extent to which their economies have benefited from the increased exposure.

Foreign direct investment

Like trade, FDI can be a powerful channel for the transmission of technology to developing countries by financing new investment, by communicating information about technology to domestic affiliates of foreign firms, and by facilitating the diffusion of technology to local firms.

Foreign investors bring both equipment and know-how

Measuring the technological contribution of FDI is particularly difficult, in part because the standard measure from the balance of payments includes both physical (brownfield and greenfield) investments and financial investments (mergers and acquisitions). This said, FDI inflows to developing countries rose from \$10 billion in 1980 to an estimated \$390 billion in 2007, or from 0.4 to 2.9 percent of GDP, with the bulk of the increase occurring during the late 1990s in response to the liberalization of FDI policies.[9] Assuming that foreign firms employ a higher level of technology than the average domestic firm, then this rising trend will have increased the average level of technology in these countries, as well as their exposure to higher technologies.

FDI as a share of GDP has risen in all developing regions and income groups since the 1980s, but the increase has been concentrated in middle-income countries, where FDI rose to almost 3 percent of GDP (table 3.2). East Asia and the Pacific had the highest ratio during the 1990s, but it has since declined, in part because of a collapse in FDI inflows to a few

Table 3.2 Foreign direct investment as a percent of GDP

	1970–79	1980–89	1990–99	2000–06
All developing countries	0.5	0.4	1.5	2.7
By region				
East Asia and the Pacific	0.5	0.5	2.8	2.3
Europe and Central Asia	0.3	0.1	0.9	2.2
Latin America and the Caribbean	0.6	0.7	1.5	3.5
Middle East and North Africa	0.5	0.5	0.6	1.1
South Asia	0.0	0.1	0.4	0.7
Sub-Saharan Africa	0.7	0.4	1	2.5
By income groups				
Low-income countries	0.3	0.2	0.8	1.1
excluding India	0.6	0.4	1.4	1.8
India	0.0	0.0	0.3	0.7
Middle-income countries	0.5	0.4	1.6	2.9

Source: World Bank 2007a.

countries affected by the East Asian financial crisis in the late 1990s (particularly Indonesia), and in part because FDI inflows to China, although still high, have failed to keep pace with the rapid growth of output. Meanwhile in Latin America and the Caribbean, efforts to increase trade openness resulted in a boom of FDI inflows, which reached an average of 3.5 percent of GDP in 2000–06. In Europe and Central Asia, FDI rose from next to nothing before the breakup of the Soviet bloc to 2.2 percent of GDP in 2000–06. In the Middle East and North Africa and South Asia, FDI remains low at around or less than 1 percent of GDP. Most recently, FDI inflows to Sub-Saharan Africa have surged, reflecting substantial investment in oil and mineral production and a more generalized interest in the region stemming from increased political stability, liberalization of FDI policies over the past 15 years, and improved growth performance.

One way that FDI boosts technology transfer is by financing new machinery and equipment purchases. The share of FDI in developing countries' fixed capital formation increased from 2.9 percent in the 1970s to 10.7 percent in this decade (table 3.3), with the increase in middle-income countries being more pronounced than in low-income countries. However, FDI includes mergers and acquisitions that may involve no additional physical investment, and the share of mergers and acquisitions, including privatization transactions, in total FDI has been rising. Nevertheless, the foreign component of aggregate investment in developing countries has likely been rising along with the extent of technological transfer through this channel. Moreover, the transfers in know-how, business process technology, and market knowledge associated with mergers and acquisitions can occur whether or not any associated physical investment is involved, and may even be more important.

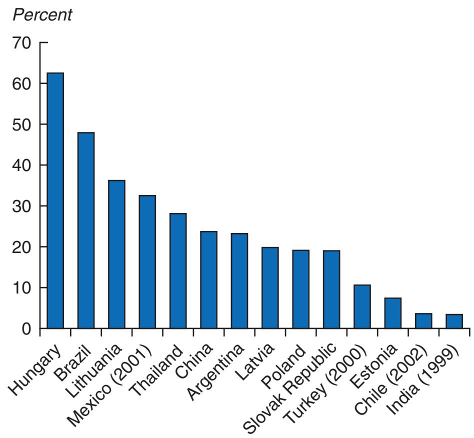
Foreign firms may also improve the technological capacity of developing countries by

Table 3.3 Foreign direct investment as a percent of fixed capital formation

	1970s	1980s	1990s	2000s
Regions				
East Asia and the Pacific	1.9	3.0	12.2	8.4
Europe and Central Asia	2.8	—	8.1	15.5
Latin America and the Caribbean	3.3	0.1	11.3	13.1
Middle East and North Africa	2.8	2.1	3.7	6.5
South Asia	0.3	0.4	2.5	4.1
Sub-Saharan Africa	3.6	2.2	9.3	18.6
Income groups				
Low-income countries	2.2	1.3	5.6	6.7
Middle-income countries	2.9	1.9	11.0	11.3
All developing countries	2.9	1.8	10.4	10.7
OECD countries	13.5	11.3	3.5	11.5

Source: World Bank 2007a.
Note: — = not available; OECD = Organisation for Economic Co-operation and Development.

Figure 3.4 Share of foreign affiliates in business R&D expenditure



Sources: OECD; Activity of Foreign Affiliates database. http://www.sourceoecd.org; UNCTAD 2005; Eurostat; R&D statistics.

Note: The year is 2003 unless otherwise indicated.

financing R&D. Multinational corporations undertake most of their R&D activities in their home country or in other high-income countries.[10] Nevertheless, the role of developing countries appears to be rising. R&D spending in developing countries by majority-owned foreign affiliates of U.S. parent companies increased from $0.9 billion in 1999 to $1.6 billion in 2003 (Bureau of Economic Analysis 2007). The contribution of multinationals' R&D to total measured R&D activity in developing countries varies from more than 60 percent in Hungary to less than 5 percent in India (figure 3.4).

FDI may generate technology spillovers

In addition to its technological impact on the firm directly touched by the investment, FDI may also affect the level of technology in domestic firms.[11] Spillovers can arise when workers receive training or accumulate experience working for multinationals and then move to domestic firms or set up their own enterprise (Fosfuri, Motta, and Ronde 2001; Glass and Saggi 2002). For example, within six years of the beginning of FDI-led export growth in Mauritius, 50 percent of all firms operating in export-processing zones were locally owned, founded, managed, and staffed—in many cases by employees who had received on-the-job training in foreign enterprises and had left to set up their own companies (Rhee, Katterback, and White 1990).

Already existing local firms may also observe the actions of foreign firms and learn about new products, equipment, marketing techniques, and management practices. For example, 25 percent of the managers of Czech firms and 15 percent of the managers of Latvian firms report that they learned about new technologies by observing foreign firms as they entered their industry (Javorcik and Spatareanu 2005). In Morocco and Tunisia, domestically owned international call centers have risen in imitation of foreign firms (box 3.2).

If multinational entry leads to an increase in demand for intermediates, it may result in the expansion of upstream domestic industries (see the experience with Zambian supermarkets in box 3.3). Downstream industries may also benefit from the increased competition and added variety of inputs created by the foreign investment. In addition, foreign investors may provide advice, designs, direct production assistance, or marketing contacts to suppliers, which the latter can then deploy more broadly than simply providing cheaper or more reliable inputs to the foreigners.[12]

The entry of multinationals is likely to increase competition for the domestic firms within the industry, potentially forcing them to improve their efficiency and introduce new technologies or business strategies (Blomstrom, Kokko, and Zejan 2000), as in Wal-Mart's joint venture in Mexico (box 3.4). Such competition can make surviving domestic competitors stronger, but other domestic firms may be driven out of business, lose market share, and experience a loss of high-skilled workers and higher costs for intermediate goods resulting from increasing demand from the foreign-owned firms.[13] These effects may vary by industry depending on factors such as the market structure before the entry of

Box 3.2 European call centers in the Maghreb have inspired local entrepreneurs and prompted a specialization in high-value-added services

Leading call center companies from France and Spain have paved the way for domestically owned and export-oriented call centers in Morocco and Tunisia. Although call centers existed in Morocco and Tunisia before the first European call centers outsourced operations to the region in the early 2000s, domestically owned firms served the local market and provided only basic telecommunications services. Only after Atento (a Spanish-owned subsidiary) set up a call center in Morocco and Teleperformance (a French-owned firm) settled in Tunisia to serve clients in Europe did local entrepreneurs jump into the European market.

This transition was not without problems. Locally owned call centers lack the international name recognition of large foreign-owned firms and have had difficulty obtaining contracts from foreign companies. In addition, most of them are small, with a maximum of 100 to 200 employees, compared with more than 2,000 positions at some foreign-owned call centers.

Interestingly, many domestically owned firms, such as Outsourcia in Morocco, have chosen to differentiate themselves by targeting higher value added services. High turnover rates have also helped domestically owned firms to hire experienced agents who were trained in the foreign call centers.

Source: World Bank forthcoming.

Box 3.3 South African investment in Zambia's retail sector has improved the quality of local produce and farmers' earnings

The liberalization of the Zambian distribution sector allowed the inflow of foreign retail companies, which replaced some of the traditional retail sector with modern supermarkets and added both upstream and downstream benefits to the domestic economy. Consumers benefited from lower costs, while local suppliers learned new production and marketing techniques that enabled them to improve the quality, efficiency, and revenues of their operations.

When Shoprite of South Africa first opened supermarkets in Zambia, it found that the quality and quantities provided by individual local smallholder farmers were too low and too unreliable, and therefore imported 90 percent of its fresh produce from South Africa. Farmers' cooperatives that benefited from donor-funded technical assistance have since managed to improve the quality of their products and services, and Shoprite is now sourcing 90 to 95 percent of its fresh produce from Zambian farmers. In the case of one cooperative, farmers' cash income has increased from $2 to $3 a month to $50 to $70 a month, and local access to health care and education services has improved. The supermarkets themselves are providing local farmers with technical assistance. Agricultural experts from the retailer's subsidiary visit farms, give advice on crop sequencing, and provide inputs.

Source: Mattoo and Payton 2007.

Box 3.4 Wal-Mart's entry in Mexico boosted the Mexican soaps, detergents, and surfactants industry

The Aurerra–Wal-Mart joint venture, which created Walmex, followed Mexico's reduction in tariffs and liberalization of FDI in the late 1980s. By exercising its bargaining power, Walmex squeezed profit margins among the major soaps, detergent, and surfactants suppliers, offering them higher volumes in return.

Local firms that were not efficient enough to meet Walmex's terms lost market share, and many failed. Those that survived grew and became more efficient and innovative. The quality and efficiency of their overall operations benefited from their interactions with both their client (Wal-Mart) and with foreign-owned suppliers, with many firms adopting techniques and products first introduced into the market by their multinational competitors.

As a result of these spillovers and labor shedding, the surfactants sector rapidly improved its value added per worker. The newly found competitiveness and exposure to the requirements of Walmex and other foreign retailers on the domestic market has allowed the Mexican surfactants sector to expand its exports and market share in the United States, targeting the Latino community in which their brands are known.

Source: Javorcik, Keller, and Tybout 2006.

foreign multinationals, the R&D intensity of the products, and the links between foreign firms and domestic firms in upstream and downstream sectors.[14]

Outsourcing decisions, domestic policies, and absorptive capacity all affect spillovers

Evidence indicates that spillovers to local suppliers are not uniform across countries or across industries within a country.[15] Multinationals may choose not to source inputs locally because of concerns about the quality of local inputs or the time required to develop relationships with local suppliers or because of centralized sourcing arrangements that may provide volume discounts or access to customized inputs (UNCTAD 2001). In host countries with underdeveloped upstream sectors or in cases of FDI with very specialized input needs, the scope for spillovers to upstream sectors may be limited. Policies may also reduce the potential for spillovers. For example, in a highly protected market, foreign plants may operate at an inefficiently small scale (Moran 2007). Requirements that foreign firms enter into joint ventures with local companies may discourage use of the most advanced technology to avoid leakage to potential competitors (Beamish 1988).

The level of spillovers also depends on the domestic absorptive capacity. For example, other advanced countries tend to gain from technology spillovers from the activities of subsidiaries of U.S. multinationals, while poor countries do not (Xu 2000). Firms using advanced technology in low-income countries fail to achieve the same level of productivity as firms in industrial countries (Acemoglu and Zilibotti 2001) or the same kinds of spillovers as in middle-income countries, in part because the gap between the quality and human capital of the domestic workforce and that for which the equipment was originally designed is too large (Borensztein, de Gregorio, and Lee 1998). In general, spillovers may be more common when the difference in technological levels between the foreign multinational and the domestic economy is not too large.

As discussed earlier, the extent to which a country benefits from spillovers to the rest of the economy also depends on the country's policy stance on basic technological literacy and more advanced skills and on promotion of the adoption and diffusion of technologies within the economy. For example, some countries such as Mexico and the Philippines have benefited relatively little from FDI spillovers because FDI inflows, although abundant, have been oriented toward exploiting low wages and have not built many links to the domestic economy. In contrast, countries like Singapore have actively sought to maximize the technology spillovers from FDI by investing in the domestic skills and competencies necessary to support high-skill and high value added industries and by welcoming and promoting FDI in such sectors (Lall 2003).

Spillovers might be highly concentrated in certain regions within a country

Geographic proximity also determines the extent of technological spillovers observed. The closer a local firm is to a foreign-owned firm, the more frequently will the firms' employees interact with each other, increasing the likelihood that employees (and their acquired knowledge) will move between the two firms. The spatial aspect is also important for vertical spillovers between foreign-owned firms and their local suppliers, which are often located close to each other (Jaffe 1989).

The existence of such cluster effects may explain why FDI tends to be geographically concentrated within a country mainly around large cities or coastal states. In Russia, for example, more than two-thirds of the FDI stock in 2000 was in Moscow and three surrounding regions (Broadman and Recanatini 2005). Similarly, almost half of FDI flows in India go to the Mumbai and Delhi areas (Reserve Bank of India 2007), while in China, almost 90 percent of FDI flows go to the western coastal region (Kui-Yin and Lin 2007). This said, because of data limitations and conceptual problems, econometric support for the notion that such clusters generate important technology spillovers is limited (Lipsey and Sjohom 2005), with some studies supporting their existence (see Girma and Wakelin 2001 for the electronics sector in the United Kingdom) and others not (see Aitken and Harrison 1999 for Venezuela and Sjoholm 1998 for Indonesia).

Developing countries also purchase foreign high-tech firms

Outward FDI, that is, the purchase of foreign firms by domestically owned ones, and the licensing of technologies are two other, more direct mechanisms by which developing countries acquire foreign technologies and research expertise.

Over the past 20 years, firms domiciled in developing countries have increasingly turned to foreign acquisitions as a means of expanding their market share and gaining control over technology. Cross-border mergers and acquisitions by multinational corporations located in developing countries increased from $400 million in 1987 (less than 1 percent of global merger and acquisition transactions) to almost $100 billion in 2006 (almost 9 percent of global merger and acquisition transactions) (World Bank 2007a). Although technology may not be the primary motivator in many of these purchases, technology transfer is associated with nearly all of them in the form of control over patents and knowledge of manufacturing processes, marketing, and business process expertise. Table 3.4 summarizes some of the more technologically important recent acquisitions of high-tech firms by developing country firms.

Developing country firms may seek to acquire a brand or a marketing or distribution network. Examples include the Thai Union Frozen Company's purchase of the Chicken of the Sea brand; the South African Brewery's purchase of Miller Brewing (a major U.S. beer maker); and Malaysian Berjaya's purchase of Taiga, the largest Canadian distributor of building materials. Developing country firms may also purchase foreign firms to acquire R&D capacity. For example, the Chinese company Shanghai Automotive Industry Corporation bought Sangyong of the Republic of Korea to enhance its R&D capabilities in sport utility vehicles. Accessing foreign technology also takes the form of establishing R&D centers in developed countries. For example, Huawei Technologies and ZTE Corporation, both Chinese companies, have established R&D centers in Sweden.

