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Technology and Technological Diffusion in Developing Countries

Technological progress—improvements in the techniques (including firm organization) by which goods and services are produced, marketed, and brought to market—is at the heart of human progress and development. At the national level, technological progress can occur through invention and innovation; through the adoption and adaptation of preexisting but new-to-the-market technologies; and through the spread of technologies across firms, individuals, and the public sector within a country.

For developing countries, the bulk of technological progress occurs through the latter two channels. Much of this chapter is concerned with measuring the extent to which this process has occurred in countries in different regions and at different income levels. Although the current state of technological achievement is itself illuminating, the pace at which it is changing is equally important, and this is estimated by comparing the level of technological achievement in the early 1990s with its current level and inferring the pace of change for different countries. The chapter concludes by looking at the speed with which specific technologies spread both across countries and within them. Armed with this broad view of technological progress within developing countries, chapter 3 explores in more detail the main factors that influence technological progress in individual developing countries. That chapter places equal emphasis on the international connections and networks that expose firms and individuals in developing countries to cutting-edge technologies and on the domestic factors that determine how successfully countries are able to absorb and apply those technologies. To establish a baseline for future work, both chapters adopt a positive (empirical) rather than a normative or prescriptive approach. Nevertheless, some clear conclusions with policy implications do emerge from the analysis.

This chapter begins its empirical examination by reviewing existing estimates of the contribution of technological progress to economic growth as measured by gross domestic product (GDP) and of income levels in developing countries. It reviews the mechanisms by which technology contributes to GDP and incomes, but also stresses the contributions of technology to other important development goals that are not well captured by GDP alone, such as health, education, and the environment. In addition, it discusses some of the principal limitations of this kind of empirical analysis and accompanying caveats. The chapter then discusses a wide range of previously published indicators of the extent to which various technologies have penetrated the economies of developing countries. For ease of exposition, these indicators are arranged in three groups: those showing the extent of scientific innovation and invention; those measuring the penetration of older technologies, such as railroads and telephones; and those measuring the penetration of newer technologies, such as personal computers and mobile phones. The chapter then develops an aggregate measure of technological achievement using a statistical technique (principal components analysis) that combines some 20 separate indicators of technological achievement along these three dimensions, plus an additional dimension, the extent to which countries are exposed to external technologies (explored in more detail in chapter 3). The distribution of overall technological achievement across countries and changes over the past decade are examined to evaluate both the speed with which technological achievement in countries is advancing and the dimensions along which change is occurring most quickly. The chapter concludes by examining a new longitudinal data set (Comin and Hobijn 2004) that tracks both the speed with which individual technologies are transmitted across countries and the pace with which they diffuse within countries.

Eight main results emerge from this chapter:

1. *While technological achievement is related to income levels across countries, the nature of this relationship differs depending upon the dimension of technology being examined.*

- While a strong correlation exists between scientific innovation and invention and income in high-income countries, almost none of this kind of activity is being performed in developing countries. As a result, virtually all technological progress in developing countries comes from the adoption and adaptation of preexisting technologies.
- At an aggregate level, the use of older technologies is positively related to income in developing countries. However, the extent to which they are employed varies substantially within income groups, suggesting that developing countries' history, geography, and past government success in delivering infrastructural technologies are equally important determinants of the extent to which older technologies are used.
- Penetration rates of more recent technologies vary more regularly with income. In part this reflects their relatively lower start-up and infrastructure costs than those of older technologies and their more flexible delivery structure.

2. *While technological achievement tends to rise with income, it tends to level off.* The level of technological achievement at which this leveling off occurs differs across countries according to their geography, history, and level of technological absorptive capacity (discussed in more detail in chapter 3). Thus, reflecting an emphasis on equal access to education and state-provided technological services, countries within the Europe and Central Asia region have significantly higher levels of technological achievement than other countries at similar income levels. By the same token, countries in Latin America and the Caribbean are somewhat less advanced than might be expected, as earlier inward-looking policies and weak basic technological literacy in the overall population have limited the extent to which technologies have permeated economic activity.

3. *Technological achievement within countries can vary widely.* Despite a level of technological achievement in major cities that can rival that in high-income countries, low levels of technological advancement in rural areas mean that, viewed as a whole, countries such as China and India are not particularly technologically advanced. Moreover, because technology spreads slowly across firms, there are wide differences in the technological sophistication of production, even within the same sector in the same country.

4. *Overall, the technology gap between middle-income and high-income countries has narrowed over the past 10 years.* Evidence of catch-up is particularly strong in Chile, Hungary, and Poland, where the overall level of

technological achievement increased by more than 125 percent during the 1990s.

5. *On average, technology is advancing more rapidly among low-income countries.* Among those low-income countries for which sufficient data are available, the penetration of technology is progressing more rapidly than in either middle- or high-income countries. However, this reflects very strong catch-up in some countries and more modest improvements, or even relative declines, in the majority. Moreover, technology in high-income countries is also advancing, and the absolute increase in these countries is larger than in developing countries.

6. *The pace at which technology spreads between countries is accelerating.* Whereas a new technology in the 1800s could take as long as 100 years to reach 80 percent of the world's countries, for a new technology to reach 80 percent of the world's countries now takes less than 20 years.

7. *Ultimately, however, what matters most for technological achievement is the speed with which technology spreads within a country.* Here too the evidence suggests a pickup in the pace of internal diffusion, but there is also widespread divergence across countries, even across those at similar income levels.

8. *Changes in the regulatory environment and in the nature of technologies partly explain the acceleration in the rate at which they penetrate into developing countries.* Many old infrastructure technologies, such as roads, railroads, sanitation, and fixed-line telephone systems, are often provided by the government and are thus subject to public sector budget constraints and the risk of government failure. By contrast, the most common new technologies, such as the Internet, mobile phones, and computers, are being delivered in a regulatory environment that encourages competition and that harnesses private capital (domestic and foreign) to provide basic infrastructure. Moreover, the past 10 years have been more stable politically than the 1980s and 1990s, which has likely given a boost to the diffusion of newer technologies.

The role of technology in development

Technological progress is at the heart of human progress and development. As the 1998 *World Development Report* on the knowledge economy (World Bank 1998) emphasized, the understanding of how things are created and the communication of that knowledge are critical drivers of economic progress. Central to understanding the role of technology is the recognition that technology and technological progress are relevant to a wide range of economic activities, not just manufacturing and computers. For example, some estimates suggest that technological progress has boosted productivity in agriculture four times as quickly as in manufacturing (Martin and Mitra 2001). Indeed, seemingly low-tech products such as corn or flowers can be the result of relatively high-tech production processes, while in some countries the production of ostensibly high-tech products such as computers is an outcome of relatively low-tech assembly activities. Finally, in many cases technology is embodied in production and management systems rather than in physical goods or software algorithms. A computer loaded with the latest software that sits unused on a desk for most of the day is a very different manifestation of technology than the same computer that is running a production process or managing an accounts payable system.

This report defines technology and technological progress in this wider sense, although data limitations may give some of the measures developed the flavor of a more narrow, physical, and manufacturing-oriented definition.

Technology is both a critical determinant and an outcome of rising incomes

Traditionally, economists view the process by which goods and services are produced as one that combines capital, labor, and other factors of production (land and natural resources) using a particular technology. The relative efficiency with which a given economy produces

Table 2.1 Disparity among TFP levels remains wide

	TFP relative to that of the United States, 2005	Annual TFP growth, 1990–2005
Regions	*(index, U.S. = 100)*	*(annual percentage change)*
East Asia and the Pacific	8.4	5.1
Europe and Central Asia	21.7	2.2
Latin America and the Caribbean	19.3	0.2
Middle East and North Africa	13.3	0.5
South Asia	5.8	2.3
Sub-Saharan Africa	5.6	0.2
Income groups		
High-income OECD countries	77.1	1.3
High-income non-OECD countries	53.1	0.7
Upper-middle-income countries	23.7	1.2
Lower-middle-income countries	9.6	3.2
Low-income countries	5.2	1.7

Source: Poncet 2006.
Note: OECD = Organisation for Economic Co-operation and Development; TFP = total factor productivity.

goods and services given a certain quantity of labor and capital is called total factor productivity (TFP). TFP is commonly interpreted as a measure of the technology of production and its rate of growth as a measure of technical progress.[1]

International comparisons of TFP suggest that enormous gaps exist between high-income and low- and middle-income countries in the efficiency with which they produce goods and services (table 2.1). In 2005, the average level of TFP in low-income countries was only slightly more than 5 percent of U.S. levels. The technology lower-middle-income countries employed was roughly twice as efficient and that of upper-middle-income countries was approximately four times as efficient. While these gaps have been narrowing for low-income and lower-middle-income countries, upper-middle-income countries have only managed to maintain their relative position in relation to high-income countries. At the regional level, these gaps have widened or remained stagnant in three of six developing regions, with TFP growing faster in high-income countries than in Latin America and the Caribbean, the Middle East, and Sub-Saharan Africa.

The relationships between income growth, technological progress, capital accumulation, and welfare are, of course, much more complex than can be summarized in a simple measure of TFP, partly because each factor of production and the technology with which factors are combined are dependent on one another. As discussed in chapter 3, capital goods often embody significant technological progress and there is no simple way to distinguish between the contribution that each makes to growth. Similarly, technology in the form of knowledge of business processes and of science and general experience is embodied in labor. Moreover, the contribution of technology to welfare is only imperfectly measured by its impact on GDP (box 2.1).

Technological progress can lower costs, improve quality, create new products, and help reach new markets

Even though measures of TFP and its progress give us a sense of the relative dispersion of technological progress, they tell us little about the mechanisms by which technology influences development. Technological progress involves much more than doing the same things better or with fewer resources. It is more dynamic, involving both the creation of new and new-to-the-market products and production techniques, but also the spread of these techniques across firms and throughout the economy. While the mechanisms by which technological progress contributes to development are in some sense obvious, the following deserve special mention:

- *Technological progress can spur development by lowering the costs of production and enabling the exploitation of increasing returns to scale.* By improving the efficiency with which existing

Box 2.1 Technology can contribute to welfare without affecting measures of short-term output

While the relative level of TFP provides a sense of the efficiency with which factors are combined, it ignores the welfare contributions of technology that do not have an immediate impact on GDP. For instance, in national accounts, the purchase of machinery that reduces air and water pollution, such as scrubbers for smokestacks, may not increase GDP. While the purchase of machinery will be recorded as income accruing to the producing firm, this may be offset by reduced profits and other factor payments of the purchasing firm. Thus, even though over the longer term the machinery may contribute to a reduction in days of work lost because of respiratory illnesses, and therefore to an increase in national income, over the medium term the machinery would have little measurable effect on GDP or TFP despite the improvement in air quality, which would provide a general, if not monetized, benefit. Similarly, technological advances that reduce the cost of public services may have little impact on recorded income, but may have important implications for the quality of life.

In developing countries, the diffusion of such technology as water and sanitation systems, oral rehydration techniques to treat diarrhea, immunization, malaria prevention, and contraceptives have been tremendously important for improving household well-being, but such innovations will affect output only over time as improved child health eventually pays off in terms of greater adult productivity (Alderman, Hoddinott, and Kinsey 2006; Behrman and Rosenzweig 2004; Glewwe, Jacoby, and King 2001). These technologies may also have important noneconomic societal benefits, such as improved gender equality, which are not recorded in GDP because women are more likely to engage in nonmarket production, or may appear only with a lag as improved health technologies facilitate women's entry into the labor force over time (Bailey 2006; Miller 2005; Schultz 2007).

products are produced, new technologies can open up the possibility of increasing output and, assuming that markets are available, taking advantage of previously unexploited increasing returns to scale.

- *Technological progress in one sector can create new economic opportunities in other sectors.* Lower production costs can create whole new products, or even sectors. A new-to-the-market innovation in one sector can result in a flowering of activity in other sectors by creating a demand for and supply of goods and services that did not exist previously (box 2.2).
- *The benefits of a new technology can extend well beyond the immediate sector or good in which the technology exists.* This is the case if the initial product is an important intermediate good in the production of other goods, for example, telecommunications or reliable electrical service.
- *Technology can yield quality improvements.* Such improvements can enable a developing country to penetrate more demanding consumer and intermediate markets. This can be as simple as employing machinery and equipment that produce goods and services that correspond to the more exacting expectations and standards of consumers and business clients in high-income countries. Technology in this sense extends beyond engineering technology to include management techniques. For example, one of the big challenges facing Ugandan fisheries was creating systems of quality assurance that allowed them to meet phytosanitary standards in the European Union on a sustained basis (Chandra and Kolavalli 2006).

Box 2.2 Technological innovation may spur further innovation in upstream and downstream activities

In Chile, the creation of a viable international salmon farming industry involved the simultaneous development of a number of related new-to-the-market products, including the domestic production of fish tanks, fish eggs, salmon food, and vaccines, and eventually the introduction of additional varieties of farmed fish. New process technology was also introduced, including systems for feeding, processing, and stocking fish that met global quality and phytosanitary standards.

The introduction of a cut flower industry in Kenya to serve the European market represents the indirect effect of the successful introduction of the industry in Colombia to serve the U.S. market. The new activity generated a wide range of additional new-to-the-market innovations in the form of greenhouses and postharvest care facilities to preserve the freshness of blossoms. Process technology involved learning how to use chemicals and mastering the logistical challenge of delivering this fragile product to the local airport on time and with sufficient regularity to meet customers' just-in-time requirements.

Success in one activity may well lead to further innovation and technological deepening. The move from producing carnations to more fragile and expensive roses is an example. Another example is the shift to higher-quality products such as chilled rather than frozen fish fillets. Yet another example of deepening is palm oil production in Indonesia, where new processes include the production of new varieties of palms; the introduction of new crude and processed palm oil refining technologies; and, notably, the introduction of oleo chemical technologies.

Source: Chandra 2006.

Even relatively simple technologies can have far-reaching development impacts

Technological advances do not need to be extraordinarily complex or reliant on the most sophisticated technology to have important development impacts. In many low-income countries, fairly commonplace technologies are often in short supply because of weak capacities to implement them (box 2.3), and relatively simple innovations can have profound effects. The green revolution is a dramatic example of the effectiveness that even modest technological advances can have in boosting incomes among the poor. In addition, greater access to the technologies required to store and process food can increase food security, particularly in communities without access to reliable electricity or means of refrigeration. The use of sawmill waste (sawdust, planer shavings, and chipper dust) to produce carbonized briquettes for use in household cooking can increase access by the poor to fuel for cooking while reducing deforestation pressures.[2] Dissemination of the simple skills required to build rainwater collection systems can greatly improve access to clean drinking water and reduce the incidence of diarrhea, a major cause of infant mortality. Insecticide-treated mosquito nets are a well-known, cost-effective strategy for preventing the spread of malaria, but the main challenge in many countries remains developing and implementing a mechanism for distributing them to those most in need and ensuring that they are used.

Despite these advantages, technological change can also be disruptive

While technological progress generates substantial benefits, it can also be disruptive, because its benefits are not necessarily evenly distributed. In particular, while the introduction of an advanced technology may mean new opportunities for the innovator and reduced costs for consumers, it can result in significant short-term losses in incomes for competitors using older technologies. For

Box 2.3 Promoting appropriate technologies in Rwanda

A recent study of Rwanda identified simple technologies whose greater use could have a substantial impact on development. For example, the study identified a lack of qualified plumbers and water sanitation technicians as a major factor holding back the implementation of simple rainwater collection strategies that have helped improve the quality of drinking water supplies in neighboring countries. Similarly, a lack of basic skills, including those necessary to manufacture stainless steel products, prevents the implementation of simple food processing techniques, such as passion fruit pasteurization and pulping, that could reduce the share of crops lost to spoilage, which sometimes results in the loss of as much as 30 percent of a crop. Public sector dissemination of best practices is hindered by poor skills and inappropriate incentives, which result in research centers producing local products that take insufficient account of users' needs and requirements. The table provides a snapshot of the status of efforts to promote the diffusion of simple technologies in Rwanda.