Developing countries can also license foreign technologies

Developing countries can also gain access to technology through licensing, which typically

Table 3.4 Selected purchases of high-tech firms by companies in developing countries, early 2000s

Acquiring company	Country of acquirer	Year	Acquired firm	Country of acquired	Industry
Netcare	South Africa	2006	General Health Care	United Kingdom	Health
Tata Tea	India	2006	Tetley	United Kingdom	Tea
Videocon Industries Ltd.	India	2006	Daewoo Electronics	Korea, Rep. of	Electronics
Chalkis	China	2005	Le Cabanon	France	Food processing
Essel Propack	India	2005	Telcon Packing	United Kingdom	Tube packing
Wipro	India	2005	New Logic	Austria	Semiconductors
Orascom	Egypt, Arab Rep. of	2005	Wind	Italy	Telecommunications
Lenovo	China	2004	IBM	United States	PC manufacturing
TCL	China	2004	Alcatel	France	Telecommunications
Ranbaxy	India	2004	RPG	France	Pharmaceuticals
BOW Technology Group	China	2003	Hynix	Korea, Rep. of	PC manufacturing
PKN Orlen	Poland	2002	BP (500 petrol stations)	United Kingdom	Downstream oil

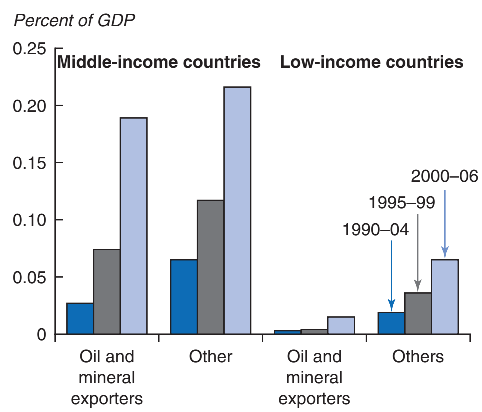
Source: World Bank 2007a.

involves the purchase of production or distribution rights for a product and the underlying technical information and know-how for producing it. As measured by the payment of international royalties and fees in countries' balance of payments, licensing fees paid by developing countries increased from $7 billion in 1999 to $22 billion in 2006, about a fivefold increase when expressed as a percentage of developing country GDP.[16] The increase was sharpest for oil- and mineral-exporting countries, reflecting higher prices for oil and contracts that often expressed these fees as a percentage of revenues or profits. Nevertheless, licensing fees paid by other developing countries also tripled, and for both low- and middle-income countries these fees represented a larger share of overall GDP than they did for oil- and mineral-exporting countries (figure 3.5).

Licensing can be used as a substitute for FDI. Uncertainty about the policy environment may lead multinationals to sell technology rather than to exploit the technology through foreign investment (domestic firms may have more information or may be better placed than foreigners to deal with a poor policy environment). Evidence suggests that both FDI and licensing respond to an adequate business environment, and factors such as patent protection may shift incentives for investors from FDI toward licensing (Maskus 2002). Where protection of intellectual property rights is weak, multinationals may be less willing to license technology for fear of it being copied by domestic firms. Alternatively, they may only be willing to license out-of-date technologies (Maskus 2000). Data on U.S. multinationals show that the likelihood of entering into licensing agreements increases as developing countries increase their protection of intellectual property rights (Antras, Desai, and Foley 2007).

Some countries have pursued a licensing-based strategy of technology acquisition in the

Figure 3.5 Licensing payments have risen sharply



Sources: Balance of Payments Database (IMF) and World Development Indicators.

belief that domestic firms will be able to upgrade their own technological capacities by working with licensed technology. For example, in the 1950s and 1960s, Japan kept its economy relatively closed to FDI to encourage multinationals that wished to gain from the growing Japanese market to license technology to domestic firms (Pack and Saggi 1997). China has also encouraged joint ventures, as opposed to FDI, to maximize technology transfers to local firms. This strategy is likely to work only if the country has sufficient market power. Moreover, such discriminatory policies run the risk of resulting in the transfer of substandard technologies (Hoekman and Javorcik 2006). In contrast, several Latin American countries discouraged the licensing of technology from abroad because of concerns about unfair pricing and competition with local technologies, a strategy that retarded or skewed technological development in that region (Pack and Saggi 1997).

The bulk of international royalties and fees stems from intrafirm transfers. In part, this may reflect a preference by multinational firms to transfer more advanced technologies only to wholly owned subsidiaries rather than to partially owned affiliates and to enter markets through wholly owned subsidiaries rather than through joint ventures (Javorcik 2006; Mansfield and Romeo 1980). However, it may also mean that these fees are being used as a mechanism for repatriating profits, perhaps for tax reasons. As a result, the level of royalties and fees may not be a market-based reflection of the value of technology purchased by the local subsidiary (Robbins 2006).

Partly because of intrafirm payments and of the close relationship between licensing and FDI, economists have had difficulty in evaluating the impact of licensing on technology transfer. Nevertheless, a few case studies have documented its benefits. Brazil and Korea achieved considerable success in absorbing new technologies through licensing (Correa 2003), and licensing agreements were an important factor for the success of floriculture in Kenya, maize in India, and the electronics sector in Taiwan, China (Chandra and Kolavalli 2006). The latter study also highlights that even though licensing may enable rapid acquisition of product and process know-how, it also requires a significant level of local technological capability to put the licensed technology to work.

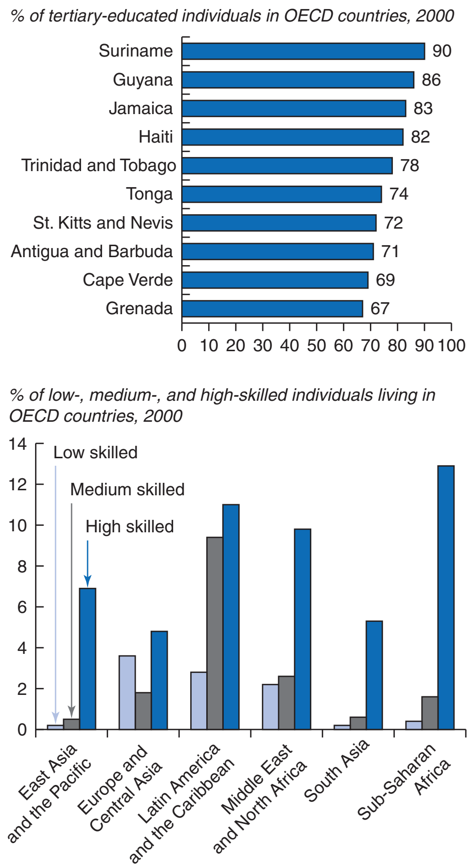
International migration

Along with trade and FDI, international migrants are another important channel for the transmission of technology and knowledge. From the perspective of developing countries, however, the direction of technology transfer can be both outward (as migrants take away scarce skills) or inward (through contacts with the diaspora).

The direction and scale of technology flows that result from international migration are less clear than for FDI and trade. On the one hand, the brain drain associated with better educated citizens of developing countries working in high-income countries is a serious problem for many developing countries. On the other hand, the contribution that these individuals would have made had they stayed home is uncertain given the lack of opportunities in some countries. Moreover, developing countries can benefit from the immigration, albeit often temporary, of managers and engineers that often accompanies FDI; the return of well-educated developing country emigrants; and the contacts with a technologically sophisticated diaspora.

High rates of skilled out-migration imply a net transfer of human capital and scarce resources (in the form of the cost of educating these workers) from low- to high-income countries (UNCTAD 2007; World Bank 2006a). For some countries, the brain drain represents a significant problem: emigration rates of highly educated individuals can exceed 60 percent in some small countries (figure 3.6), and since 1990, the highly educated diaspora of developing countries has doubled in size.[17] However, the share of developing country tertiary-educated individuals living abroad remained stable and relatively low,

Figure 3.6 The brain drain is a severe problem in a number of small countries



Source: World Bank staff calculations based on Docquier and Marfouk 2004.

Note: OECD = Organisation for Economic Co-operation and Development.

ranging from 5 to 13 percent depending on the region (figure 3.6), because the number of such individuals also doubled.

The emigration of professionals who make a direct contribution to production, such as engineers, may result in reduced rates of domestic innovation and technology adoption (Kapur and McHale 2005a). Emigration rates for scientists, engineers, and members of the medical profession tend to be higher than for the general university-educated population. For example, in India, the emigration rate for those with a tertiary education is 4 percent, but the rate for graduates of the elite Indian Institutes of Technology ranged from 20 to 30 percent in the 1980s and 1990s (Docquier and Marfouk 2004; Khadria 2004).

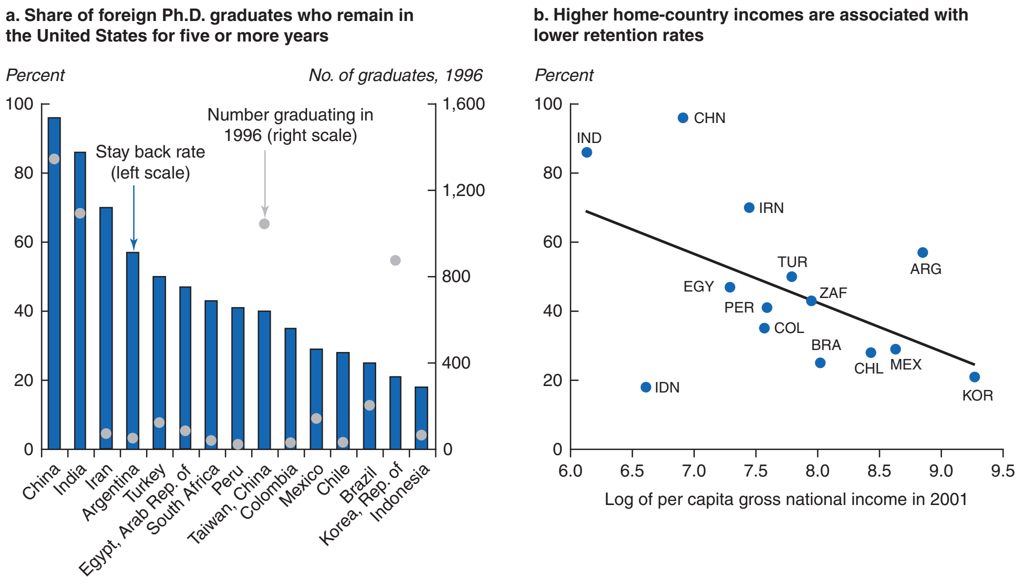
More moderate migration rates may be beneficial, especially when domestic opportunities are limited, because of technological transfers from the diaspora and because most migration is not a one-way flow. For example, a majority of foreign students from many developing countries who earn their doctorates in the United States return home (figure 3.7), bringing with them a great deal of technological and market knowledge that represents an important technological transfer in favor of the developing country.

The share of recent doctoral graduates from developing countries who remain in the host country varies significantly across countries of origin. In part, these cross-national differences reflect differences in opportunity costs. The likelihood that a student remains in the United States after graduation falls as average per capita incomes in the home country rise. However, even at a given income level, the length of stay varies significantly across countries, with fewer graduates returning home to countries such as Argentina, China, India, and the Islamic Republic of Iran than would be expected based on income alone. Other factors explaining high retention rates include the quality of living conditions and research facilities in high-income countries, as well as the density of research networks and the size of the preexisting diaspora. Factors favoring a return include proximity to family, cultural affinities, and emigrants' desire to contribute to technological progress in their native country.[18]

The diaspora is a major source of skills and capital

Repeated waves of emigration have led to the creation of vibrant diasporas that possess cutting-edge technology, capital, and professional contacts. For example, developing countries accounted for three-quarters (approximately 2.5 million) of the 3.3 million

Figure 3.7 Share of Ph.D. students still living in the United States five years after graduation

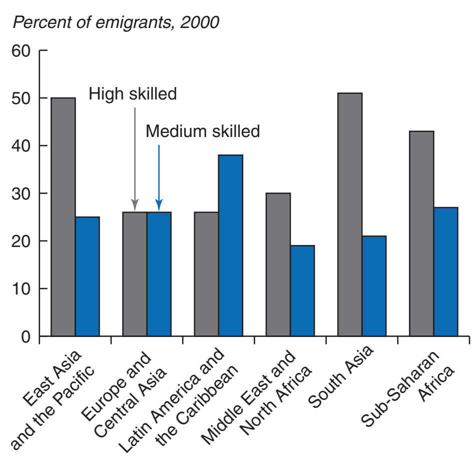


Source: World Bank calculations based on Finn 2003.
Note: Country mnemonics follow ISO standards.

immigrant scientists and engineers living in the United States in 2003.[19] Moreover, because out-migration rates are higher for high-skilled individuals than for low-skilled individuals, on average, the diaspora is much more skilled than the home-country population and represents an important concentration of expertise (figure 3.8). Notwithstanding the size of the diaspora, relatively little rigorous empirical research exists on whether and to what extent it influences technology adoption and creation in emigrants' home countries.[20] The primary evidence of diaspora contributions to knowledge transfers comes in the form of case studies. At a minimum, the technical, market, and marketing knowledge of national diasporas is a huge potential technological resource.[21]

Returning migrants can be a major source of entrepreneurship, technology, marketing knowledge, and investment capital (Brinkerhoff 2006a, 2006b; Kapur 2001).[22] Migrants returning to Egypt tend to have higher levels of human capital than nonmigrants and are likely to be more entrepreneurial the longer they work abroad (McCormick and Wahba 2003; Wahba 2007). Returning migrants and members of national diasporas who are still abroad

Figure 3.8 High-skilled emigrants are disproportionately represented in the diaspora



Source: Docquier and Marfouk 2004.

Box 3.5 Technological transfers through the diaspora and return migrants: Some examples

An émigré from Bangladesh working in the financial sector in the United States returned to help create the Grameen Phone network and make mobile phones available to poor people in remote villages (Sullivan 2007). Through its successful Village Phone Program, the network has provided business opportunities to some 260,000 Village Phone operators, mostly poor rural women. Grameen Phone now has 15 million customers, more than 10 times the maximum potential client base initially estimated by Bangladesh Telecom.

In India, Sam Pitroda, a global entrepreneur who divides his time between India and the United States, founded the Center for Development of Telematics, which developed rural automatic telephone exchanges and introduced shared public call offices all over the country, thus expanding access to cheap and reliable domestic and international calling. The relatively low-cost telephone exchanges are designed to operate without air conditioning and require significantly less maintenance than conventional exchanges. The technology has been exported to several other developing countries.

Bata Shoes of the Czech Republic is an early example of technology diffusion through migration and return. Faced with the threat of bankruptcy at his small shoemaking business in the early 1900s, the founder of the company, Tomas G. Bata Sr. went to the United States in 1904 to learn more efficient mass production methods. Bata returned to the Czech Republic to apply these production techniques. He eventually expanded production to several other countries, including India, Poland, and the former Yugoslavia, and became the world's leading footwear maker by the 1930s. Faced with nationalization in 1945, the founder's son moved his family and the company's headquarters to Canada, returning to the Czech Republic once again in 1989 with a further transfer of technology and business know-how acquired over the intervening years. Since then, the Bata company has continued to spread technology. It has opened stores in Croatia, Poland, Russia, and Slovenia, as well as a production facility in China, and is modernizing its Batanagar factory complex in India.

Source: http://www.bata.com; Factiva; Telenor press releases.

have made major contributions to technological progress in their home countries (box 3.5).

The diaspora also contributes to technology transfers and adoption by strengthening trade and investment linkages. The high-skilled diaspora of countries such as India has contributed to the growth of the information technology sector, outsourcing (Kapur and McHale 2005b; Pandey and others 2006), and FDI in their home countries. The flow of outward FDI from the United States is strongly correlated with the stock of migrants from the origin country.[23] Nearly half of the $41 billion in FDI that China received in 2000 may have originated from its diaspora abroad (Wei 2004). Similarly, 60 percent of the increase in bilateral trade in differentiated products within Southeast Asia may be attributable to ethnic Chinese networks (Rauch and Trindade 2002).[24] Moreover, technology appears to diffuse more efficiently through culturally and nationally linked groups, and shared ethnicity appears to counteract the kind of home bias effects that underpin the geographic network or the cluster effects that give high-density R&D zones an innovation advantage (Agrawal, Kapur, and McHale 2004).

Diaspora networks and returnees help promote technology adoption

The diaspora's political engagement in home countries can also improve local technological absorptive capacity, both through return and by exercising pressure on home country politicians from afar. Many leaders of developing countries were educated abroad and returned to strengthen political institutions in their countries of origin (Easterly and Nyarko 2005). In addition, migrants have often played a valuable role in the transfer of market-based institutions, such as venture capital, entrepreneurship, and corporate transparency, to their countries of origin.[25] Overseas Taiwanese engineers and returnees, for example, worked closely with policy makers to establish a successful venture capital industry. This has provided local entrepreneurs with an alternative source of finance, which has helped them overcome the constraint posed by the reluctance of state-owned financial institutions to lend to high-risk entrepreneurial activities in the technology sector (Kuznetsov 2007).