Diffusion of selected "appropriate" technologies in Rwanda

Rural energy	• Biogas for institutions: installations ongoing and spreading • Biogas for households: pilot program of 163 units to start 2007 • Micro hydropower: 6 projects in preparation, more in future? • Biofuel: no national program or policy as yet • Wind: no program or policy as yet • Peat: large stocks but limited exploitation • Efficient stoves for urban areas: national program ongoing • Efficient stoves for rural areas: some programs ongoing • Rice and coffee husks for briquette production: limited programs • PV systems: technology available but slow market • Solar water heating: technology available but slow market
Water and sanitation	• Roof water harvesting: only on limited scale for households • Boreholes: few and expensive • Hand pumps: imported from region or India • VIP and Ecosan latrines technology: available, limited uptake
Agricultural technologies and transport	• Irrigation through treadle and motorized pumps: limited uptake • Drip irrigation: starting • Animal traction for tillage and transport: promoted in certain areas • Small tractors for rice puddling and transport: few units imported • Rice threshing and winnowing: few machines available and locally produced • Rice hulling: opportunities for small-scale processing • Maize milling: machines imported and locally made • Oil presses for sunflower, soya, essential oils: starting • Livestock spraying: locally made machine now available
Low-cost building	• Rice and coffee husks and peat for brick burning: some use • Hand brick press machines: locally made and imported • Engine brick press machines: imported

Source: Watkins and Verma 2007.

example, improved production and processing of sugarcane in Brazil has allowed production, incomes, and employment in that country to increase significantly, but it has done so at the expense of sugar producers in other countries, who have been unable to compete. While the associated income losses may be painful, the global impact tends to be positive, because the income losses promote the reallocation of resources and activity to more effective uses.

Technological progress may also benefit certain classes of workers over others. Technological change that uses high-level skills more intensively may hurt less skilled workers in high-income countries by increasing the demand for skilled workers and simplifying tasks or allowing the outsourcing of tasks that previously were accomplished by relatively well-paid semiskilled workers. Many economists cite the recent tendency for technological progress to benefit more skilled workers as a major source of the rise in earnings inequality in most advanced countries.[3] Note, however, that technical change does not always raise the demand for skilled workers relative to unskilled workers, nor does the disruption necessarily occur to the detriment of low-skill workers. Thus the weaving and spinning machines that benefited lower-skilled workers by enabling them to produce textiles formerly produced by skilled artisans were destroyed in the Luddite and Captain Swing riots of the 19th century (Acemoglu 2002).

Moreover, if changes in earnings in developing countries are taken into account, it is no longer clear that technical change has been biased toward skilled workers. By some measures, global inequality has not increased over the past two decades.[4] Global income distribution has benefited from the rapid growth in China and India, which has enabled hundreds of millions of people to escape poverty. Technical change interacting with increased globalization may have increased inequality within some countries by increasing the demand for skilled workers. By opening up opportunities for technical progress through the production of export goods that require relatively high-level skills, greater participation in international trade has led to increasing demand for skilled workers, and thus to greater income inequality in some countries (Arbache, Dickerson, and Green 2004; Zhu and Trefler 2005). At the same time, technical progress can be strongly pro-poor, for example, the discovery of simple technologies to store and process food in areas with insufficient access to electricity or to enable low-cost approaches to combating disease.

The disruptive nature of technological progress can generate important benefits to society by spurring competition. For example, the introduction of mobile phone technology in several developing countries has introduced an important element of competition not only in the telecommunications sector, but also in banking and other information-sensitive sectors. Partly as a result, many of the informational asymmetries generated by a lack of effective communications that various middlemen used to exploit have been eliminated, raising producer prices and lowering consumer prices.[5] These benefits are often accompanied by shifts in the distribution of income whereby some groups can lose either relative to others or in absolute terms. These losses can be difficult for the poor to absorb, underlining the importance of safety nets to minimize social conflict and to ensure that overall progress does not come at too high a cost for some individuals.

Measuring technology in developing countries

The remainder of this chapter is concerned with measuring the level of technological achievement in developing countries and recent progress in this regard. This first section goes beyond indirect measures of technology like TFP, and seeks a more direct measure of technological achievement by exploring the extent to which specific technologies have permeated economic activity in developing countries and the intensity of scientific innovation and invention.

Measuring technology directly is difficult, mainly because, unlike pencils or automobiles, technology has no easily counted physical presence. Nor does it have a well-defined price that would allow it to be measured and aggregated in the same way that services are. Rather, technology is embodied in products, intermediate inputs, and processes. As a result, most efforts to measure it have been forced to use indirect techniques (see Archibugi and Coco 2005 for a review). Some indexes emphasize inputs into technological advancement, such as education levels, numbers of scientists and engineers, and expenditures on research and development (R&D) or R&D personnel, for example, the index of innovation capability put out by the United Nations Conference on Trade and Development (UNCTAD 2005). Other indexes also incorporate information on the diffusion of technologies and on indicators of innovation, such as the number of patents granted. The technology achievement index, published by the United Nations Development Programme is an example. Still other indexes focus on outputs, such as the share of high-tech activities in manufacturing value added and exports, for instance, the index of competitive industrial performance published by the United Nations Industrial Development Organization (UNIDO 2002). Some indexes focus more on the mechanisms by which technological progress is achieved (Sagasti 2003) or by which technological learning occurs (Soubattina 2006). For example, the national innovative capacity index reflects government and firm-level policies associated with successful innovation (Porter and Stern 2003).

Each of these approaches has its strengths, but none of them is entirely satisfactory, both because the indicators used fail to do justice to the broad definition of technology adopted here (box 2.4), and because the methods by which these indexes are constructed are sometimes arbitrary (Archibugi and Coco 2005). To overcome these deficiencies, the indexes developed in the remainder of this chapter include a number of indicators not previously included in technology indexes. Summary indexes are derived from these along three dimensions of technological achievement: the extent of scientific innovation and invention, the diffusion of older technologies, and the diffusion of newer technologies. We begin by reviewing current levels of technology and their dispersion and recent trends in a number of indicators that the literature pertaining to these three dimensions of achievement has used.

In a subsequent section, summary indicators of achievement along each of these dimensions are derived using principal components analysis. Their current levels and recent trends are discussed, an overall index of technological achievement is generated from these summary indicators, and a fourth indicator (developed in chapter 3) summarizes the extent to which external technology is used in the production process.

Scientific innovation and invention

Most technological improvements in developing countries are at least partially dependent on the diffusion of technology from more advanced countries. Nevertheless, scientific innovation is important in some developing countries, and advanced technologies often need to be adapted to local conditions, which may require further innovation.

The intensity of innovation is closely related to per capita income . . .

The degree of scientific innovation in developing countries, as measured by the number of journal articles and patents granted (scaled by population), varies sharply with per capita income (table 2.2).[6] Authors from high-income countries report 7 times as many published articles than those from upper-middle-income countries and 88 times as many as authors from low-income countries. Variations for measures of patents granted and license fees earned are even larger. This result is generally reflected in regional data, with countries in regions with higher incomes such as Latin America and the Caribbean reporting higher levels of patents and journal articles than regions such as South

Box 2.4 Shortcomings of available measures of technological achievement

Available indicators provide only a partial view of the level of technological achievement in developing countries and of the gap with high-income countries. Most available indicators reflect the quantity of technology used, whereas the quality of delivery is often what is critical. For example, the value of electricity in production is a function of both the amount consumed and its reliability. In general, global indicators of technology levels do not take differences in quality sufficiently into account. To the extent that quality of delivery varies systematically with income levels, the indicators likely understate the differences between rich and poor countries. For example, Kaufmann, Leautier, and Mastruzzi (2005) find that access to infrastructure services (similar to what we measure here) and the quality of infrastructure services in urban areas are both closely related to the strength of governance, which is itself highly correlated with income levels.

Nor do the available indicators reflect the disparity of achievement within countries. National indicators of technological achievement are based on country averages, but large gaps exist in the extent to which technologies are used within regions, income groups, and countries. For example, the relatively low performance of South Asia reflects the slowness of technology diffusion from the relatively advanced major cities to rural areas, as well as from the rich to the poor within urban areas. Indeed, the degree of technological diversity across Chinese regions or Indian states mirrors the extent of diversity across developing countries, with regions containing large technologically sophisticated cities, such as Mumbai or Delhi, being well ahead of areas that lag behind in economic development.