Expatriate knowledge networks have been created to foster regular contacts; transfers of skills; and opportunities for business with researchers, scientists, and entrepreneurs in the country of origin. Brown (2000) identified 41 such networks for 30 different countries. These networks tend to be rich depositories of talent with high concentrations of members with advanced degrees, many earned in the host countries.[26] Colombia's Red Caldas network, set up with government assistance in 1991, was one of the first diaspora networks that succeeded in promoting collaborative research between domestic scientists and Colombian researchers abroad through workshops and symposiums, joint research programs, visiting researchers, scientific events, publications, and research and training opportunities (Chaparro, Jaramillo, and Quintero 2006). Less formal networks played an important role in the transition of the Republic of Korea and Taiwan (China) from developing to high-income economies.[27] Some diaspora networks have failed, principally because they were too ambitious, particularly in cases where the policy and institutional environment in the home country were not supportive.[28] Research suggests that the most successful models start small to build up trust and credibility before attempting to sponsor a major research project or cooperative agenda (Kuznetsov 2006).

Remittances can promote technology diffusion by making investments more affordable

Remittances to developing countries have grown steadily in recent years, reaching $207 billion in 2006, and are now are larger than FDI and equity inflows in many countries, especially small, low-income countries. Remittances can support the diffusion of technology by reducing the credit constraints of receiving households and encouraging investment and entrepreneurship (Fajnzylber and López 2007; Puri and Ritzema 1999; Woodruff and Zenteno 2007; World Bank 2006a). A survey of self-employed workers and small firms in Mexico found that remittances were responsible for one-fifth of the capital invested in microenterprises in urban Mexico (Woodruff and Zenteno 2001). In the Philippines, households work more hours in self-employment and become more likely to start relatively capital-intensive household enterprises in response to an exogenous increase in remittances (Yang 2006).

Remittance flows have also contributed to the extension of banking services (often by using innovative technologies), including microfinance, to previously unserved, often rural, sectors. This has improved the access of households and firms to financial services (box 2.8; Gupta, Pattillo, and Waugh 2007), and their ability to purchase and invest in technology. For example, remittance revenues may have helped Ghana's ApexLink and Mongolia's Xac banks to expand their networks and services (Isern, Donges, and Smith 2006). Cell phone money transfers, such as G-cash and Smart Padala in the Philippines, and card-based remittances are becoming prevalent in a number of countries, including Mozambique, South Africa, and the United Arab Emirates, and are likely to expand to other countries in the coming years (Helms 2006; Jordan 2006). Remittances have also helped domestic banks foster links with banks in high-income countries. In turn, such links have fostered technology transfers as banks in high-income countries have helped local partners to upgrade their systems to comply with the anti-money-laundering, antiterrorism, and know-your-customer regulations in developed countries.

A summary index of trends in the exposure of developing countries to external technology

The preceding paragraphs have argued that developing countries gain access to foreign technology through trade, FDI, and the diaspora and that these links have been increasing over time. This section reports on the results of an effort to summarize these trends by applying principal components analysis to five data series covering trade and FDI following the same basic methodology as used in chapter 2 to create the index of technological achievement.[29]

The index shows that the relationship between income levels and exposure to external technology is relatively weak across countries. Even though the average exposure is higher as one moves from low-income to upper-middle-income developing countries, substantial variation is apparent across countries. This variation partly reflects issues of country size (smaller countries tend to be more open than larger countries), but it also stems from varying degrees of specialization among countries.

The index also shows that many countries have increased their exposure to technology during the 1990s (figure 3.9). Of the developing countries for which data are available, 17 experienced a reduction in exposure to foreign technologies over the 1990s and 70 saw their exposure rise. The average percentage increase was highest in low-income and in upper-middle-income countries, with the increase among lower-middle-income countries actually being below that observed among high-income countries. These average results reflect a mix of strong increases in excess of 100 percent in a number of countries and less spectacular increases in others.

Much of the variation is attributable to strong increases in the degree of openness among the transition economies. The average improvement in the index of exposure to foreign technology for the countries of Europe and Central Asia was 80 percent. Excluding these countries from the sample lowers the average increase in middle-income countries significantly, resulting in a clear negative relationship between the observed increase in exposure to foreign technologies and incomes (table 3.5). This is particularly encouraging for low-income countries, as the gains from such exposure tend to be nonlinear and enduring (Lumenga-Neso, Olarreaga, and Schiff 2005). For middle-income countries and South Asia, however, this result suggests that many countries (notably those in South Asia) may be missing out on the potential benefits to be achieved from increased openness.

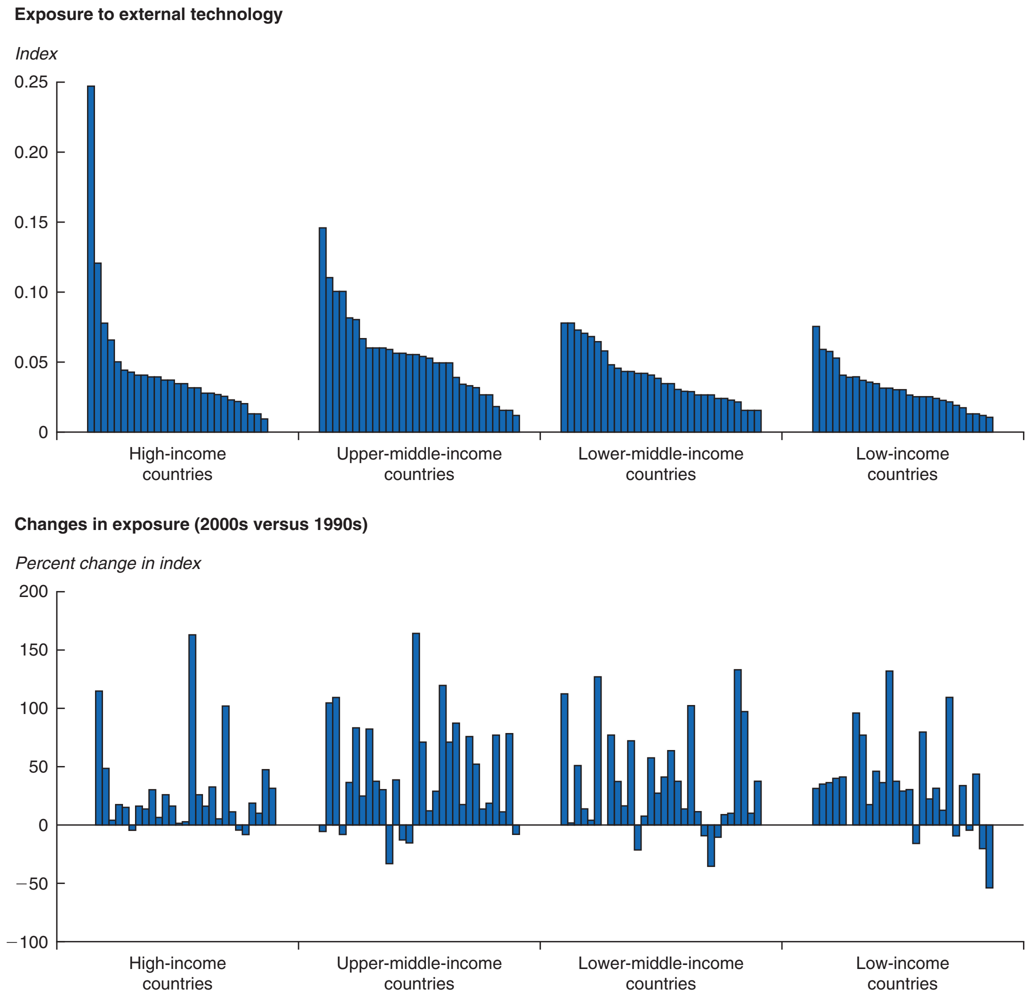
Nurturing technological adaptive capacity

Openness to trade, FDI, and international communication through the diaspora, other networks, and various media all serve to expose a country to technologies and applications of technologies that may not have been exploited domestically. Exposure does not, however, guarantee that these new technologies will spread and grow within the domestic economy. Too often technologically sophisticated processes or products are limited to a few major centers or foreign-owned enclaves. How far these technologies diffuse within a country is determined by its technological adaptive capacity, that is, the quality of its labor force and the business environment (including access to finance) in which firms operate and are able (or unable) to start up, expand, and reap the financial rewards of their new-to-the-market innovations. In the following sections we explore recent trends in technological adaptive capacity among developing countries and the roles firms, governments, and individuals play in creating and supporting that capacity.

Governance and the business climate

A stable and predictable economic environment reduces the risk that returns to investments in technology and innovative business activities will be lost to conflict or widely variable inflation and exchange rates. A stable regulatory environment that facilitates the conduct of business by enforcing property

Figure 3.9 Most developing countries have increased their exposure to external technology



Source: World Bank.

rights, by limiting corruption, and by not imposing onerous requirements that make the creation or expansion of firms or their adoption of new technologies unnecessarily difficult also contributes to an economy's technological adaptive capacity.

Political and macroeconomic stability have improved countries' ability to exploit technology

Over the past 15 years, the number of countries involved in international or domestic conflict, as measured by the International Crisis Behavior Project, has declined significantly (figure 3.10). The decline has been most pronounced in Sub-Saharan Africa, where the total number of countries in conflict declined from a peak of 10 in 1998 to only 2 in 2004. Among its many benefits, the cessation of conflict can provide an environment that is more conducive to both private and public sector investments in technology. For example, 12 years after the end of hostilities, the government of Rwanda launched an ambitious

Table 3.5 Increases in exposure to external technologies index, 1990s to 2000s

	All countries	(excluding Europe and Central Asia)
Regions	*(percent change)*	
East Asia and the Pacific	13.4	
Europe and Central Asia	83.7	
Latin America and the Caribbean	33.4	
Middle-East and North Africa	37.8	
South Asia	13.7	
Sub-Saharan Africa	33.4	
Income groups		
High-income countries	27.7	27.7
Upper-middle-income countries	45.1	24.4
Lower-middle-income countries	36.2	31.7
Low-income countries	33.5	33.5

Source: World Bank.
Note: Values are unweighted averages of country-specific changes.

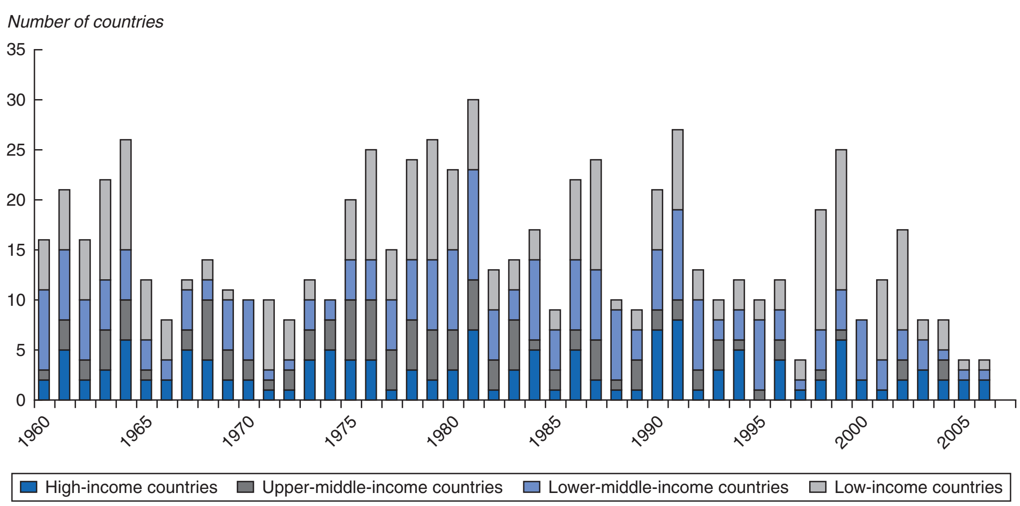
program of technological capacity building (Watkins and Verma 2007).

Improved macroeconomic stability and growth in developing countries has also contributed to an environment that is more friendly toward technological investment.[30] High and variable inflation and high exchange rate volatility increase the risk involved in investments in technology and increase the returns to financial manipulation relative to investment. High government deficits and debt also increase uncertainty, especially when combined with a rigid exchange rate regime, a combination that increases the likelihood of an abrupt revaluation that would further cloud expected future returns. The median inflation rate in developing countries fell from 19 percent in the early 1990s to 4 to 6 percent during the first half of this decade, exchange rate volatility is down, and government deficits have declined across the board and are now below 3 percent of GDP in every developing region except South Asia. Moreover, the acceleration of per capita income growth over the past 15 years, which has been most marked over the past 6 years, has improved the overall affordability of technology (table 3.6).

A weak business environment and poor governance can impair technological progress

Regulatory restrictions that impair the economy's flexibility may limit the absorption of technology. Restrictions on labor mobility and rules that constrain firms' ability to reallocate workers within the firm can be important barriers to the adoption of new technologies (Parente and Prescott 1994). For example,

Figure 3.10 Number of countries in conflict worldwide



Source: International Crisis Behavior database. http://www.cidcn.umd.edu.icb.

Table 3.6 Macroeconomic stability has improved in developing countries

	Median inflation rate[a]			Real effective exchange rate volatility[b]		
	1990–94	2002–06	Difference	1990–94	2002–06	Difference
World	11.1	3.6	−7.5	3.7	1.4	2.3
High-income countries	3.4	2.1	−1.3	1.6	0.8	0.8
Upper-middle-income countries	19.2	4.5	−14.7	2.8	1.4	1.4
Lower-middle-income countries	16.3	4.7	−11.6	6.5	1.2	5.3
Low-income countries	9.2	4.0	−5.2	3.9	2.0	1.9
Developing countries	18.8	4.2	−14.5	4.5	1.5	3.0
East Asia and the Pacific	7.1	3.4	−3.7	1.3	1.2	0.1
Europe and Central Asia	326.8	4.3	−322.5	10.6	1.2	9.4
Latin America and the Caribbean	17.1	5.5	−11.6	2.9	1.3	1.6
Middle East and North Africa	8.9	3.7	−5.2	1.9	1.2	0.7
South Asia	9.8	5.4	−4.4	1.4	1.1	0.3
Sub-Saharan Africa	9.2	4.6	−4.6	3.9	2.1	1.8

	General government balance[c]			General government debt[d]		
	1990–94	2002–06	Difference	1990–94	2002–06	Difference
World	−5.0	−1.5	3.5	62.6	64.1	1.5
High-income countries	−4.3	0.8	5.1	58.7	55.6	−3.0
Upper-middle-income countries, excluding ECA	−2.3	−2.1	0.2	55.1	74.5	19.4
Lower-middle-income countries, excluding ECA	−3.8	−2.9	0.9	64.3	57.5	−6.8
Low-income countries, excluding ECA	−5.4	−1.9	3.5	97.9	106.5	8.7
Developing countries, excluding ECA	−4.1	−2.2	1.9	73.3	78.7	5.4
East Asia and the Pacific	−2.0	−2.1	−0.1	45.6	57.0	11.4
Europe and Central Asia	−9.4	−1.9	7.5	38.9	37.2	−1.7
Latin America and the Caribbean	−2.2	−2.8	−0.6	67.5	69.7	2.2
Middle East and North Africa	−6.6	−2.8	3.9	71.6	71.3	−0.3
South Asia	−7.7	−6.1	1.5	78.2	76.3	−1.9
Sub-Saharan Africa	−5.3	−1.4	3.9	88.6	97.6	8.9

	GDP per capita growth[e]		
	1985–94	1995–2006	Difference
World	1.8	2.5	0.7
High-income countries	2.1	2.5	0.4
Upper-middle-income countries, excluding ECA	2.9	2.1	−0.8
Lower-middle-income countries, excluding ECA	1.1	2.1	1.0
Low-income countries, excluding ECA	−0.5	1.6	2.1
Developing countries, excluding ECA	2.0	2.0	0.0
East Asia and the Pacific	3.7	2.5	−1.1
Europe and Central Asia	−2.4	4.9	7.3
Latin America and the Caribbean	2.1	1.7	−0.5
Middle East and North Africa	3.2	2.1	−1.1
South Asia	2.6	3.3	0.7
Sub-Saharan Africa	0.6	2.6	2.0

Source: DataStream, International Monetary Fund, JP Morgan, World Bank.
Note: ECA = Europe and Central Asia.

a. Calculated as the mean over each indicated period of the median monthly (year over year) Consumer price index inflation rates of the countries in each grouping.
b. Calculated as the period average of the absolute value of the month-over-month percent change of the real effective exchange rate of countries in each grouping.
c. Calculated as the period average of the simple mean across countries of the central government budget deficit as reported by the International Monetary Fund.
d. Calculated as the period average of the simple mean across countries of the government debt as reported to the World Bank (for low- and middle-income countries and as per the IMF for high-income countries).
e. Calculated as the period average of the simple mean across countries of the growth in GDP per capita.

stringent labor market regulations in Brazil undermine productivity and technical efficiency (World Bank 2005), and the removal of labor market regulations that result in involuntary overstaffing would increase labor productivity by 7 percent in India (World Bank 2004b). Similarly, restrictions on firm exit and entry can impede technological progress by propping up inefficient firms and limiting the expansion and creation of innovative firms.[31]

Rules and regulations governing firm start-up can be particularly important, because they have the potential to prevent a new technology or new-to-the-market product or process from seeing the light of day. The World Bank's indicators on doing business suggest substantial room for improvement in most developing regions. On average, an entrepreneur seeking to begin a new business must undertake more than 9 separate procedures, which can take almost 50 days to complete (table 3.7). Among high-income countries that belong to the Organisation for Economic Co-operation and Development (OECD), the equivalent figures are 6 procedures and 17 days. Moreover, in developing countries the associated fees are particularly onerous given income levels, consuming more than an amount equivalent to 1.5 years worth of per capita income for a person living in South Asia, compared with 5 days worth of the per capita income of someone in an OECD country. Minimum capital requirements are also high compared with income and likely limit the size of formal small and medium enterprise sectors, particularly in the Middle East and North Africa and in Sub-Saharan Africa, where they represent more than two years of average earnings.

Ensuring timely and efficient exit by failed businesses also promotes technological progress by freeing unemployed and underemployed capital and workers for more efficient uses. Developing countries, on average, require much more time to resolve insolvencies (ranging from 2.7 years for East Asia and the Pacific to 5.0 years for South Asia) than OECD countries (which require an average of 1.3 years). In addition, the amount recovered averages less than 30 cents on the dollar in all developing regions (and only 20 cents in South Asia and 17 cents in Sub-Saharan Africa), compared with 74 cents on the dollar in OECD countries.[32]

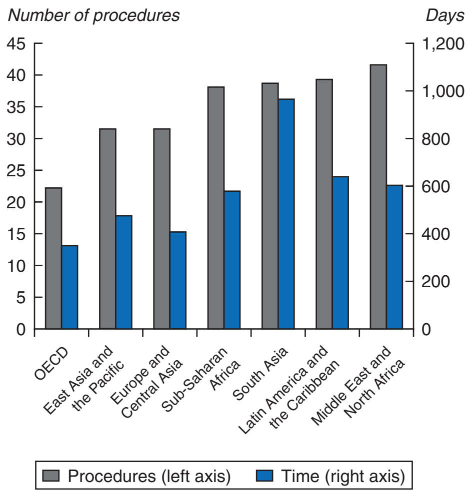
The quality of regulation, including its enforcement, and of the business legal environment are critical determinants of the capacity of new and innovative firms to grow and expand. For example, the ability of such firms to finance their initial operations or conduct arms-length operations, both of which are crucial for technologically advanced companies that require a large customer base to exploit economies of scale, depend on the

Table 3.7 The regulatory burden is heavier in developing countries than in the OECD

	Procedures	Duration	Cost	Minimum capital requirements
	(number)	*(days)*	*(% of GNI per capita)*	*(% of GNI per capita)*
East Asia and the Pacific	8.2	46	43	60
Europe and Central Asia	9.4	32	14	54
Latin America and the Caribbean	10.2	73	48	18
Middle East and North Africa	10.3	41	75	745
South Asia	7.9	62	163	1
Sub-Saharan Africa	11.1	33	47	210
Developing-country average	**9.5**	**47.8**	**65**	**181**
OECD countries	**6.2**	**16.6**	**5**	**36**
Memo:				
Ratio of developing-country average to OECD average	**1.5**	**2.9**	**12.2**	**5.0**

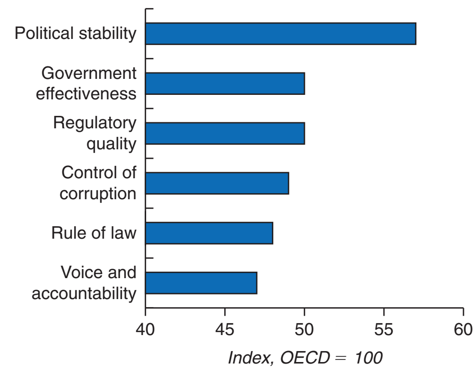
Source: World Bank; Doing Business. http://www.doingbusiness.org
Notes: Procedures required to register a firm, average time spent during each procedure, offical cost of each procedure, and minimum capital required as a percent of income per capita; GNI = gross national income.

Figure 3.11 Efficiency of contract enforcement



Sources: World Bank; Doing Business. http://www.doingbusiness.org.

Figure 3.12 Developing country governance scores relative to OECD average



Source: Kaufmann, Kraay, and Mastruzzi 2007.

system's ability to enforce contracts, establish property rights, and enforce court decisions in a timely and cost-effective manner.

Although the number of procedures required to enforce a court decision in the case of a contract dispute in developing countries is significantly higher than in OECD countries, the time taken to reach a decision is not too much greater (with the notable exception of South Asia), generally less than 25 days, compared with 13 days in OECD countries (figure 3.11). However, the time required to enforce legal decisions approaches two years in four of six regions. This seriously affects firms' (and consumers') ability to effect arms-length transactions with confidence, and is therefore an important inhibitor to the growth of technologically sophisticated firms.

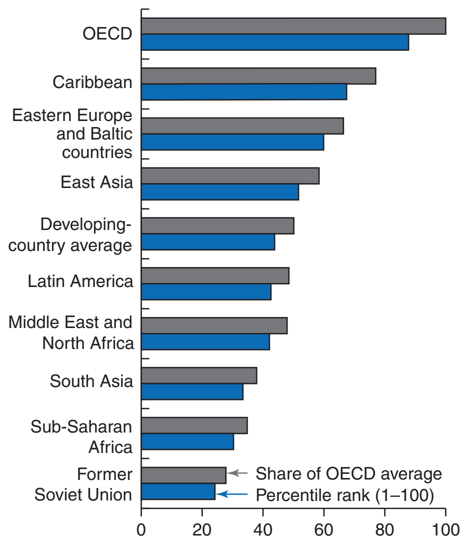
Corruption can also prevent entrepreneurs from making investments in technology and expanding their businesses in a manner that helps extend the penetration of technologies into the economy, while increasing the relative return to activities aimed at influencing policy makers. Moreover, better governance is also associated with improvements in process technology, particularly in the delivery of government and regulated services. For example, Kaufmann, Kraay, and Mastruzzi (2007) estimate that an improvement of one standard deviation in the summary governance indicator is associated, in the long term, with a two-thirds reduction in infant mortality and a tripling of incomes.

Surveys suggest that developing countries lag behind high-income countries on a wide range of governance indicators (figure 3.12). For example, government effectiveness and regulatory quality are typically considered to be at half of OECD levels, with indicators for corruption, rule of law, and voice and accountability being even lower.

These aggregate results hide a certain amount of variation across countries and regions (figure 3.13). Governance in the Caribbean and in Eastern Europe and the Baltic countries appears to be much stronger (more than 70 percent of the OECD level) than in the rest of the developing world, while countries in the former Soviet Union and Sub-Saharan Africa have the lowest ratings, only 34 and 28 percent of OECD levels, respectively.

In contrast to other indicators of performance, such as inflation and openness, there is little evidence that developing countries have

Figure 3.13 Regional averages of six governance indicators



Sources: World Bank; Doing Business. http://www.doingbusiness.org.

markedly improved their governance over the past decade. Despite individual country improvements and marked gains in the regulatory environment in Europe and Central Asia, on average, the quality of governance around the world has not improved much over the past decade (see the World Bank's *Governance Matters* series). For each country that has done well, one has experienced deterioration in its governance indicators. Two countries that have experienced notable deterioration are Belarus and the República Bolivariana de Venezuela. Many countries have not experienced any significant change in either direction. On the positive side, the *Governance Matters* series shows that where countries are committed to reform, improvements can take place relatively quickly. For example, during the relatively brief period of 2002–06, Kenya, Liberia, and Ukraine made significant advances in voice and accountability, while Algeria and Angola made substantial progress in political stability. Thus the potential exists for a rapid, substantial improvement in the quality of governance in many developing countries, an improvement that would encourage technological progress.

Basic technological literacy

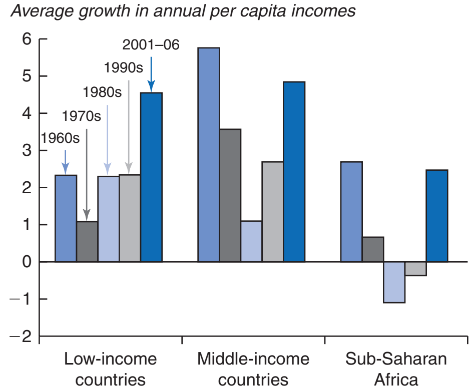
While the policy environment is critical to the absorption of technology, technological progress also requires a literate workforce. The process by which external technologies are absorbed, adapted, and integrated into an economy is not a mechanical one, but one that depends on the quality, quantity, and distribution of human capital, that is, on the technological competencies and the health of the people that use and implement the technology. For this reason, efforts to increase the technological competency, knowledge, and understanding of populations, firms, and governments lie at the heart of the World Bank's technology agenda. Especially among poor countries and in rural areas, existing deficits in terms of basic skills are a binding obstacle to technological progress and income growth.

Low incomes and poor health impair skill formation for technological progress

Low income and poor health are perhaps among the most basic constraints to technological progress. Even if profitable investments in technology are available, inadequate income limits the ability to generate resources for investment. At the level of the economy, low income is both a cause and an effect of low levels of human capital, limited funds allocated to research, thin financial markets, often poor governance, and sometimes violence and macroeconomic instability, all of which limit the ability to absorb technological innovations.

Recent developments in relation to income levels are heartening. Growth rates of GDP per capita have picked up throughout the developing world over the past 15 years (figure 3.14). The number of people living in absolute poverty has declined by more than 250 million, and their share in the population of the developing world is expected to fall from 18 percent in 2004 to around 11 percent by 2015 (chapter 1).

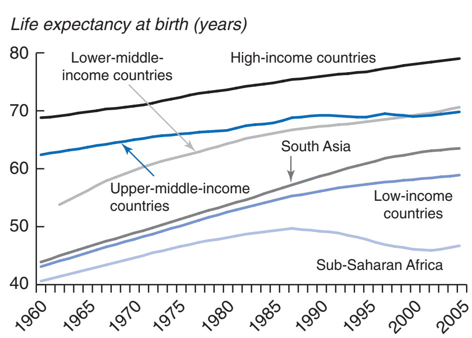
Figure 3.14 Per capita incomes have accelerated in recent years



Source: World Bank.

Similarly, welcome developments have taken place in basic health. Life expectancy at birth has reached 70 years in middle-income countries and continues to converge to still-rising high-income country levels (figure 3.15). Among low-income countries, life expectancy is also converging with high-income countries. Excluding Sub-Saharan Africa, where life expectancy has been declining because of HIV/AIDS, life expectancy in low-income countries increased from 59 years in 1990 to 64 years in 2005, suggesting that in much of the world, poor health should be decreasing as a factor impeding technological progress.

Figure 3.15 Except in Sub-Saharan Africa, life expectancy is improving



Source: World Development Indicators.

In Sub-Saharan Africa, the combination of incomes that are still extremely low and the ravages of HIV/AIDS are more problematic. The failure to control HIV/AIDS is itself an example of poor dissemination of technology and problems of affordability, as both the know-how to limit the spread of the disease and to control its health effects are well known, even though implementation strategies are controversial and tend to be country specific. Some countries, such as Uganda, have succeeded in reducing HIV infection rates. Other countries in western Africa have succeeded in limiting its spread. Still others, notably Botswana, are doing better at treating those infected than in preventing new infection. In too many countries, however, the epidemic continues to grow more or less uncontrolled, with widespread societal consequences (World Bank 2007b). Estimates suggest that in Burkina Faso, Rwanda, and Uganda, HIV/AIDS is likely to increase the percentage of people living in extreme poverty by as much as 6 percentage points between 2000 and 2015 (UNDP 2003). In Kenya, HIV/AIDS may reduce GDP per adult by 11 percent by 2040 compared with what it would have been in the absence of HIV/AIDS (Bell, Bruhns, and Gersbach 2006). In addition to the incalculable human costs implied, continued high death rates in the adult population will have further negative implications for the ability of these countries to acquire and to apply technology, both because the experience and technological competencies of the adults expected to die will be lost and because the educational attainment and literacy of their children and dependents will be impaired (Bell, Devarajan, and Gersbach 2004).

Illiteracy is declining, but still blocks countries' ability to absorb new technologies

The level of human capital is a major determinant of an economy's ability to adapt and absorb both sophisticated and even more basic technologies.[33] In both high-income (Eaton and Kortum 1996) and developing countries

(Caselli and Coleman 2001), the extent to which a given technology is used within a country depends importantly on the educational attainment of the population, both because such skills help individuals learn how to make effective use of a new-to-the-firm or farm technique, and because they increase the likelihood that firms will learn of new innovations beyond the scope of their local communities.

Although the gap between the educational attainment of individuals living in developing countries and those in high-income countries remains wide, it is closing, both in terms of the most basic indicators (literacy and primary school completion rates) and more sophisticated indicators, such as tertiary education enrollment rates (table 3.8). Over the past 15 years, literacy rates have increased throughout the developing world, with the biggest increases recorded among low-income countries, particularly in South Asia. Reported literacy rates in Europe and Central Asia rival those in high-income countries, while in East Asia and the Pacific and Latin America and the Caribbean, literacy rates are at or close to 90 percent. Elsewhere literacy lags considerably, with only 73 percent of the population in the Middle East and North Africa being able to

Table 3.8 Educational attainment indicators

	Adult literacy rate		Female literacy rate		Expected years of schooling	
	1990–2005	2005[a]	1990–2005	2005[a]	2001–05	2005
Regions	*(% point change)*	*(% of population aged 15 and older)*	*(% point change)*	*(% of female population aged 15 and older)*	*(% change)*	*(years of schooling)*
East Asia and the Pacific	10.7	91	14.9	87	1.9	11.2
Europe and Central Asia	1.3	97	1.8	96	0.8	12.7
Latin America and the Caribbean	2.3	90	2.6	89	0.5	13.1
Middle East and North Africa	14.7	73	16.5	63	2.1	11.7
South Asia	11.6	58	12.8	46	4.0	9.7
Sub-Saharan Africa	5.1	59	5.2	50	3.5	8.0
Income groups						
World	**6.0**	**82**	**7.3**	**77**	**2.0**	**10.9**
High income	0.3	99	0.3	98	0.4	15.8
Upper middle income	0.8	93	1.9	92	0.5	13.3
Lower middle income	9.2	89	12.0	85	2.0	11.5
Low income	9.3	61	10.1	50	3.5	9.0

	Primary completion rate		Secondary completion rate		Tertiary completion rate	
	1991–2005	2005	1990–2000	2000	1990–2000	2000
Regions	*(% point change)*	*(% of relevant age group)*	*(% point change)*	*(% of population aged 15 and older)*	*(% point change)*	*(% of population aged 15 and older)*
East Asia and the Pacific	−1.7	97.7	1.5	13.7	0.8	2.5
Europe and Central Asia	2.2	94.9	0.1	13.5	1.6	5.5
Latin America and the Caribbean	16.9	98.5	1.1	8.7	1.2	4.9
Middle East and North Africa	13.7	90.7	2.1	10.0	1.4	3.4
South Asia	18.1	83.5	0.5	7.0	0.5	2.0
Sub-Saharan Africa	11.5	60.8	0.5	2.3	0.4	1.0
Income groups						
World	**n.a.**	**87.6**	**0.4**	**11.9**	**1.0**	**4.9**
High income	n.a.	97.4	−0.7	18.6	2.9	13.3
Upper middle-income	10.3	98.5	0.7	12.4	1.4	4.9
Lower middle-income	2.7	96.6	1.4	12.4	0.9	2.9
Low income	17.0	75.9	0.5	6.1	0.4	1.8

Source: World Development Indicators.
a. Actual reference year varies by country.

read and write and about 60 percent in South Asia and in Sub-Saharan Africa. Moreover, there are concerns about the comparability of these data, as some low-income countries reportedly define literacy as the ability to read and write one's own name.