Finally, most indicators tend to be biased toward goods (as opposed to services), and among these, toward electronic and other high-tech goods. Most measures also focus on product technology (goods and services that themselves are highly technical) rather than final (or intermediate) goods and services that may be technologically unremarkable, but which are the result of a technologically sophisticated production process, for example, maize that is produced using sophisticated crop rotation methods, enhanced irrigation and fertilization strategies based on satellite imaging, and bioengineered seeds.

Asia or Sub-Saharan Africa, which are dominated by lower-income countries. The ratio of patents granted to residents to the total number of patents a country grants (an indicator of the extent to which innovations are generated domestically) is only weakly correlated with income. Equally important influences include the domestic economic structure, the country's openness to foreign direct investment (FDI) (see chapter 3), the domestic costs of making a patent application, local intellectual property rights, and the legal environment—all factors that dictate the potential benefits from holding a patent.

Patent activity in middle-income countries has increased over the past 20 years (figure 2.1), primarily because of a sharp jump in patenting (relative to population) among upper-middle-income countries in the early 1990s following the integration of the transition economies of the former Soviet Union into the world economy. The continuous increase in patent activity among lower-middle-income countries mainly reflects activity in China, whose share in world patent applications rose from about 1.5 percent in the late 1980s to a peak of nearly 10 percent in 2004. Excluding China, additional patenting activity in lower-middle-income countries has been relatively modest. While patent activity has also risen in low-income countries, it remains far below that in middle-income countries both in the absolute numbers of patents issued and relative to the population.

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Table 2.2 Scientific and innovative outputs

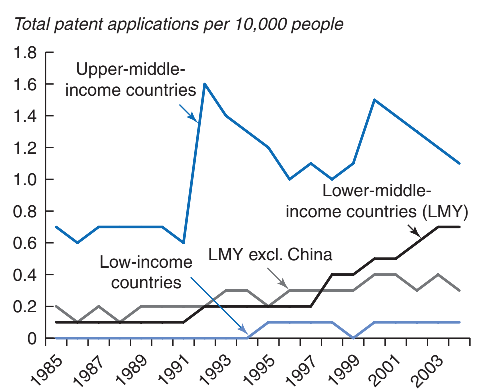
Regions and income groups	Scientific and technical journal articles, 2003	USPTO patents, 2006	EPO patents, 2005	Total patents, 2003	Number of patents to nonresidents 2003	Royalty and license fee receipts 2004
	(Number per million people)				*(percent of total)*	*(percent of GDP)*
Regions						
East Asia and the Pacific	17	0.7	0.01	37	77	0.02
Europe and Central Asia	90	0.9	0.40	95	28	0.06
Latin America and the Caribbean	35	0.7	0.21	46	98	0.03
Middle East and North Africa	18	0.1	0.03	—	—	0.02
South Asia	9	0.5	0.07	1.4	60	0.00
Sub-Saharan Africa	5	1.4	1.16	157	100	0.06
Income groups						
World	***111***	***38.6***	***11.4***	***127***	***41***	***0.27***
High-income countries	584	135.1	42.6	331	38	0.33
Upper-middle-income countries	85	1.4	0.40	91	42	0.04
Lower-middle-income countries	21	0.6	0.01	46	64	0.03
Low-income countries	7	0.4	0.07	3.5	56	0.00

Source: World Development Indicators, USPTO, EPO, and World Intellectual Property Office data.
Notes: EPO = European Patent Office, USPTO = U.S. Patent and Trademark Office. To reduce home bias, the total patents granted by the USPTO to high-income countries exclude those granted to the United States, and the total patents granted by the EPO exclude those granted to high-income European Union countries.
— = not available.

. . . although the Europe and Central Asia region is an outlier

Reflecting a history of advanced scientific and engineering work in a number of former Soviet bloc countries, the Europe and Central Asia region has relatively high levels of scientific innovation and invention (table 2.2). Publication rates there are equal to those in many high-income countries, and patent activity is more than twice the level in any other developing region. The region is also the most self-reliant of developing regions in terms of patent activity, with only 28 percent of patents being filed by nonresidents, a figure that is even lower than the high-income country average of 38 percent. The East Asia and Pacific region also scores high in terms of patents, although its publication record is more in keeping with that of other developing regions. In some countries, such as China and India, conscious efforts to raise R&D spending have led to higher levels of scientific innovation than might be expected based on income (Lederman and Saenz 2005), while low levels of innovation in Latin America and the Caribbean reflect an academic research tradition with few links to industry (Maloney 2006).

Figure 2.1 Patent activity is rising in middle-income countries



Source: World Development Indicators.

Penetration of older technologies

The clear dominance of high-income countries in the number of scientific and technical journal articles published, the number of patents

Box 2.5 Deepwater petroleum technology in Brazil

Experience in the extractive sectors can help generate new technologies that in turn can be used as a source of global comparative advantage. The experience of Brazil's Petrobras, a majority state-owned company, in exploiting that country's considerable deepwater oil and natural gas resources provides an interesting example.

To exploit the Campos Basin, which lies in the Atlantic at a depth of more than 100 meters and now accounts for nearly 84 percent of Brazil's oil production, Petrobras created the anticipated production system on a floating platform. This advanced system, developed with the help of foreign experts, cut the delay between discovery and early production of deepwater fields from as long as six years to a mere four months and has since become a model for the industry worldwide.

Petrobras has successfully leveraged this experience, developing many patents both on its own and in conjunction with the rest of the industry, universities, and research institutes. It has invested heavily in research and education, creating its own R&D center, to which it allocates 1 percent of its gross income. The center, whose staff is increasingly made up of Brazilian experts, has contributed significantly to Petrobras's many patents and continues to help develop cutting-edge technology for the company.

Petrobras is now recognized as a world leader in all phases of deepwater technology—from drilling; to underwater completion, pumping, and production using floating structures; to mooring and processing—with its particular expertise is in the areas of unmanned subsea installations, marine engineering, and floating production systems. About two-thirds of its production is at a depth of more than 300 meters, and at various times Petrobras has set a number of records, including oil production at a water depth of 1,853 meters and the then-deepest exploration well (2,853 meters) in the giant Roncador field.

Petrobras has used its advanced technology to perform exploration and production work in Angola, Argentina, Bolivia, Colombia, Nigeria, Trinidad and Tobago, and the United States and has acquired offshore exploration blocks and interests in Equatorial Guinea, Libya, Senegal, and Turkey (Black Sea). It has also recently signed various agreements in China, India, Mexico, Mozambique, and Tanzania.

Source: World Bank.

granted, and the extent of licensing and royalty fees realized points to the relatively minor role that at-the-frontier innovation plays in determining technological progress in developing countries and the relative importance that adoption and adaptation of existing technologies must play. We look first at the diffusion of older technologies.

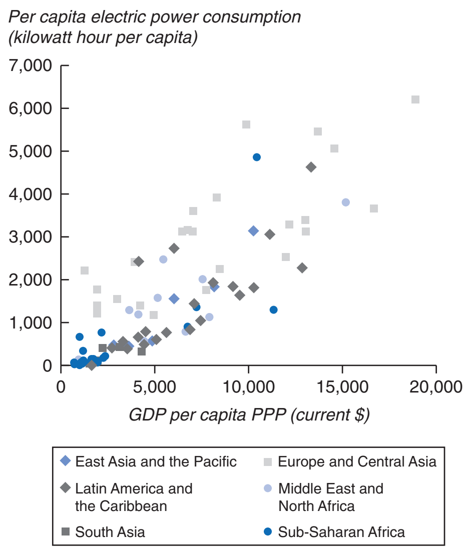
The major technological innovations of the past two centuries—such as steam power, electricity, the internal combustion engine, the telephone, radio, and television—exist to some degree in virtually every country in the world. However, the extent to which they are available within countries varies enormously, depending both on the technical adaptive capacity of the country (chapter 3) and on the affordability of the technology.

Many of the most prominent technologies are in the manufacturing sector. However, the efficient extraction of natural resources often requires advanced technology and can encourage technological progress. Indeed, the failure to absorb new technologies is an important reason for the slow growth of many natural resource-based economies in Latin America (box 2.5).

Affordability limits the penetration of electrical networks in some countries . . .

Affordability, exacerbated by fiscally constrained governments, helps explain the modest diffusion of many technologies critical to development. This appears to be the case for a number of infrastructure technologies such as electricity (figure 2.2), rail and road transportation, and fixed-line telephony. In each of these cases, a reliance on governments to provide these services, coupled with weak institutions and a lack of domestic capacity to

Figure 2.2 Electrical consumption varies markedly even at similar income levels (2004)



Sources: World Bank; World Development Indicators.

maintain systems, has limited their diffusion in a number of low- and middle-income countries.

Other factors, such as industrial structure, climate, tax policies, and preferences, are also at play. In the case of electricity, the way a country organizes its power sector (the process technology employed) can also have a strong bearing on the diffusion of the specific technology within the economy. For example, many countries in the former Soviet bloc enjoy near-universal access to electrical power and per capita consumption rates that are more than double those in any other developing region (table 2.3). This reflects a much earlier decision to emphasize electrification and the provision of subsidies under communist rule. Access to power in other regions is more spotty, with most of the population in most large cities having access (or at least the possibility of access) to the electrical power grid, but with a large share of the rural population, particularly in the poorest countries, having no or only limited service. In India for example, only 85 percent of rural villages have access to the power grid. In Sub-Saharan Africa, only 8 percent of the rural population has access to electricity, compared with 51 percent of the urban population. In South Asia, only 30 percent of the rural population has access to electricity, compared with 68 percent of the urban population (Besant-Jones 2006).

Moreover, the reliability of the grids varies enormously, partly because of the amount of electricity lost through pilferage or in transmission. Because of electricity's importance as an intermediate input, the reliability of the electrical supply may be even more important to the diffusion of other technologies than its availability. Many machines are sensitive to the quality of electrical power and many processes are intolerant of interruptions. As a result, unreliable power can be an important factor in preventing the implementation of these technologies in some countries. For the world as a whole, electricity losses amount to an average of 9 percent of the power produced. Countries in East Asia and the Pacific and Sub-Saharan Africa and members of the Organisation for Economic Co-operation and Development (OECD) do better than this average, while losses in South Asia approach 30 percent. Furthermore, the impact of power reliability differs across countries. In Bangladesh, for example, where transmission and distribution losses represent only 9 percent of produced power, some 70 percent of managers indicate that unreliable power is a serious constraint to business. In contrast, in Cameroon and Moldova, where transmission losses are much greater than in Bangladesh, the share of managers making this complaint is much lower—13 percent in Cameroon and less than 4 percent in Moldova (World Bank 2007e).

. . . and restricts access to efficient transportation . . .

Like the electrical network, transportation systems are old technologies that enable other technologies, and their dissemination within countries has been closely affected by

Table 2.3 Indicators of the diffusion of older technologies

	Electric power consumption 2004	Electric power transmission and distribution losses 2004	Telephone mainlines 2004
Regions	*(kilowatt-hours/capita)*	*(percentage of output)*	*(per 100 people)*
East Asia and the Pacific	1,343	7	19
Europe and Central Asia	3,637	12	26
Latin America and the Caribbean	1,674	17	18
Middle East and North Africa	1,289	16	13
South Asia	414	26	4
Sub-Saharan Africa	550	9	2
Imcome groups			
World	***2,606***	***9***	***19***
High-income countries	9,609	6	54
Upper-middle-income countries	3,454	12	23
Lower-middle-income countries	1,448	10	19
Low-income countries	375	23	3

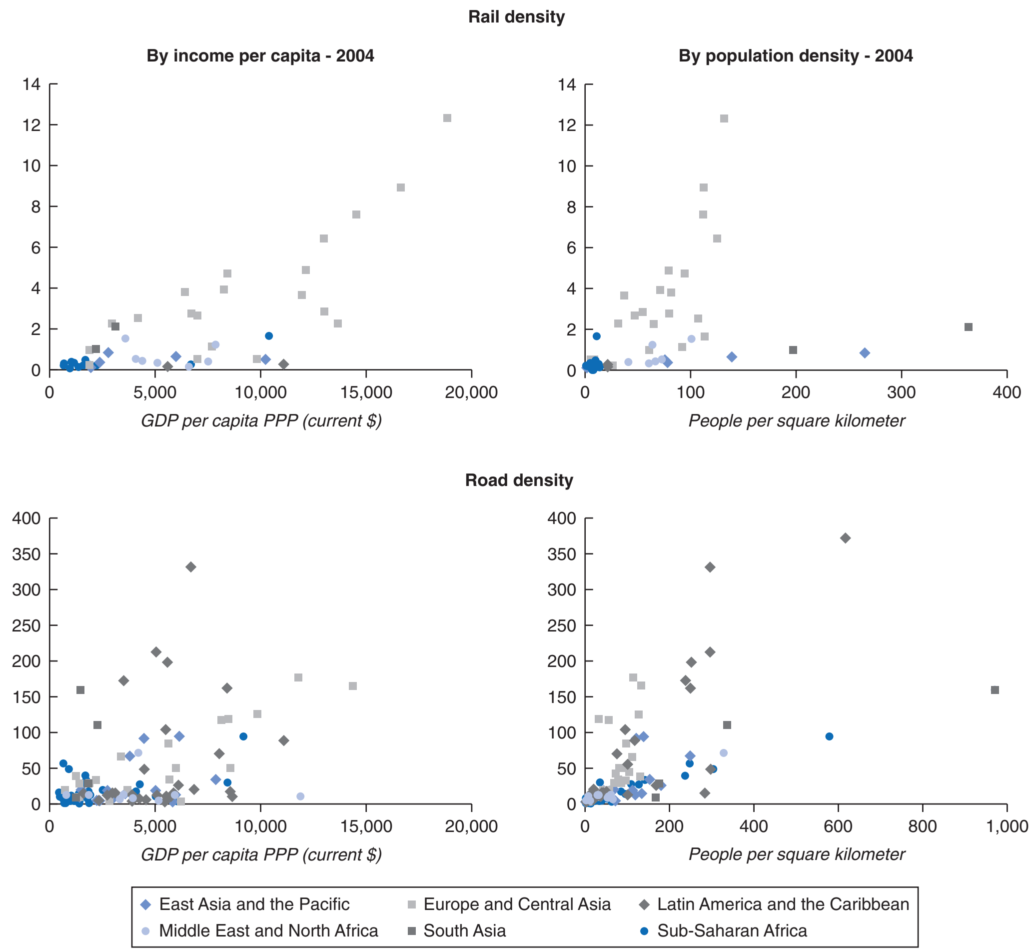
	Price basket for residential fixed telephone line 2004	Road density 1999	Rail density 2005
Regions	*(percentage of gross national income/capital/month)*	*(kilometers of road/100 square kilometers of land area)*	*(kilometers of rail/100 square kilometers of land area)*
East Asia and the Pacific	—	14.2	0.42
Europe and Central Asia	3.5	11.8	0.81
Latin America and the Caribbean	3.2	16.1	0.31
Middle East and North Africa	4.4	6.8	0.27
South Asia	10.6	80.6	1.55
Sub-Saharan Africa	29.3	6.4	0.18
Income groups			
World	***2.2***	***22.1***	***0.66***
High-income countries	1.0	41.2	1.17
Upper-middle-income countries	3.9	11.9	0.70
Lower-middle-income countries	6.0	14.5	0.39
Low-income countries	20.7	19.0	0.36

	Agricultural machinery and tractors 2003	Irrigated land 2003	Air transport 2004
Regions	*(per 100 square kilometers of arable land)*	*(as a percentage of cropland)*	*(number of registered carrier departures/1,000 people)*
East Asia and the Pacific	93	—	1.1
Europe and Central Asia	184	11	2.1
Latin America and the Caribbean	123	11	2.8
Middle East and North Africa	141	32	1.2
South Asia	143	39	0.3
Sub-Saharan Africa	13	4	0.5
Income groups			
World	***202***	***18***	***3.7***
High-income countries	433	12	18.0
Upper-middle-income countries	173	10	3.2
Lower-middle-income countries	113	24	1.3
Low-income countries	90	24	0.3

Sources: World Bank; World Development Indicators.
Note: — = not available.

government regulation and affordability. Many process technologies (for example, the assembly, sorting, refrigeration, and delivery of fresh fruit) depend on an effective transportation network. The diffusion of railroads among developing countries varies widely, with the countries of the former Soviet bloc having a much more extensive rail transport system than other developing countries at similar income levels. This variance is explained in part by differences in population density (figure 2.3). The cost per passenger mile of a rail system tends to fall with population density, which helps explain the particularly low density of railroads observed in Sub-Saharan Africa (Stelling and Jensen 2001). Interestingly, with the exception of Europe and Central Asia, per capita income does not appear to be an important factor in explaining the diffusion of either rail or road networks. Moreover, the observed distribution of road networks is only weakly correlated with population density. Relative to other regions, Latin America and the Caribbean has significantly more roads

Figure 2.3 Rail and road densities rise with income and population density (2004)



Sources: World Bank; World Development Indicators.

than would be expected on the basis of population and income, while the high average road density in South Asia mainly reflects high densities in Bangladesh and India and low densities elsewhere in the region.