Divergence in the literacy rates for women explain much of the disparity. For example, in South Asia fewer than half of women age 15 and older are literate. Women in the Middle East and North Africa and Sub-Saharan Africa fare somewhat better, with literacy rates of 63 and 50 percent, respectively. Although the technological consequences of such widespread illiteracy are difficult to quantify, illiterate mothers are much less successful in assisting their children to learn (Behrman and others 1999), have much more difficulty in absorbing new techniques and instructions that are transmitted in written form, and are likely to be less effective workers than their better educated peers. Indeed, female illiteracy and the resulting relative ignorance of best practices in child rearing may be a major causal factor in poor child health care and poor female labor force outcomes (Rosenzweig and Wolpin 1994).

Rising primary school completion rates should drive further improvements in adult literacy

The rise in literacy rates is due in no small part to increased and longer participation in formal education. Primary school completion rates approach 100 percent in about half of the developing regions and have increased substantially among poorer regions, notably South Asia and Sub-Saharan Africa. Although reflective of the average literacy in the geographical region, these numbers hide important variations across countries. Thus the low score for South Asia reflects mainly low literacy in India, and it masks the fact that some 95 percent of Sri Lankan youth can read and write. Similarly, China's relatively high literacy rates and its large weight in East Asia aggregate mask the less than 90 percent literacy rates of less populous countries such as Cambodia and the Lao People's Democratic Republic. In particular, the gap between school completion rates for girls and boys has narrowed significantly. Partly as a consequence, youth literacy rates are much higher than adult literacy rates in South Asia and Sub-Saharan Africa, which over time should be reflected in better literacy scores for women and improved transmission of knowledge and technology to future generations (table 3.9).

Table 3.9 Relatively high youth literacy rates

	Youth literacy rate	
	1990–2005	2005[a]
Regions	*(% point change)*	*(% of population age 15–24)*
East Asia and the Pacific	3.43	98
Europe and Central Asia	1.67	99
Latin America and the Caribbean	2.29	96
Middle East and North Africa	12.23	88
South Asia	13.72	73
Sub-Saharan Africa	5.42	70
Income groups		
World	**4.16**	**88**
High-income countries	0.23	99
Upper-middle-income countries	1.82	98
Lower-middle-income countries	3.68	96
Low-income countries	10.41	73

Source: World Bank; World Development Indicators.
a. Actual reference year varies by country.

Of course, progress in providing effective basic education is a necessary precursor of more formal secondary and tertiary education. Nevertheless, the more advanced technical and problem-solving skills that are taught at the basic level can significantly increase students' capacity to learn to work with, adapt, and maintain more technologically advanced goods. Indeed, the main obstacle to deepening the use of a given technique or process in a country is frequently a lack of sufficient numbers of individuals trained to maintain and install systems. For example, in Rwanda a shortage of plumbers and sheet metal workers has been identified as a principal factor constraining the deployment of the simple kind of rain-harvesting technologies that have succeeded in increasing the supply of sanitary drinking water in neighboring countries

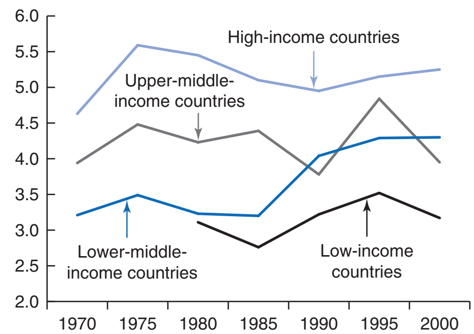
(Watkins and Verma 2007). While nearly 19 percent of the population completes secondary school in high-income countries, secondary school attainment rates range between 10 and 14 percent in East Asia and the Pacific, Europe and Central Asia, and the Middle East and North Africa, but are below 9 percent in Latin America and the Caribbean, South Asia, and Sub-Saharan Africa (table 3.8). Between 1990 and 2000, secondary completion rates more than doubled in the Middle East and North Africa, East Asia and the Pacific, and Latin America and the Caribbean, but remain low. In contrast, improvements have been much less marked in South Asia and Sub-Saharan Africa, and no appreciable gain was apparent in Europe and Central Asia. By income grouping, the strongest gain in the secondary completion rate is reported by the lower-middle-income countries with an increase of 1.4 percentage points during 1990–2000, compared with half as much or less of an improvement among other income groupings.

This same general pattern is observed for tertiary-level students. In East Asia and the Pacific, South Asia, and Sub-Saharan Africa, 2.5 percent or less of the population aged 15 years or older has completed tertiary education. Europe and Central Asia and Latin America and the Caribbean have almost double the number of tertiary-level graduates, while the Middle East and North Africa falls in between these two groups of regions (table 3.8). The share of secondary graduates who go on to tertiary studies is relatively high in Latin America and the Caribbean, 60 percent, compared with 70 percent in high-income countries. However, the share of university students following a scientific as opposed to a social science curriculum is relatively low (Maloney 2006). Elsewhere, the ratio is 42 percent or lower, with only 18 percent of secondary graduates going on to the tertiary level in East Asia and the Pacific.

This performance in educational attainment across levels of schooling is largely consistent with patterns of public expenditures dedicated to education. For example, public expenditures

Figure 3.16 Educational expenditures have risen in some regions

Public expenditures as a percent of GDP

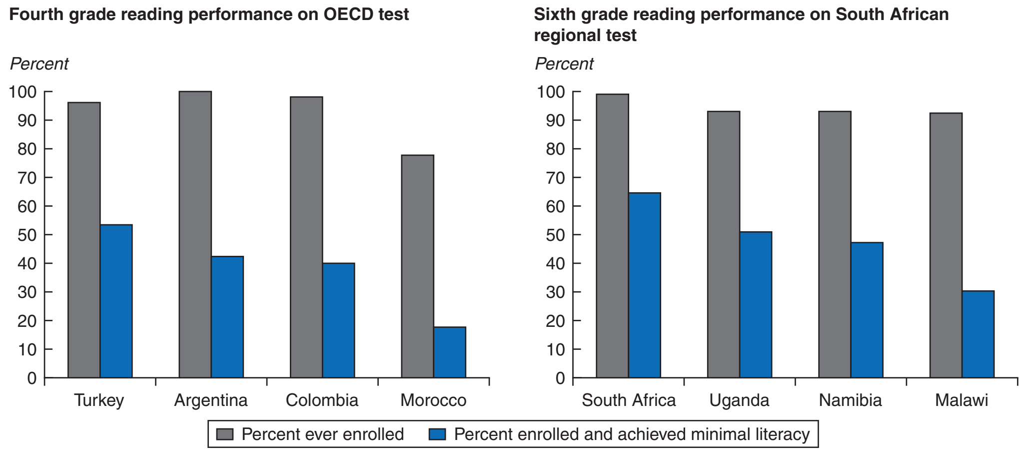


Sources: UNESCO Institute of Statistics; World Bank.

on education among lower-middle-income countries averaged about 3.3 percent of GDP during the 1970s and 1980s and rose to a fairly steady 4.3 percent during 1990 through 2000 (figure 3.16). Among low-income countries, the share of public outlays rose by about half a percentage point to an average of 3.3 percent of GDP during 1990–2000, up from an average of 2.9 percent during 1980 through 1985. These shares compare with government expenditures on education of close to 5.3 percent of GDP in high-income countries, down from a peak of just over 5.6 percent during the mid-1970s.[34]

While educational attainment rates and expenditure data are available for a fairly wide number of countries, the data are silent on the quality of the education (or knowledge) received, and it is the quality of education that determines the effectiveness with which individuals can absorb and exploit technology. Here significant concerns have been raised, particularly for poorer countries where the quality of educators and limited resources sap the value of time spent in school. This suggests that the education deficits in developing regions could be larger than indicated by national indicators, which, in turn, implies that the expansion of knowledge attained (and the capacity to adopt and adapt technological

Figure 3.17 Many developing country students fail to meet literacy standards



Source: World Bank 2007d.

knowledge) is not necessarily rising in accordance with higher educational attainment. The availability of international test scores across countries is very limited outside of high-incomes countries, but some data underscore these concerns. For example, in a number of middle-income countries, the majority of primary school students fail to meet OECD literacy standards. In Sub-Saharan Africa, despite enrollment rates of close to 100 percent, in some countries fewer than half of grade six students are deemed literate (figure 3.17). Although based primarily on data from high-income countries, research suggests that teacher quality is a key determinant of differences in student outcomes (Hanushek and Woessmann 2007).

Financing innovative firms

So far, the discussion has described how the policy environment and human capital can promote technology diffusion. At the same time, and as indicated in chapter 2, affordability, both at the level of the firm and of the consumer, can be a major impediment to the diffusion of technology within a country. In this regard, the success with which an economy's financial system succeeds in channeling resources (savings) toward their most productive use (investments) is an important determinant of its technological adaptive capacity.

Limited financial intermediation restricts technology diffusion

Neither the banking system, nor equity markets, nor private sector bond markets in developing countries have channeled savings into the private sector to the same extent as they have in high-income countries (table 3.10). As a result, the arm's-length channels through which private savings can be directed toward innovative firms are limited. While banks in high-income countries play a significant role in relaying private savings to investors (private-sector debt is equivalent to some 50 percent of GDP in high-income countries), this kind of intermediation occurs at about half that level in middle-income countries and almost not at all in low-income countries. On a more encouraging note, the run-up in international investors' appetite for risk has increased market capitalization in developing countries by significant margins since 2000 (with the exception of East Asia, where valuations declined). Valuation ratios are now much closer to those observed in high-income countries.

Table 3.10 Weak financial intermediation hinders technology in developing countries

	1990	2000	2005	% change 2005/1990	1990	2000	2005	% change 2005/1990
	Financial system deposits				Stock market capitalization			
	(% GDP)				*(% GDP)*			
Regions								
East Asia and the Pacific	40.9	41.7	45.6	11.5	38.7	44.1	51.3	32.5
Europe and Central Asia	23.8	22.8	31.2	31.0	8.5	13.8	19.7	130.8
Latin America and the Caribbean	31.1	39.9	39.8	28.1	11.7	28.2	46.4	298.3
Middle East and North Africa	46.5	47.4	59.8	28.7	16.0	26.1	63.8	298.3
South Asia	22.5	33.3	43.7	94.0	6.7	13.4	26.1	290.0
Sub-Saharan Africa	18.5	19.9	24.4	31.4	31.0	27.0	34.9	12.4
Income groups								
High-income countries	76.0	87.0	91.4	20.4	45.1	105.0	112.2	148.7
Upper-middle-income countries	34.3	43.6	45.2	31.8	37.7	36.5	50.2	33.4
Lower-middle-income countries	36.0	34.3	39.4	9.7	13.4	20.4	34.3	156.7
Low-income countries	16.7	17.4	21.8	30.7	7.6	10.8	22.3	194.7
	Private-sector credit				Private-sector debt			
	(% GDP)				*(% GDP)*			
Regions								
East Asia and the Pacific	30.3	36.7	44.9	48.2	—	37.5	31.0	..
Europe and Central Asia	22.3	18.2	27.9	25.3	—	12.7	12.2	.
Latin America and the Caribbean	28.6	40.6	32.1	12.3	—	27.2	23.3	..
Middle East and North Africa	35.3	40.5	46.1	30.7	—	—	—	..
South Asia	16.2	21.6	34.1	110.4	—	1.9	4.0	..
Sub-Saharan Africa	17.4	16.3	18.2	4.4	—	20.1	30.2	..
Income groups								
High-income countries	81.1	94.2	108.2	33.3	—	47.9	50.0	..
Upper-middle-income countries	32.8	42.5	40.5	23.6	—	27.5	26.1	..
Lower-middle-income countries	27.3	29.3	31.9	16.7	—	27.7	23.4	..
Low-income countries	14.9	13.4	16.4	9.7	—	1.9	4.0	..

Source: Beck, Demirgüç-Kunt, and Levine 2000. Financial Structure Dataset updated March 20, 2007. For Private Sector Debt the source is World Bank, Financial Sector Development Indicators. http://www.financial-indicators.org (February 2007).
Note: — = not available; .. = undefined.

Barriers to the finance of high-risk activities severely impede the spread of technology

Although weak intermediation is a general problem in developing countries, the problem for innovative firms or companies seeking to employ an untested new-to-the-market technique or product is more severe. Innovation can involve high risk, and traditional sources of capital—banks, stock exchanges, and bond markets—often lack the technical expertise to evaluate innovative investments. Thus in the absence of demonstrated cash flows or enforceable collateral, innovative firms or entrepreneurs are less likely to obtain financing than experienced entrepreneurs operating with proven techniques. Coupled with thin markets, this translates into higher capital costs for innovative firms in developing countries than for those in high-income countries, a fact that is reflected in lower R&D intensities (Lederman and Maloney 2006) and a reduced likelihood that their financing needs are met.[35]

Innovative firms in developing countries are also less likely to have access to equity financing than do their counterparts in high-income countries because of strict listing requirements imposed by the regulators of emerging-market exchanges[36] (Pfeil 2000). Less stringently regulated, so-called new markets, modeled after the NASDAQ in the United States, have been developed to fill the void. Many of these markets help investors by providing some, albeit less rigorous, due diligence of listed firms and by offering risk-pooling services (offerings of bundled shares that reduce investors' exposure to any one firm). Such capital pool companies allow listing firms to access equity finance in amounts that are too large for angel investors to provide, but are too small for institutional investors. However, the full promise of such markets has yet to be felt, in part because many of them have been obliged to maintain relatively strict listing requirements to attract foreign investors (Yoo 2007).

Increasingly, venture capitalists and "business angels" are playing a role in financing new technologically sophisticated firms in developing economies.[37] These investors tend to have more technological know-how than do traditional lenders and to be better able to judge the potential profitability of new ventures. Often the transfer of business and marketing expertise is as important as the infusion of capital in determining the difference between success and failure for young firms (Avnimelech and Teubal 2004; Mayer 2003). Even though empirical evidence is still scarce, this activity appears to be translating into increased innovation (Pfeil 2000). Western-based venture capitalists are increasingly becoming involved in markets in Asia (China and India), Eastern Europe (notably the Czech Republic, Hungary, and Russia), and South Africa. Notwithstanding this increased activity, Nastas (2007) reports that only 1 in 200 small and medium enterprises in emerging markets is likely to secure venture capital financing, and the ratio is undoubtedly lower for firms in less-developed countries.

Supporting innovative firms with R&D and outreach

While the process of technological advance occurs fundamentally at the firm level, the government, along with international and national organizations, including nongovernmental ones, can play a role in promoting the dissemination of knowledge within the domestic economy. In addition to the formal education system, less formal continuing education—notably, outreach programs and R&D programs that focus on adapting technologies to local conditions—have a central role to play.

R&D efforts to adapt existing technology to local conditions are expanding

Domestic R&D capacity is critical in determining an economy's capacity both to generate new technologies and to absorb technologies from abroad. Foreign technologies frequently need to be modified so that they are suitable for domestic circumstances. For example, equipment and processes may need to be adapted to differences in the quality of inputs and in the relative abundance of labor and capital, and a stock of researchers is often necessary to understand and evaluate advanced technology (Cohen and Levinthal 1989). Building up R&D capacity facilitates the imitation and adaption of foreign technologies and improves the extent to which positive spillovers from FDI and trade accrue to the rest of the economy (Fagerberg 1988; Kinoshita 2000). Moreover, countries tend to acquire technology more readily when domestic firms have R&D programs and when public research laboratories and universities have relatively close ties to industry (Maskus 2000).

Available data indicate that most developing regions have been increasing their R&D expenditures relative to GDP (table 3.11).[38] East Asia and the Pacific has experienced a particularly rapid rate of increase in R&D expenditures and also has the highest level of such expenditures among those regions for which data are available. In contrast with other regions, in Latin America and the Caribbean, both the number of researchers and expenditures on R&D have been falling or stagnant, reflecting both a reorientation of policy away from university-led R&D (Maloney 2006) and tighter fiscal policies.

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Table 3.11 R&D intensities have increased

	R&D expenditure		Researchers in R&D	
	1997–2002	2002	1997–2002	2002
Regions	*(% point change)*	*(% of GDP)*	*(% change)*	*(per million people)*
East Asia and the Pacific	0.45	1.06	4.4	545.3
Europe and Central Asia	0.06	0.88	–1.4	2008.7
Latin America and the Caribbean	0.01	0.57	—	—
Middle East and North Africa	—	—	—	—
South Asia	0.13	0.77	—	—
Sub-Saharan Africa	—	—	—	—
Income groups				
World	**0.12**	**2.18**	—	—
High-income countries	0.12	2.43	2.6	3750.0
Upper-middle-income countries	0.09	0.71	—	—
Lower-middle-income countries	0.46	1.01	3.9	499.9
Low-income countries	0.18	0.80	—	—

Source: World Development Indicators.
*Note:** Interpolation applied where appropriate; — = not available.

While developing countries spend less on R&D than high-income countries, the gap is not extreme. Relative to GDP, low-income countries spend about one-third as much on R&D than high-income countries. One issue with the data is that the coverage of commercial R&D expenditures is poor in many developing countries, so the figures largely reflect R&D expenditures by the public sector and universities. As firms in many developing countries probably focus on adapting foreign technology to local conditions, a significant portion of this important activity may therefore not be captured.

Firm-level R&D is most effective in promoting technological progress

All R&D can contribute to an economy's capacity to create, adapt, and adopt technology. Nevertheless, because of the fundamental role that firms play in diffusing technology through the economy, the most productive R&D tends to be that conducted by firms or by public or university laboratories working actively with the private sector. Across developing countries, the share of R&D conducted by firms (as opposed to government or university laboratories) is highest in East Asia and the Pacific, where it rivals the share in

Table 3.12 Private-public sector R&D

		Sector of performance			Sector of funding		
	R&D spending	Business	Government	Higher education	Business	Government	Higher education
	(% GDP)	*(share of total)*			*(share of total)*		
World	2.28						
High-income countries	2.45	63	13	27	49	34	2.1
Developing countries	0.83	—	—				
East Asia and the Pacific	1.44	62	22	14	54	35	2.3
Europe and Central Asia	0.94	43	29	20	38	54	0.5
Latin America and the Caribbean	0.56	29	27	33	33	37	27
Middle East and North Africa	—	—	—	—	—	—	—
South Asia	0.73	—	—	—	—	—	—
Sub-Saharan Africa	—	—	—	—	—	—	—

Source: Gill and Karas 2007.
Note: — = not available.

high-income countries (table 3.12). Note, however, that in China, despite rapid technological progress, the efficiency of R&D spending is relatively low and the impact of R&D is impaired because of poor linkages among government R&D institutes, businesses, and universities (Zeng and Wang 2007). In Europe and Central Asia and in Latin America and the Caribbean, academia and the government are responsible for a much higher share of R&D. Moreover, in the latter region coordination between R&D carried out by government institutions and private firms has been poor, reducing the impact of R&D on productivity growth (de Ferranti and others 2003).

Research on OECD countries suggests that the more R&D is conducted at the firm level, the higher the rate of return to public and academic R&D, presumably because having R&D expertise close to the firm increases the likelihood of successful adaptation of a technology created in government, academic, or even foreign laboratories (Guellec and Pottelsberge de la Potterie 2004). Maloney (2006) concludes that state-funded R&D that is too academic and/or too disconnected from the private sector is less effective at promoting technological progress than firm-conducted R&D or state-supported R&D that has a strong connection to business needs. Indeed, the relatively high share of private sector R&D in East Asia and South Asia may have contributed to the more rapid technological progress in those regions than in Latin America and the Caribbean and Europe and Central Asia.

Outreach plays a critical role in bringing technology to the broader population

Too often the overall effectiveness of R&D undertaken by government and specialized research institutes is reduced because such organizations are divorced from their eventual clients and their incentives are poorly aligned with the ultimate dissemination of their inventions and adaptations.[39] Especially in poor countries plagued by illiteracy and weak communication networks, technology outreach programs can play a critical role in increasing the diffusion of often simple but important technologies. Agricultural outreach programs were instrumental to the green revolution, even though it took much longer than initially expected for those programs to bear fruit (World Bank 1998). Difficulties encountered in other efforts to disseminate technology include a lack of skilled personnel to staff the outreach program and the need to earn the trust of the local population. Here challenges include minimizing the risks people run in trying a new technology, listening to their experiences, and adapting techniques as a consequence (World Bank 2007d). Enhancing the role of farmers in agricultural outreach programs and relying more on cooperation between government and the private sector—in those areas where private benefits from technology transfer can be substantial—may improve both the impact and financial sustainability of outreach efforts.

Direct government policies to promote technology

Innovation requires entrepreneurs: people who are willing to take risks to invest in uncertain projects and who have the organizational skills required to bring new products to the market. Given the high risks involved, the returns to successful entrepreneurship must be high, but the returns to investment in new technology in developing countries can be limited, because potential profits may be reduced by imitation, because of a lack of coordination between firms that produce complementary inputs, or because economies of scale and agglomeration generate threshold effects that prevent firms from breaking into mature markets (box 3.6).

Government policy can play a central role in helping firms overcome market failures

The difficulties that these externalities pose for firms in certain sectors and those seeking to adopt a new-to-market (or even new-to-the-firm) technology imply that specific government interventions may be necessary to encourage investment in technology.

Box 3.6 Principal market failures impeding technological progress in developing countries

The nonpatentability of new-to-the-market products and processes. The vast majority of innovation that occurs in developing countries involves the adaptation of already discovered techniques and products to the domestic market, and such innovation is not patentable. Lack of patent protection facilitates imitation, which may speed diffusion, but reduces the returns to the individual or firm introducing the technique or product to the domestic market. As a result, private entrepreneurs underinvest in easily reproduced techniques, even though they could have large social benefits.

Coordination failures limit investment in technology. Some technologies rely on the availability of complementary inputs. Coordination failures can arise when new industries exhibit scale economies and some of the inputs require geographical proximity. For example, producing cut flowers for export requires an adequate electrical grid, irrigation, logistics and transport networks, quarantine and other public health measures, and resources devoted to marketing the country as a dependable supplier (Rodrik 2004). However, these services have high fixed costs and will not be supplied unless demand is sufficient, creating a vicious circle where demand is not forthcoming because of the lack of supply. The market for training is another example of potential coordination failure, as workers will demand training only if a demand for trained workers exists, but in the absence of training there is no demand (Rodriguez-Clare 2005). Perhaps reflecting such factors, in almost all the successful case studies of innovation reported in Chandra (2006), government played an important role by providing infrastructure, marketing, or training support.

Threshold effects caused by economies of scale in many manufacturing sectors prevent entry by firms into global markets or the introduction of a new process in a small market dominated by a preexisting, large-scale competitor. Economies generated from learning by doing and the productivity boosts generated by the accumulation of small innovations are related impediments that imply that start-ups must endure an initial period of relatively high costs, which in the absence of adequate intermediation, may prevent them from accumulating sufficient experience or scale to attain adequate levels of profitability. For example, Arrow (1962) cites evidence that productivity in the production of airframes is a decreasing function of the total number of airframes of the same type produced previously.

Knowledge spillovers tend to be geographically bounded within a region where the new economic knowledge is created (Audretsch and Feldman 2004). Audretsch and Feldman (1996) find that the propensity of innovative activity to cluster geographically tends to be greater in industries where new economic knowledge plays a more important role as has occurred in, for example, Silicon Valley and Bangalore. Studies also find that access to venture capital in the United States is heavily skewed by region (Sorenson and Stuart 2001).

Agglomeration effects, whereby firms benefit from the knowledge and human resource spillovers arising from the geographical proximity of firms in the same area of business, may also prevent developing economy firms from breaking into established markets (Glaeser and others 1992). The absence of such effects represents an important barrier to development in Sub-Saharan Africa and in more remote areas of China and India, where lack of physical proximity both raises trading costs and minimizes the potential for benefits from interactions with more rapidly growing areas.

Source: World Bank.

Governments in developing countries have undertaken a host of direct interventions in productive activities to provide demonstration effects, encourage innovation that otherwise would not occur because imitators reap the lion's share of benefits, resolve coordination failures, and move an industry toward efficient technologies that it would not otherwise adopt because of capital market imperfections. These steps have included the following:

- *Providing support for industry-specific research*. For example, Malaysia funded industry-specific R&D, provided

Box 3.7 Government sponsored innovation: Brazilian biofuels

Brazil launched its National Alcohol Program in 1975 to reduce its dependence on crude oil imports and to guarantee the profitability of the sugar industry by allowing excess sugar production to be converted into alcohol (ethanol) in special distilleries located near sugar mills.

Government support for the initiative has been extensive. Initially it was supported by legislation that mandated that 24 percent of fuel sold for automobiles must be in the form of ethanol. This requirement was complemented by sponsored research into the production of, and eventually the subsidization of sales of, cars that ran entirely on ethanol. Moreover, government credit guarantees and low-interest loans to construct the refineries amounted to some 29 percent of the overall investment cost of these ventures. At the same time, the state oil company, Petrobras, was required to make infrastructure investments in ethanol distribution and to keep the cost of ethanol to consumers significantly cheaper than the cost of gasoline. Overall, the government spent $12.3 billion on the National Alcohol Program during 1975–98.

During periods of high oil prices the program has been relatively successful, with ethanol-powered cars representing 90 percent of sales between 1983 and 1988. However, as oil prices fell, the technology became less attractive and the costs of supporting the industry rose. At the same time, world sugar prices rose and sugar growers shifted their cane to the production of sugar for export instead of ethanol for the domestic market. Ethanol shortages developed and ethanol-powered car sales dropped. As a result, the government gradually rescinded the program's incentives and subsidies, although it still mandated that all gasoline contain roughly 20 percent ethanol, citing environmental benefits to justify the mandate.

The flex-fuel car engine, which was able to run on any combination of ethanol and gasoline, was introduced in 2002 and, along with the surge in crude oil prices, led to a revival of ethanol in Brazil. With the recent rise in oil prices, ethanol-based cars are once again competitive, and ethanol produced from Brazilian sugar can be produced for less than the equivalent quantity of gasoline. Other developing countries are increasingly interested in adopting the Brazilian technology to reduce their energy dependence and also to support their sugar sectors.

Source: Coelho and Goldemberg 2004; World Bank 1994; Xavier Marcos 2007.

financing, built infrastructure, and offered tax incentives to encourage the processing of palm oil (Chandra and Kolavalli 2006).[40] Governments have also encouraged innovation by improving networking among enterprises, universities, and government research institutes (Goldman and Ergas 1997). For example, government-funded technology parks in Taiwan, China, encouraged research by providing high-quality facilities and by facilitating interactions among scientists. Many governments finance agricultural research and support farmers' efforts to exploit new technologies.

- *Providing direct subsidies for specific products.* The government started the first commercial-scale salmon farming operation in Chile to demonstrate its feasibility (Rodrik 2004). Korea and Japan provided fiscal subsidies to create "national champions" in key sectors (Hoekman, Maskus, and Saggi 2005). Similarly, the Brazilian aircraft and biofuel sectors (box 3.7), the Indian pharmaceuticals sector, and the South African automobile industry were developed using tax incentives, regulatory policies that encouraged domestic competition, science and technology support, and collaboration with foreign firms (UNCTAD 2003).
- *Imposing more dirigiste policies.* Some countries, particularly in East Asia, have guided production decisions through initially high import tariffs, export

Box 3.8 A successful government program of technological development and innovation financing in the Republic of Korea

GDP per capita in Korea increased from $150 in 1960 to $16,000 in 2005, with GDP growing particularly rapidly during the 1980s and early 1990s as technological progress accelerated. Although an outcome of many factors, Korea's technologically intensive growth spurt had a strong public policy element. Government-funded research institutes, including the Korea Science and Engineering Foundation in the 1970s, recognized the need to enhance cooperative research between universities and industry (80 percent of the nation's research capability was university based in the 1970s). The government created research centers located within corporations to supply industry with high-tech research capability and industry dictated the focus and area of research.

With time, industry realized that domestically-developed technology could be internationally competitive and began investing heavily. As a result, Korean industry transformed itself from a low-tech, labor-intensive exporter to one of the world's leading high-tech producers. Private sector expenditures on R&D have increased rapidly since 1990—almost doubling over the past decade—and are now the main source of R&D financing. Nanotechnology, information technology, and biotechnology are the main axes of the government's focus on R&D at the generation stage.

Source: World Bank.

subsidies, government influence over the allocation of production, and directed credit programs. The extent to which such policies were necessary to these countries' success has generated some controversy (Hernandez 2004), and the forms of intervention in high-growth East Asian economies were by no means identical. For example, Korea (box 3.8) favored tariff protection and constraints on FDI to maximize technology transfer; Singapore encouraged FDI; and Hong Kong, China, practiced laissez-faire policies. Nevertheless, some observers doubt that such interventions were pervasive in many of the most successful East Asian economies.

But government efforts at promoting technological champions have often failed

Notwithstanding the wide range of support policies that governments have tried and the existence of many apparent success stories, such policies have often been spectacular failures. Even among the examples cited, it is not clear that all should be considered successes. For example, the Brazilian aircraft maker Embraer did not become commercially successful until it was privatized. More generally, the import-substitution policies followed by many countries in Latin America and Africa and India's inward-focused policies severely hampered economic and technological development. To take two of the countless examples, first, rather than promoting the development of a technologically sophisticated export industry, the tariffs, price harmonization, and import licensing programs imposed in Côte d'Ivoire diminished incentives for efficiency in its textile industry, making it internationally uncompetitive. Second, Brazil's attempts to promote its domestic personal computer sector by banning imports and FDI, awarding licenses for production, providing fiscal incentives, and establishing a public research center resulted in an inefficient industry, high domestic prices, and lagging technology (World Bank 1998).

Two important issues distinguish industrial policies in the successful East Asian countries with those in many other countries. First, in contrast to Latin America, where subsidies were often provided free of performance criteria, East Asian countries conditioned subsidies on performance (often export performance), essentially relying on external competition to discipline the market.[41] Second, East Asian countries maintained high-quality bureaucracies that for the most part avoided capture by industrial interests, thereby maintaining a balance between knowledge and involvement in productive activities and state autonomy. In Latin America, industrialists often captured bureaucracies, while in many Sub-Saharan African countries, the interests of industrialists or corrupt officials dominated government interventions.

Imitation opportunities may boost technological diffusion, but have costs

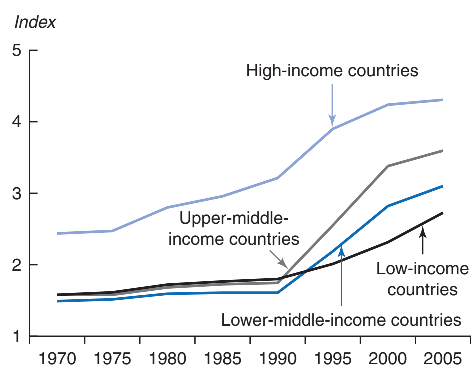
The possibility of adopting technologies already elaborated in more technologically advanced economies represents a fundamental advantage of less-advanced developing economies and is the basis for much of their R&D and outreach activity. Indeed, many developing countries with relatively advanced levels of technological achievement (Brazil, China, India, the Republic of Korea, Mexico, and Malaysia), as well as Japan, initially used an explicit policy of copying foreign technologies. While this strategy proved successful to a point, eventually the successes that these economies had in the markets of their higher-technology competitors meant that these competitor countries became increasingly unwilling to share technology with them.

A substantial literature attempts to grapple with the trade-off between the impact of weaker intellectual property regimes and the potential for increased technological diffusion in a host country and with the impacts that such regimes might have on foreign partners' willingness to undertake FDI and licensing agreements. Although the theoretical literature emphasizes the importance of intellectual property regimes (Lai 1998; Taylor 1994), the empirical evidence is ambiguous overall.