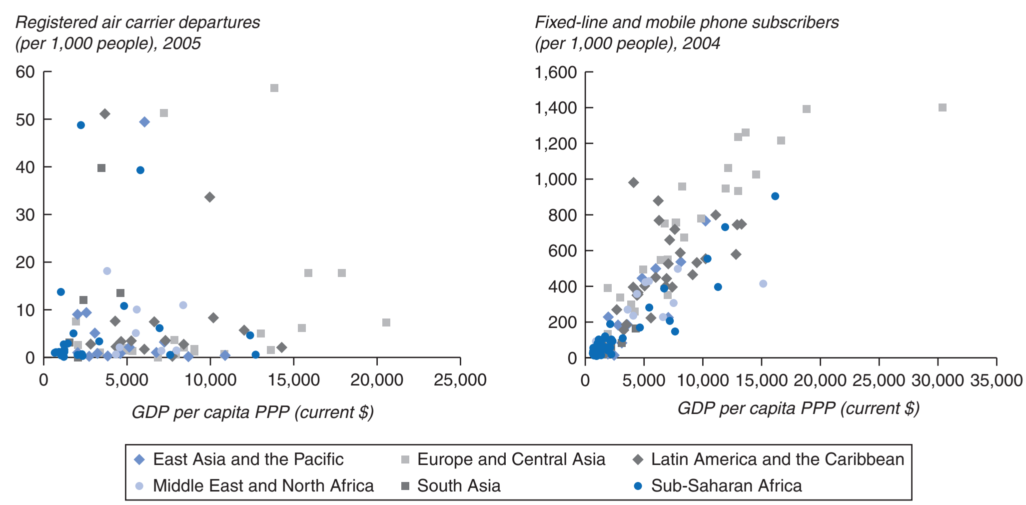
Considerable disparities in access to road and rail transport services are found within many developing countries. Rural areas in particular suffer from poor access to transport services. During 1994–2001, only an estimated 61 percent of the rural population in low-income countries lived within two kilometers of an all-season road (Briceno-Garmendia, Estache, and Shafik 2004). Poor access to transport facilities can cause the neglect of potentially productive land, limit yields of used lands to levels below their potential, and reduce profits from the sale of produce, all of which weakens incentives for farmers to maximize production, thereby limiting the prospects for alleviating poverty (World Bank 2006). Improving road access can thus have a dramatic impact on growth in remote areas.

. . . and air transport and telephones

A well-developed air transport network is also essential for some technologies and may be a particularly important enabling technology for landlocked economies with poor access to ports in neighboring countries. Air transport is a newer technology, and its distribution across countries tends to follow income at the most aggregated level. Thus high-income countries registered 18 carrier departures per 1,000 people in 2004, compared with 0.3 departures for low-income countries. Although middle-income countries have a higher number of carrier departures relative to population than do low-income countries, the cross-country correlation between income and air transport intensity is relatively low for all developing countries (figure 2.4). This suggests that factors such as the importance of tourism to the economy and access to alternative forms of transport—especially relevant for island nations—are among the most important determinants of the intensity of air transport use.

The delivery of fixed-line telephone services follows a similar pattern. On average, the incidence of this mature technology among upper-middle-income countries is less than half that in high-income countries, and in low-income countries falls to almost 5 percent of developed country levels. Across regions, the

Figure 2.4 Telephone densities are highly correlated with income, but air transport is not



Sources: World Bank; World Development Indicators.

Table 2.4 Affordability of fixed-line phones falls rapidly with lower incomes

(cost of fixed-line phone service as a percentage of monthly income in dollars and PPP)

	Per capita income		Monthly price fixed-line phone	Price as a % of monthly income	
	GNI	PPP		GNI	PPP
Regions					
East Asia and the Pacific	1,630	5,194	5.9	4.3	1.4
Europe and Central Asia	4,143	9,152	9.5	2.8	1.2
Latin America and the Caribbean	4,045	8,116	10.0	3.0	1.5
Middle East and North Africa	2,198	6,084	7.3	4.0	1.4
South Asia	692	3,142	5.1	8.8	1.9
Sub-Saharan Africa	746	2,004	14.0	22.5	8.4
Income groups					
World	***7,011***	***9,424***	***11.7***	***2.0***	***1.5***
High-income countries	35,264	32,550	27.6	0.9	1.0

Sources: World Bank; World Development Indicators.
Note: GNI = gross national income; PPP = purchasing power parity.

incidence is once again much higher in Europe and Central Asia, reflecting the heritage of the communist era. Elsewhere, East Asia and Latin America have fewer than 20 phone lines per 100 people and South Asia and Sub-Saharan Africa have fewer than 5 lines per 100 people.

In contrast to air transport, the cross-country correlation between the availability of telephones and income levels is strong (figure 2.4). The cost of residential service is significantly higher in the low-income regions of South Asia and especially Sub-Saharan Africa (8.4 percent) than in the predominantly middle-income regions (table 2.4).

The adoption and adaptation of old technologies varies by sector

The diffusion of old technologies has contributed to rapid growth in the agriculture sector in many developing countries. During 1967–92, TFP (often used as a proxy for increases in technology) is estimated to have increased four times as quickly in agriculture as in the manufacturing sector in both high-income and developing countries (Martin and Mitra 2001). In part this growth represents the exit of underemployed farm workers to better paying jobs in other sectors, but it also represents significant improvements in seeds; more capital intensive forms of embodied technology such as tractors, fertilizer, and irrigation systems; and better process technology, such as crop rotation and management techniques for disease-resistant crops (box 2.6).

At the same time, the diffusion of medical technologies within low-income countries has been slow. Some of the most important technological developments of the past 100 years have been medical, including the discovery and widespread distribution of antibiotics and the eradication and effective treatment of a wide range of previously deadly or debilitating viruses, including retroviruses such as those that cause HIV/AIDS.

The diffusion of knowledge about treatments is generally relatively speedy and efficient within the medical community, but their diffusion and application within the population of the developing world is much slower. In Europe and Central Asia, Latin America and the Caribbean, and the Middle East and North Africa, the average share of children immunized for measles, diphtheria, pertussis (whooping cough), and tetanus is 89 percent or better, bringing them close to the immunization rates in high-income countries. East Asia and the Pacific also posts immunization rates above 80 percent. However, immunization

Box 2.6 The green revolution

The green revolution is an example of the dramatic effects that modest technological advances can have in boosting the incomes of the poor. The green revolution was a decades-long effort, guided primarily by public sector and nonprofit institutions, to create and disseminate agricultural technologies to developing countries. The principal technologies involved were pesticides, irrigation, and synthetic nitrogen fertilizer, which had long been available in industrial countries, along with the development of high-yielding varieties of maize, wheat, and rice. Asia's green revolution doubled cereal production between 1970 and 1995 while increasing the land area devoted to cereals by only 4 percent (World Bank 2007b). Even though the impact of the green revolution on the poor was initially a source of controversy, by the late 1990s it was clear that poor people had reaped substantial benefits from higher incomes, less expensive food, and increased demand for their labor. The public sector was critical to this effort, because the development of new seed technologies has some aspects of a public good: developers cannot capture the full benefits, because once the seed is widely available, it can be easily reproduced. The green revolution also demonstrates some of unintended effects that can accompany the adoption of new technologies: the excessive use of agrochemicals has polluted waterways, wasteful irrigation has contributed to water scarcity, and high livestock concentrations near urban areas have contributed to the spread of disease.