Some studies find no relationship between the level of intellectual property rights and FDI or licensing (Primo Braga and Fink 2000; Branstetter, Fisman, and Foley 2005; Maskus and Konan 1994). Other studies show a positive effect of strong intellectual property regimes on FDI both in influencing location decisions by multinational corporations and in inducing foreign firms to invest in production rather than in distribution activities (Javorcik 2004; Lee and Mansfield 1996; Mansfield 1994; Maskus 1998).[42] Some evidence suggests that while a stronger intellectual property rights regime is associated with a rise in flows of knowledge to affiliates and in inward FDI toward middle-income and large developing countries, this is not the case for poor countries (Fink 2005; Hoekman, Maskus, and Saggi 2005; Smith 2001).

Overall, the impact of intellectual property rights on FDI depends on the nature of the sector. Intellectual property rights appear to have little impact on investment in lower-technology goods, such as textiles and apparel; services sectors, such as distribution and hotels; or in sectors where the sophistication of the technology itself or the cost of production already serves as an effective barrier to entry. Indeed, the increased ease with which some products such as pharmaceuticals, chemicals, food additives, and software are reproduced

Figure 3.18 Levels of intellectual property protection



Source: World Bank calculations based on individual country data provided by Walter Park, American University.
Note: A higher score on the index indicates stronger intellectual property rights.

may explain the rising interest in establishing intellectual property rights (Maskus 2000).

Perhaps reflecting such considerations, a general trend toward strengthening the legal protection afforded by intellectual property rights has been apparent since the latter half of the 1980s (figure 3.18). Among developing countries, the legal basis for such rights has progressed most in upper-middle-income countries, where levels of protection now exceed the levels in high-income countries in the mid-1990s. Progress in lower-middle-income and low-income countries has been less marked, reaching about the same level as in high-income countries in the 1990s and 1970s respectively (note, however, that the index in figure 3.18 refers to the protection offered in statutes, not in practice).

Governments can also promote technological progress in their own operations . . .

In many developing countries the government accounts for a significant share of productive activities. Using technology to increase the productivity of government operations can help raise the efficiency of the economy as a whole by improving health and education services (see chapter 2 and the foregoing discussion of human capital); enhancing the effectiveness and reducing the costs of publicly-provided power, telecommunications, and water and sanitation; providing approaches to regulation and tax administration that are less burdensome to firms; and demonstrating the feasibility of new technology that firms can copy. One area where dramatic efficiency gains are possible is greater use of technology in government procurement. Countries that have implemented Internet-based procurement systems include Brazil (including in some local governments), Chile, Mexico, and the Philippines.[43] Implementing e-procurement systems may require changes in laws and policies governing government operations (for example, ensuring that government agencies can contract with foreign firms that can provide such systems. Although procurement is often a focus of corruption and is frequently biased in favor of local products (most developing countries provide preferential treatment to local suppliers in government procurement [Kohr 2007]), the use of advanced communications and information technologies can raise the transparency and efficiency of government procurement and can ensure greater competition, thereby contributing to an overall improvement in the quality of government services.

More broadly, the integration of information and communications technology tools has tremendous potential for improving access to government information, increasing public participation in government decision making, and making government services more readily available to the public (World Bank Information for Development Program and Center for Democracy and Technology 2002). In addition to enhancing government efficiency, such improvements can help reduce costs and improve services to private sector firms, thereby increasing the potential for technological progress. While many industrial countries have used the Internet to improve local access to information and services, its potential remains largely unexploited in many developing countries. Nevertheless, some developing countries are implementing e-government systems that are as or more sophisticated than those used in some high-income countries (United Nations 2003). Also, the use of electronic systems has helped improve the efficiency of customs services in many countries.

A survey of case studies in developing countries outlines some initial steps in use of the Internet to improve tax administration and general services and to enhance the transparency and efficiency of government operations (Ndou 2004). The survey underlines the importance for the success of e-government initiatives of appropriate stocktaking of the current state of telecommunications networks; of raising awareness of the potential for, information and communications technology beginning with relatively small projects to test feasibility; of stimulating collaboration among government departments; and of making substantial investments in equipment and software, human capital, and appropriate organizational changes. Other important issues pertinent to implementing e-government systems include its coverage (comprehensive, national efforts may be appropriate for small countries, but may be too complex and difficult in large countries); the ability of the enabling environment to support e-government initiatives, for instance, adequate infrastructure, an appropriate legal framework, political commitment, and public involvement; and the availability of strong project management skills (Bhatnagar and Deane 2002).

. . . and encourage improved technology through product standards

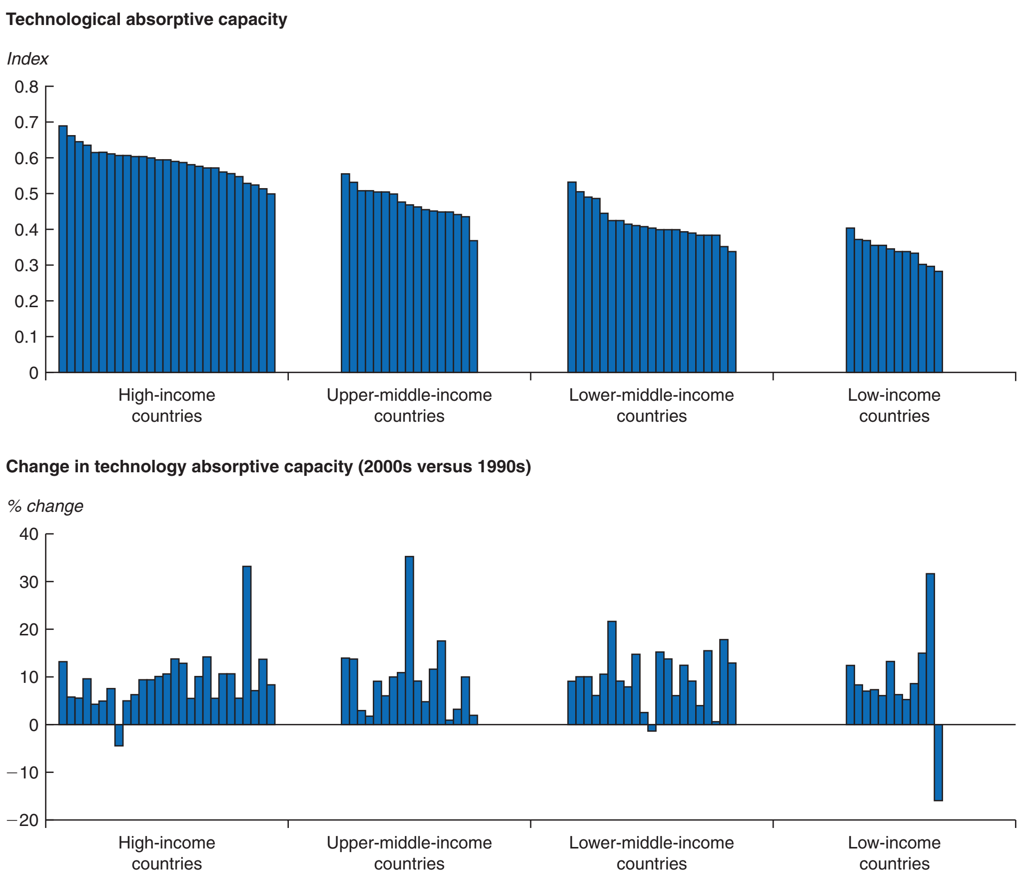
Governments can play a key role in boosting technological progress by defining and promoting standards for products made by private firms and by facilitating quality control to help firms comply with standards. Good standards support technological progress by increasing consistency and ensuring minimum product performance; facilitating the connection of components in complex systems by standardizing the interfaces between different parts of the system; offering buyers a greater choice of suppliers at lower risk and lower cost and the prospect of faster and more reliable system development; and offering manufacturers and vendors easier entry to markets, economies of scale, and lower product liability risks (Yokota and Weiland 2004). The transmission of information about standards can be an extremely useful channel for technology transfer. Implementing well-defined standards, including testing and sanctions for noncompliance, can be critical in maintaining a country's reputation for quality, which is important for establishing and maintaining access to global markets.

The value of a country's reputation, the benefits of coordination, and the protection of health and safety underline the government's role in promoting and enforcing standards, even in competitive product markets, but the government's specific role will depend on the product and the market structure involved. Standards may be defined by private firms with dominant market shares or agreed on through a collaborative process negotiated within the context of professional organizations. They may also be imposed by government regulation, or they may derive from some combination of collaboration and imposition. Participation in international organizations can help developing countries understand and influence international standards. The International Organization for Standardization, with 132 developing country members, is a forum for agreement on technical specifications for a variety of products.[44]

Coherent policies and committed government leadership are critical for technological progress

No single blueprint for technological progress exists, but most success stories have involved strong central leadership to ensure a consistent and effective policy framework that supports the development and commercialization of innovations. Technological progress is largely implemented by private firms. However, progress at the firm level requires government support, elements of which include the following: an appropriate incentives framework, including overall political and economic stability and government transparency, along with specific technology policies such as protection of intellectual property rights; investments in human capital, including general education and technical training where firms underinvest in training because of the potential mobility of trained staff; support for R&D of new-to-the-market technologies because of difficulties in appropriating the full benefits from such efforts; and, where appropriate, government interventions to overcome market failures involving coordination, threshold effects, and agglomeration effects (box 3.6). Most technological success stories, including Germany in the 19th century, Japan before and after World War II, the East Asian miracle countries, Chile, Ireland, and Israel have involved strong national leadership

Figure 3.19 Level of and recent changes in technological absorptive capacity



Source: World Bank.

and a coherent strategy for promoting technology.

An overall index of technological absorptive capacity

Figure 3.19 summarizes countries' level of technological absorptive capacity and changes over the past 10 years. The overall index was generated following the same methodology used to construct the index of technological achievement discussed in chapter 2 and the index of exposure to external technologies discussed earlier in this chapter. As was the case for technological achievement, a two-step procedure was followed. The first step was to estimate a separate summary index of the quality of the macroeconomic environment, financial market intermediation, human capital, and governance. The technical annex to chapter 2 describes the estimation process used and the results of the principal components analysis in more detail than provided here and table A2.2 summarizes the individual indicators that went into the index.

The most important determinants of the overall index are the governance variables (with a 37 percent weight), followed by human capital variables (with a 25 percent weight), and financial intermediation (with a 27 percent weight), followed by the macroeconomic environment (with an 11 percent weight).

Compared with the technological achievement index, technological absorptive capacity is more clearly correlated with income, with less of an overlap across countries in different income groups. This probably results from the complex causal relationship that may exist between technological absorptive capacity, technology, and income, in which technology is a function of technological absorptive capacity and affordability, income is a function of technology, and affordability is a function of income, with income being both an indirect cause and an effect of technological absorptive capacity.

Reflecting the complexity of the institutions that generate technological absorptive capacity and the difficulties of reforming some of the measures included in the index (see technical annex to chapter 2), progress has been more limited than was the case for technological achievement (where the index increased by 160 percent for low-income countries). Relatively few countries improved their overall score for absorptive capacity by more than 10 percent between 1990 and 2000 (the strongest negative score in low-income countries was recorded by Zimbabwe and reflects mainly the deterioration in macroeconomic and governance conditions there in recent years). Moreover, in contrast to technological achievement, there is little sign of catch-up. Developing countries are improving their technological absorptive capacity at about the same rate as high-income countries.[45]

The relatively weak improvements in absorptive capacity notwithstanding, the relative strength of the technological improvement observed to date might be comforting. At the same time, the relatively weak increases in technological achievement in Latin America and the Caribbean and in the Middle East and North Africa may reflect that technological progress (and TFP growth) in those countries has reached the limits that can be achieved from relatively easy adoption and imitation of existing technologies given current levels of absorptive capacity and that further improvement may require substantial enhancement of absorptive capacity.

Conclusion

Technology diffusion in developing countries depends both on access to foreign technology (through trade, FDI, international migration, and other networks) and on the ability to absorb technology (as determined by the quality of government policy and institutions, the stock of human capital, the efforts at R&D, and the financial system). One implication of the analysis and data presented in the preceding two chapters is that prospects for further technological progress in low- and middle-income countries are good. Over the past 15 years, the main international channels through which technology is transferred have increased. Developing countries' imports of high-tech goods and of capital goods have risen relative to GDP, and their share in global high-tech export markets has increased. Inflows of FDI have increased sixfold relative to developing countries' output, and opportunities to purchase technology have risen along with FDI outflows.

Simultaneously, the absorptive capacity of developing countries has been increasing, albeit more slowly. Youth literacy rates are as much as 15 percentage points higher than for the adult population. As a result, the basic technical literacy of the population has been increasing, and it should continue to do so for many decades. The macroeconomic instability that plagued developing countries during the 1970s and 1980s has declined, and the business climate has improved, although not by as much or as uniformly as one might have hoped. Technological achievement should continue to rise over the medium term as long as these trends continue and assuming there are no major disruptions to global trade and financial systems.

Of particular note is the speed with which communications technologies are evolving and diffusing in the developing world. Only 27 years after the introduction of cell phone technology, mobile phones are being used in virtually every country, and penetration rates are rising rapidly. Moreover, the range of economic activities that were once heavily dependent on infrastructure and that are now being conducted using mobile phone technology is impressive and growing daily. Already mobile phones are bringing banking, remittances, and arm's-length financial transactions to regions of the world that until recently were unserved. Given the pace at which things are changing, most developing countries should continue to see a rise in their ability to communicate and process information over the next few decades, which should help speed the diffusion of other technologies as well.

For middle-income countries, the relatively rapid technological progress of the past few years and the improvements in both openness and technological adaptive capability suggest that their level of technological sophistication should continue to converge with that of higher-income countries. However, even the most advanced of the middle-income countries will be unable to benefit fully from the new technologies that are expected to become both technically and economically viable over the next several years because of inadequacies in their infrastructure (unreliable power or communications systems), insufficient technical literacy, or the absence of a critical mass of scientists and engineers necessary to exploit the technology (box 3.9). For some countries, the relative slowness with which technological absorptive capacity has been advancing could slow the pace of convergence as missing competencies become an increasingly binding constraint on the absorption of additional technologies.

For low-income countries, the prospects are more complex. On average, among the low-income countries for which sufficient data are available to calculate recent increases in technological achievement, convergence is occurring and is doing so more quickly than in middle-income countries. However, this finding reflects rapid progress in a few countries and more modest performance in many others that are only maintaining their ground relative to high-income countries.

Notwithstanding strong technological progress in some cities and greater openness to technological flows, the gap between existing competencies and those needed to converge with technological progress in high-income countries is immense, especially in rural areas. Moreover, the pace at which absorptive capacity is rising is disappointing. While some countries have recorded significant increases, on average, developing countries are not catching up to high-income countries, suggesting that the gap in their technology potential is not closing. As a result, unless substantial steps are taken to raise basic competencies and invest in local networks that successfully disseminate technologies and technological competencies, many of these countries are not expected to be able to master anything more than the simplest of forthcoming technologies (box 3.9).

One bright spot is the relatively rapid diffusion of some new technologies in low-income countries. Declining computing costs and prospects for rapid declines in the cost of wireless Internet connections may enhance the efficiency of ongoing economic activities in low-income countries and may enable them to leapfrog into more advanced technologies (Primo Braga, Daly, and Sareen 2003).[46] However, successful exploitation of these new technologies will require stepped-up investments in human capital and reforms in policy and regulation to provide an appropriate incentives structure for investments in information and communications technology.

A rigorous road map for achieving rapid technological progress does not exist. Nevertheless, the evidence presented in this report points to a number of conclusions, principles, and policy directions that appear likely to promote technological progress and that may be able to guide policy makers. Exactly how

Box 3.9 Technology in 2020

A recent report by the Rand Corporation (Silberglitt and others 2006) examines some 56 emerging technologies expected to be commercially available by 2020 and evaluates in detail the 16 judged to be most important on the basis of technical feasibility, marketability, and societal impact. These applications include improvements in health services (targeted drug delivery, improved diagnostic and surgical methods), in access to information (rural wireless communications, quantum cryptography), and in the environmental sustainability of products and services (improved water purification, green manufacturing, hybrid vehicles). It then examines the technical base a country requires to make effective use of each technology and the likelihood that each of 80 representative economies, including both high-income and developing countries from every region in the world, will be able to exploit these technologies by 2020.