Source: World Bank 1998, 2007b.

rates in South Asia and Sub-Saharan Africa average 59 to 63 percent (table 2.5). In part, this reflects particularly low immunization rates in some of the larger countries in these regions, notably India (less than 60 percent) and Nigeria (less than 35 percent), which outweigh the better performance of some of the smaller countries, for example, in Sri Lanka, 99 percent of children aged 12 to 23 months are immunized. The disappointing failure to deliver this basic technological service arises despite the intense involvement of the international community in assisting, and in some instances taking full responsibility for, this process. Moreover, the pace at which these rates are rising is disappointingly low as countries continue to struggle to implement effective delivery systems. Partly as a result,

Table 2.5 Immunization rates lag significantly in South Asia and Sub-Saharan Africa

(children aged 12–23 months immunized)

	DPT		Measles		DPT	Measles
	1993	2003	1993	2003	2003	2003
Regions	*(percent immunized)*		*(percent immunized)*		*(ratio to high-income countries)*	*(ratio to high-income countries)*
East Asia and the Pacific	83	83	79	83	0.87	0.90
Europe and Central Asia	80	89	84	91	0.94	0.99
Latin America and the Caribbean	78	90	82	93	0.95	1.01
Middle East and North Africa	85	91	84	92	0.96	1.00
South Asia	59	63	59	61	0.66	0.66
Sub-Saharan Africa	49	59	51	61	0.62	0.66
High-income countries	88	95	83	92	1.00	1.00
World	***71***	***76***	***71***	***75***	***0.80***	***0.82***

Sources: World Bank; World Development Indicators.
Note: DPT = diphtheria, pertussis, and tetanus.

Table 2.6 Diffusion of both water and sanitation technology is low in rural areas

	Improved water sources					
	Total population		Rural population		Urban population	
	1990	2004	1990	2004	1990	2004
Regions			*(percent of population with access)*			
East Asia and the Pacific	71.8	78.5	61.4	69.8	97.3	91.9
Europe and Central Asia	91.7	91.7	83.4	79.8	97.0	98.7
Latin America and the Caribbean	82.8	91.0	60.0	73.0	92.6	96.0
Middle East and North Africa	87.5	89.5	78.9	80.8	96.1	96.3
South Asia	70.6	84.4	64.9	81.3	88.6	93.6
Sub-Saharan Africa	48.9	56.2	36.1	42.4	81.9	80.1
Income groups						
World	***76.4***	***82.7***	***63.2***	***72.2***	***95.2***	***94.5***
High-income countries	99.8	99.5	99.1	98.5	99.8	99.8
Upper-middle-income countries	88.1	92.7	73.5	77.8	94.8	97.7
Lower-middle-income countries	74.2	80.8	62.9	70.9	96.4	93.1
Low-income countries	64.3	75.0	56.7	69.4	87.0	88.1

	Improved sanitation facilities					
	Total population		Rural population		Urban population	
	1990	2004	1990	2004	1990	2004
Regions			*(percent of population with access)*			
East Asia and the Pacific	29.7	50.6	15.3	36.1	65.5	72.4
Europe and Central Asia	86.1	85.0	72.0	70.3	93.7	93.0
Latin America and the Caribbean	67.4	77.1	35.4	48.7	80.7	85.7
Middle East and North Africa	69.9	76.2	52.0	57.9	87.1	92.3
South Asia	17.4	37.2	6.3	26.6	50.3	62.7
Sub-Saharan Africa	31.5	37.2	23.8	28.2	52.4	53.3
Income groups						
World	***44.4***	***57.0***	***22.8***	***37.7***	***77.2***	***79.4***
High-income countries	100.0	100.0	100.0	100.0	100.0	100.0
Upper-middle-income countries	76.7	81.4	52.6	59.9	87.1	88.6
Lower-middle-income countries	37.3	55.4	19.7	38.8	72.9	76.2
Low-income countries	21.3	38.3	11.6	28.5	49.6	60.5

Sources: World Bank; World Development Indicators.

child mortality rates remain elevated in these regions.

The health benefits of clean drinking water and sanitation facilities have been understood for centuries. Nevertheless, one in five people living in developing countries lack access to improved water sources and only half have access to improved sanitation facilities (table 2.6). In South Asia and Sub-Saharan Africa, only some 37 percent of the population has access to improved sanitation services, while only slightly more than half of the Sub-Saharan African population has access to improved drinking water (this share rises to 65 percent if Nigeria, where only 35 percent of the population has access to improved water, is excluded). The rest of the developing world does much better on these measures. For example, close to 90 percent of the population in Europe and Central Asia has access to improved water (91.7 percent) and sanitation sources (85 percent). Nevertheless, the diffusion of these basics technologies is weak in rural parts of all developing areas, reflecting more intense affordability issues and the relative scarcity of basic technological literacy and the competencies necessary to install and maintain such systems (see the discussion on basic technological literacy in chapter 3). For example, in China and India, only 44 and 33 percent, respectively, of the rural population have access to improved sanitation.

Older technologies have become widely diffused in many countries, but large disparities remain

Older technologies have penetrated less completely into developing countries than into developed countries, but the gap is much less pronounced than the gap for indicators of scientific innovation and invention. Moreover, the relationship between income levels and the diffusion of older technologies within the developing world is relatively weak, suggesting that the efficiency of the regulatory environment and the diffusion of basic skills within countries are more important than incomes in determining the actual level of diffusion of these technologies. Countries with the highest achievement in each income group find themselves at about the median level of achievement of the next highest income group. Once again, the level of diffusion of the older technologies tends to be higher for countries of the former Soviet bloc than for other countries at the same income level, while both the upper-middle-income and lower-middle-income countries of Latin America and the Caribbean tend to report lower levels of diffusion than other countries at similar income levels.

The striking differences between Europe and Central Asia on the one hand and Latin America and the Caribbean on the other hand in the diffusion of older technologies may reflect differences in income distribution and in the nature of R&D activities (box 2.7). Europe and Central Asia had more equal access to education combined with greater government investment in infrastructure, which facilitated more rapid diffusion of technologies than in Latin America and the Caribbean. In addition, whereas R&D activity was clearly linked to the industrial strategy of Soviet-era firms in Europe and Central Asia, R&D in Latin America was concentrated in universities, was oriented toward research at the global frontier (but generally not of cutting-edge quality), and had few links to firms (Maloney 2006).

Penetration of recent technologies

The relatively slow diffusion of many old technologies in developing countries contrasts sharply with the relatively rapid penetration of newer technologies (table 2.7). Macroeconomic turmoil, civil strife, and fiscal constraints limited the within-country diffusion of many older technologies, but more hospitable circumstances—including low inflation, low government deficits, and a technical and regulatory environment that has better harnessed private sector financing of new technologies—have contributed to the spread of more recent technologies. In a few cases, newer technologies have leapfrogged over older ones, for example, mobile phones now have higher penetration rates in some countries than fixed-line telephones.

Distinguishing between old and recent technologies is necessarily arbitrary. To a certain extent, road infrastructure is an ancient technology, and yet the technology embodied in producing a kilometer of German autobahn is completely different from that required to construct a kilometer of dirt track in Somalia. Similarly, exports that are currently classified as high-tech are in some cases evolutionary developments from relatively old technology (mobile phones, for example, evolved from radios and fixed-line telephones).[7] Nonetheless, the distinction is useful, because in many cases the factors that have impeded the diffusion of old technologies within developing countries are qualitatively different from those that impede the distribution of more recent technologies. For instance, the diffusion of many of the older technologies depended upon the creation and maintenance of expensive government infrastructure at a time when many governments were grappling with severe budget constraints and weak technical and governance capacity. Not only are today's technologies being exploited in a more

Box 2.7 Technology and growth in Latin America's natural resource-based economies

While much of the value added from extractive industries, such as crude oil production and mining, is a return to land, the technology employed in these activities is often very sophisticated. Some economies, such as Australia, Canada, and Sweden, achieved rapid rates of growth over the 20th century through the efficient exploitation of natural resources. By contrast, Latin America's natural resource-based economies achieved relatively limited growth; until recently, substantial mineral deposits have gone unexploited. Two central reasons explain the failure to capitalize on Latin America's natural resource opportunities.