While many countries are expected to be able to take advantage of some of the simpler-to-use technologies, a wide range of countries are not expected to be able to do so because they lack the required technological infrastructure, because their population is not sufficiently technically literate, or because a critical mass of scientists and engineers is not present to exploit the technology (see the table). The report finds that most high-income countries will be able to adopt and exploit all the technologies effectively. A second group of countries, including China, India, Russia, and the countries of Eastern Europe, are found to have a considerable level of scientific and technological proficiency in specific applications. However, barriers to technology adaptation are likely to limit their ability to take advantage of the most sophisticated network applications. A third group of middle-income countries, which consists of several Latin American countries, Indonesia, South Africa, and Turkey, lacks more prerequisites and is therefore expected to exploit fewer of these technologies. A final group that comprises most of the world's poorest countries, including most of the countries of Africa, the Middle East, and Oceania, is projected to make use of only the simplest of the new technologies.

This analysis provides a useful snapshot of the prospects for technological progress based on current data. However, it does not incorporate the potential for dynamic improvements in technological progress, for example, through the rapid dissemination of existing new technologies, which could rapidly improve developing countries' ability to absorb new technologies.

Technological adaptive capacity may restrict the diffusion of future technologies

Requires increased technological sophistication ↓

Technology application	Most of Africa, Middle East, Oceania	Latin America, South Africa, Turkey, Indonesia	China, India, Russia, Eastern Europe	Industrial countries
	Technologies likely to be mastered by 2020 (✓)			
Cheap solar energy	✓	✓	✓	✓
Rural wireless communication	✓	✓	✓	✓
Genetically modified crops	✓	✓	✓	✓
Filters and catalysts	✓	✓	✓	✓
Cheap autonomous housing	✓	✓	✓	✓
Rapid bioassays		✓	✓	✓
Green manufacturing		✓	✓	✓
Ubiquitous RFID tagging		✓	✓	✓
Hybrid vehicles		✓	✓	✓
Targeted drug delivery			✓	✓
Improved diagnostic and surgical techniques			✓	✓
Quantum cryptography			✓	✓
Ubiquitous information access				✓
Tissue engineering				✓
Pervasive sensors				✓
Wearable computers				✓

Source: Silberglitt and others 2006.
Note: RFID = radio-frequency identification.

much weight to give to each of these conclusions and how they interact depends on specific country circumstances and should be the subject of future research. These policy directions include the following:

- Openness to external technologies through foreign trade, FDI, diasporas, and other international networks is critical for technological progress for both low- and middle-income countries, where most progress occurs through the adoption, adaptation, and assimilation of preexisting but new-to-the-market or new-to-the-firm technologies.
- The capacity of firms or individuals to use a technology depends critically on the basic technological literacy of workers and consumers. The level of technological literacy, in turn, depends on the government's capacity to deliver a quality education to the largest number of people possible.
- The preeminent vehicles for the dissemination and diffusion of technology in a market economy are firms and entrepreneurs. Their success in doing so depends on their ability to undertake and expand new activities. This requires a stable macroeconomic environment, together with a regulatory environment that effectively enforces property rights and the rule of law, does not excessively restrict firms' ability to hire and fire, and does not impose excessive regulatory or financial burdens.
- The capacity of firms or individuals to take advantage of a technology can be constrained by affordability and by liquidity, thereby placing a premium on the efficiency with which the financial system intermediates between savers and borrowers both domestically and abroad.
- Given the existence of market failures, the government has a role to play in assisting firms to learn how to adapt, adopt, and market new technologies. In addition to focusing on R&D in new-to-the-market technologies, applied R&D agencies need to emphasize outreach, testing, marketing, and dissemination activities. The huge rural–urban divide in both technology and absorptive capacity in many developing countries underlines the importance of such activities to inclusive development.
- The government can also have an important impact on economic progress by integrating new technology into its own operations, including in the provision of education, health, and publicly-provided infrastructure; in the procurement of goods and services; in the provision of information and in fostering public dialogue; and in the definition of standards for commercial products.
- The principal challenge facing many low-income countries is not their access to technology, but their absorptive capacity, including physical, human, and institutional capacity; their limited financial resources; and the extent to which their social and political environments are supportive of entrepreneurship, investment, and technological progress.

These conclusions highlight the critical role of the government in establishing the general conditions that support rapid technological progress, in helping to overcome market failures that constrain innovations by firms, and in providing (and purchasing) high-quality goods and services. Countries that have achieved sustained and rapid technological progress have generally benefited from committed national leadership that follows coherent development policies, although the nature of these policies—in particular, the degree of public sector intervention in private markets—has varied enormously.

Notes

1. The econometric evidence is mixed. Harrison (1994) for Côte d'Ivoire and Haddad, de Melo, and Horton (1996) for Morocco find no statistically significant impact of import penetration on productivity following trade liberalization. Nishimizu and Page (1982) for the former Yugoslavia; Tybout, de Melo, and Corbo (1991) for Chile; and Tybout and Westbrook

(1995) for Mexico find a positive relationship between import penetration and firm efficiency. Grether (1999) and van Wijnbergen and Venables (1993) for Mexico, Earle and Estrin (2001) for Russia, Falk and Dierking (1995) for Poland, Levinsohn (1993) for Turkey, and Roberts (1996) for Colombia find a positive impact of import penetration on either industry markups or measured labor productivity.

2. Keller (1998) casts doubt on these results by showing that the relationship also holds for randomly generated import shares, but Lumenga-Neso, Olarreaga, and Schiff (2005) find that imports from countries that import from other R&D centers are positively related to productivity and that these indirect spillovers are at least as important as direct spillovers.

3. Lall (2000, 2001) identifies four categories of products: resource-based products; low-tech products, which include textiles and fashion; medium-tech products; and high-tech products. According to this classification, which is defined using SITC 3-digit rev. 2, technological products do not include agricultural products, moderately processed food products, tobacco products, minerals, construction materials, and energy products.

4. Available data provide only a rough indication of the sophistication of economic activity, because ascertaining the level of sophistication of the capital goods imported is not possible. Also some countries may import relatively sophisticated capital goods for use in enclave production (for example, oil and minerals) with little spillover into the rest of the economy.

5. Chandra and Kolavalli (2006) cite important spillover effects from exporting electronics and software.

6. The contradictory evidence from case studies and econometric studies may be due to the different impacts of exports across industries and countries, as well as difficulties inherent in classifying firms (some studies classify exporters on the basis of surveys with yes-no answers rather than measuring the volume of exports) (Keller 2004). Also the argument for technology transfers through exports refers only to some exports—namely, new products or products that have evolved over time, and export statistics may not capture such subtleties. Firms that export the same product that is not subject to significant upgrading may not benefit from spillovers. If some firms improve their productivity through exports and some do not, and available data do not permit distinguishing between these firms, measuring the extent of productivity improvements over time may be difficult. For specific examples, see Tybout and Westbrook (1996), who find that trade liberalization in Mexico benefited exporters because of declines in prices of imported inputs, but had no effect on productivity. Soderbom and Teal (2000) find that Ghanaian firms with higher technical efficiency become exporters. Isgut (2001) finds that exporting firms in Colombia had higher labor productivity than nonexporters three years before entering the export market, but that afterward there is no difference in the growth of labor productivity of exporters as compared with nonexporters. Fafchamps, Zeufack, and El Hamine (2002) find that in Morocco, more productive firms move into exports. However, after initiating exports they do not achieve more rapid reductions in production costs than nonexporters, although they do learn to improve product design to suit foreign markets.

7. Following Lall (2001), the nomenclature used is SITC 3-digit, Rev. 2.

8. Costa Rica has emerged as a high-tech platform for foreign investors and increased its world market share of high-tech products from 0.01 to 0.20 percent between the mid-1990s and 2002–04.

9. Between 1992 and 2003, developing countries made some 2,563 favorable changes to national laws and regulations relating to FDI. The most frequent changes concerned FDI promotion and incentives (855), sectoral restrictions (497), operational conditions (406), guarantees (304), and corporate regulations (153). During the same period, 113 developing countries became members of the World Trade Organization, which required the elimination of many restrictions and impediments to FDI, particularly in the services sector (World Bank 2004a).

10. The world's largest R&D investors conducted an average of 28 percent of their R&D outside their home territory in 2003 (UNCTAD 2005).

11. This section builds on many studies of FDI spillovers that have identified possible channels for technology transfers and knowledge spillovers through FDI (Görg and Greenaway 2004; Görg and Strobl 2001; Javorcik 2007; Lipsey 2002; Moran 2007; Saggi 2002).

12. Javorcik (2004) finds that the TFP of Lithuanian firms is positively correlated with the extent of potential contacts with multinational customers in downstream sectors. Blalock and Gertler (forthcoming) and Kugler (2006) find strong evidence that vertical supply chains were a channel for technology transfers in Colombian and Indonesian manufacturing sectors. Swinnen and others (2006) show that investments by foreign companies in processing and retailing in Eastern Europe have introduced higher standards, which in turn led to significant efficiency gains by suppliers.

13. Javorcik (2007) documents the increased competitive pressures from foreign entry in Czech and Latvian firms, and the McKinsey Global Institute (2003) cites case studies where competition is a key factor in diffusing FDI-introduced innovations.

14. Ayyagari and Kosova (2006), using Czech FDI data for 1994 to 2000, show that spillovers vary substantially across industries. Although service industries benefited from huge FDI spillover effects through both horizontal and vertical channels, manufacturing industries did not show any significant positive spillover effects from FDI.

15. Belderbos, Capannelli, and Fukao (2000) find that the proportion of inputs sourced locally by Japanese multinationals increases with the number of years of operation in a given host country.

16. These data are incomplete, as only 90 of 150 developing countries (on average across 1999–2006) reported royalty and license fee payments. The data may also overstate payments for technology transfer, as developing countries with mineral or oil investments abroad may report the payment of substantial royalties that represent fees for extraction rights rather than for the purchase of technology.

17. Between 1990 and 2000, the number of tertiary-educated emigrants from developing countries that resided in OECD countries rose from 19.1 million to 37.8 million (Docquier and Marfouk 2004).

18. Even though a majority of Argentine doctoral graduates in the United States prefer to remain in the host country, most respondents in a survey of high-skilled Argentine diaspora members in Europe, the United States, and elsewhere expressed their willingness and interest in helping develop science, technology, and education in their home country (Kuznetsov, Nemirovsky, and Yoguel 2006).

19. Of these technologically sophisticated émigrés, 56 percent were born in Asia, with Latin America and the Caribbean accounting for another 15 percent (Kannankutty and Burrelli 2007).

20. Agrawal, Kapur, and McHale (2007), using patent data, find evidence of the influence of the diaspora in technology transfers to home countries.

21. The Mexican Ministry of Science and Technology views the presence of 1 million tertiary-educated Mexican migrants in the United States, with an estimated 400,000 in managerial positions, as a unique, unexplored opportunity for knowledge transfers (Kuznetsov 2006). Emigrants from China and India were running almost 30 percent of Silicon Valley's (California) technology businesses by the end of the 1990s (Saxenian 2000, 2002). In addition, 25 percent of all engineering and technology companies started in the United States during 1995–2005 had a foreign-born person as a key founder (Wadhwa and others 2007).

22. Page and Plaza (2006) argue that technology transfer by migrants takes place through several channels: (a) licensing agreements between diaspora-owned or managed firms in host countries and firms in sending countries, (b) knowledge spillovers when returning migrants assume managerial positions in their home country, (c) networks of diaspora researchers and scientists performing research directed at the needs of their country of origin, (d) "virtual" return through extended visits and electronic communication in fields such as medicine and engineering, and (e) return to permanent employment in the country of origin after gaining work experience in the host country.

23. Estimates suggest that a 10 percent increase in skilled migrant stock in the United States is associated with a 4 percent increase in the flow of FDI (in current dollars) to the home country (Mattoo, Özden, and Neagu 2005).

24. This result is supported by work on high-income countries that shows immigrant ties have been important determinants of U.S and Canadian bilateral trade (Gould 1994; Head and Ries 1998; Wagner, Head, and Ries 2002).

25. Kuznetsov (2007) argues that diasporas can act as global search networks by leveraging their contextual knowledge of their home countries' economy and institutions to identify untapped resources and opportunities, such as research capabilities, availability of technical manpower, and business-friendly local governments.

26. Among members of the Philippines Brain Gain Network, 35 percent have a master's degree and 23 percent hold a doctorate, while 49 percent of the members of the South African Network of Skills Abroad have a master's degree and another 30 percent have a doctorate (Brown 2000).

27. The Taiwanese diaspora and returning migrants were active conduits for technology transfers. For example, in 2000, 113 out of 289 companies at the Hinschu Science-Based Industrial Park in Taiwan, China, were started by U.S.-educated Taiwanese (O'Neil 2003).

28. Countries with strong institutions such as Chile, the Republic of Korea, and Scotland have been able take advantage of their high-skilled diasporas, while others such as Argentina, Armenia, and Colombia have not succeeded as well despite having many programs (Kuznetsov 2006).

29. Finding a relevant, available indicator of the size of the diaspora to include in the index proved difficult. The data series used included FDI net inflows, royalties and license fee payments, imports of high-tech goods, imports of capital goods, and imports of intermediate goods—all as a percent of GDP. Imports of intermediate goods and net FDI inflows have the largest weight in the calculation, accounting for more than half the total.

30. The productivity benefits from the adoption of new technology are best realized in the context of low

inflation, stable exchange rates, sustainable government finances, and positive income growth (Pack 2006).

31. Liu and Tybout (1996) and Roberts and Tybout (1997) present data from Chile, Colombia, and Morocco confirming that the entry and exit of firms makes an important contribution to productivity growth.

32. Data are taken from the World Bank's Doing Business Web site (http://www.doingbusiness.org).

33. See Keller (2004) for a survey of the economic literature on this topic. Education levels are typically important in empirical studies of cross-country differences in growth rates and in labor productivity (Chen and Dahlman 2004), but these studies do not determine the channel through which human capital contributes to growth.

34. In some countries, the limited rise in public expenditures on education may have been balanced by increases in private expenditures.

35. Ayyagari, Demirgüç-Kunt, and Maksimovic (2007) find a positive correlation between financial market depth (proxied by credit to the private sector as a percent of GDP) and R&D intensities.

36. These requirements are generally imposed to reduce volatility in these often thin markets and to bolster investor confidence in the safety of investing in listed firms. While they enable some well-established firms to access global capital markets by providing the exchanges with legitimacy, they exclude more speculative firms less well. Similarly, the use of American deposit receipts, which make investing in emerging-market firms easier for foreign investors, is largely restricted to large, well-established, and mainly export-oriented firms (Claessens and Schumkler 2007).

37. The OECD (2005) defines venture capital "as capital provided by firms who invest alongside management in young companies that are not quoted on the stock market. The objective is high return from the investment. Value is created by the young company in partnership with the venture capitalist's money and professional expertise." The flow of venture capital from the investor to a start-up company and back can be thought of as a cycle that runs through several phases. The International Finance Corporation monitors about 90 venture capital funds active in developing countries.

38. Internationally comparable data have been available only since 1997.

39. See the discussion from the World Bank Global Forum on Science, Technology, and Innovation, February 13–15, 2007, in Washington, DC. http://go.worldbank.org/DWODQ7E3E0.

40. Note that an OECD (2003) study found that fiscal incentives to support R&D in rich countries were not very effective on average, with success being heavily dependent on the design of the tax measures.

41. Such programs are more difficult to implement today in light of World Trade Organization restrictions on export subsidies (Rodrik 2004).

42. The intellectual property regime is only one consideration among many, including various local market and sector characteristics, that enter into multinational corporations' decisions on how to deploy technology internationally (Mansfield 1994, 1995).

43. See World Resources Institute Digital Dividend (http://www.digitaldividend.org) and the Working Group on E-Government in the Developing World (http://www.pacificcouncil.org/pdfs/e-gov.paper.f.pdf).

44. See http://www.iso.org.

45. There is a slightly inverted U shape to the distribution of improvements in technological absorptive capacity, with high-income countries recording a 9.1 percent improvement, compared with 9.4 percent for upper-middle-income countries, 9.8 percent for lower-middle-income countries, and 8.6 percent among those low-income countries for which data are available.

46. The development of simple, low-cost computers and the spread of open-source technology has already enhanced the affordability of new technologies for low-income countries.

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