First, the region had low levels of human capital and weak institutions that slowed the adoption and creation of new technologies. Latin American countries invested much less than other regions in promoting education systems, with the result that by 1870, the literacy rate was only one-third to one-fourth as high as in Canada and the United States. Early industrialization reflected the cumulative impact of numerous small advances made by many individuals, but in Latin America, the lack of access to education translated into limited innovation and slower technological progress, because colonial institutions deemphasized technical education and universities failed to produce sufficient engineers and scientists through the 19th century.

Second, innovation was discouraged and firm entry was inhibited by anticompetitive guilds, labor markets that were excessively protective of insiders' rights, concentrated credit markets that only lent to insiders, explicit trade barriers that impeded knowledge spillovers from trade interactions, and barriers to FDI. The concentration of wealth also discouraged innovations by newcomers. Rights to organize corporations and financial institutions were rationed to protect the value of rights held by powerful interests and the costs associated with filing patents were exorbitant. After the Great Depression, attempts to force rapid industrialization through import substitution policies led to sectors that were out of line with comparative advantage, that were walled off from competition and sources of innovation, and that required substantial subsidies to survive. Natural resource sectors, the likely source of Latin America's comparative advantage, were starved of capital and workers who were drawn to the heavily subsidized and inefficient manufacturing enterprises.

The combination of inefficient industrialization with the stifling of natural export sectors left many countries in the region vulnerable to balance of payments crises and severely constrained growth.

Source: Lederman and Maloney 2007.

relaxed and stable regulatory environment, but also many of them are being financed and built by private sector investors with access to ample funds and outside expertise.

Exports of high-tech goods are only loosely related to incomes

One frequently used indicator of the diffusion of recent technology is the share of high-tech goods in total merchandise exports. To be sure, the informational content of this measure has decreased with the proliferation of relatively low-tech assembly operations of high-tech goods, which in turn has reduced the level of technological competence associated with a given level of export of high-tech goods. Nevertheless, the share of high-tech exports is generally positively correlated with other indicators of technological achievement.[8]

Middle-income countries as a group have a much higher share of high-tech exports than low-income countries. Within the middle-income group, however, the lower-middle-income countries average a higher share of high-tech exports than the upper-middle-income countries (table 2.8). The East Asian countries have much higher shares of high-tech exports than the other regions, and the Middle East and North Africa region has much lower shares than the

Table 2.7 Diffusion of recent technologies

	Internet users		Internet bandwidth		Broadband subscribers	
	2005	Percentage change 1999–2005	2004	Percentage change 1999–2004	2005	Percentage change 2001–05
Regions	*(per 1,000 people)*		*(megabytes/second)*		*(per 1,000 people)*	
East Asia and the Pacific	89	48	8,735	149	26	236
Europe and Central Asia	190	48	6,670	132	21	208
Latin America and the Caribbean	156	41	4,513	121	16	89
Middle East and North Africa	89	64	899	91	—	—
South Asia	49	66	2,249	114	1	131
Sub-Saharan Africa	29	42	114	62	—	—
Income groups						
World	***137***	***20***	***43,856***	***108***	***42***	***59***
High-income countries	527	14	121,433	107	163	45
Upper-middle-income countries	196	36	5,611	126	21	147
Lower-middle-income countries	95	50	5,533	134	23	187
Low-income countries	44	72	708	120	1	143

	Personal computers		Cellular subscribers		Digital cellular subscribers	
	2004	Percentage change 1997–2004	2004	Percentage change 1995–2004	2004	Percentage change 1999–2004
Regions	*(per 1,000 people)*		*(per 100 people)*		*(per 1,000 people)*	
East Asia and the Pacific	38	26	24	58	257	54
Europe and Central Asia	98	20	44	79	512	43
Latin America and the Caribbean	88	17	32	51	337	42
Middle East and North Africa	48	17	13	73	142	70
South Asia	12	29	4	87	40	88
Sub-Saharan Africa	15	11	8	61	83	47
Income groups						
World	***130***	***14***	***28***	***37***	***284***	***29***
High-income countries	579	12	77	28	768	19
Upper-middle-income countries	113	18	48	58	521	37
Lower-middle-income countries	45	23	24	61	255	54
Low-income countries	11	25	4	92	43	88

Sources: World Bank; World Development Indicators.
Note: Period growth rates are compound annual growth rates.
— = not available.

other predominantly middle-income regions. In part these differences reflect the impact of long-standing policies in several East Asian countries that emphasized exports of increasingly sophisticated products and these countries' proximity to transport corridors that facilitated their participation in international production networks.

Although well below half the level of East Asia and the Pacific, Latin America and the Caribbean's share of high-tech exports relative to the total of manufactured exports of 13 percent in 2004 was larger than that of the other regions (table 2.8). This mainly reflects a high share of high-tech exports in Mexico (20 percent). The average share for individual countries in Latin America and the Caribbean is 8.6 percent, with high-tech exports representing 7 percent or less of the total merchandise exports of Argentina, Colombia, Honduras, Nicaragua, and Paraguay.

Personal computers have diffused relatively slowly . . .

Personal computers (PCs) are among the recent technologies for which data exist for a wide number of countries. PCs are a relatively new technology that, despite their present-day ubiquity in high-income countries, have

Table 2.8 Share of high-tech products in total exports

(high-tech exports as a percent of manufactured exports)

	2004	1999–2004
Regions		*Percentage point change*
East Asia and the Pacific	33.4	2.7
Europe and Central Asia	8.7	−0.7
Latin America and the Caribbean	13.1	−1.4
Middle East and North Africa	3.2	−0.4
South Asia	4.1	0.5
Sub-Saharan Africa	—	—
Income groups		
World	*21.3*	*−0.4*
High-income countries	22.3	−0.4
Upper-middle-income countries	16.2	−3.1
Lower-middle-income countries	22.2	4.0
Low-income countries	—	—

Sources: Centre d'Etudes Prospectives et d'Informations Internationales; World Bank.
Note: — = not available.

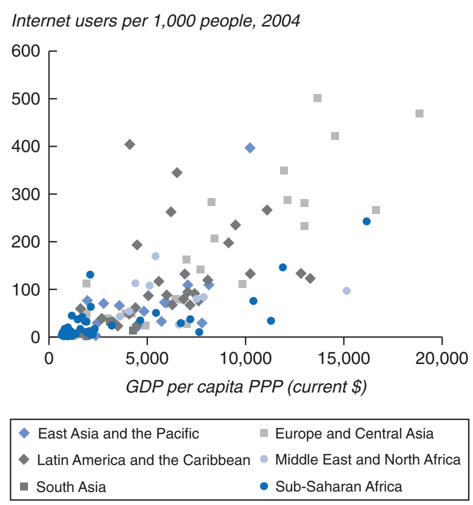
actually diffused relatively slowly throughout the world since their introduction in the 1980s, at least compared with the speed at which the use of mobile phones and the Internet has spread. Thus in 1995, France had just under 145 computers per 1,000 inhabitants, fewer than half as many as in the United States at the time (325) and roughly the same as in Hungary today. France now has 575 computers per 1,000 inhabitants, compared with 762 in the United States, and many developing countries in Europe and Central Asia and Latin America have PC ownership rates similar to Hungary's. Indeed, the regional average for Europe and Central Asia is brought down by low penetration rates in Turkey and Ukraine (the second and third most populous countries in the region, respectively), which have only 52 and 28 computers per 1,000 individuals, respectively. If we use the simple average of the penetration rate in individual countries in the region, there are about 150 computers per 1,000 people, with many countries posting penetration levels close to the unweighted average for high-income countries (460 PCs per 1,000).[9]

Nevertheless, three-quarters of low-income countries have 15 or fewer PCs per 1,000 people and one-quarter have fewer than 5 per 1,000 people. Yet, several low-income countries have substantially more. Mongolia, for example, reports having 133 PCs per 1,000 people, illustrating that even though the density of PC ownership is correlated with income, substantial variations exist across countries at similar income levels.

. . . while diffusion of the Internet and mobile phones has been extremely rapid

The penetration of Internet use, a more recent technology,[10] offers an interesting comparison (figure 2.5). Internet bandwidth consumption and the number of broadband subscribers more than doubled from 1999 to 2004 in both middle- and low-income countries. High-income countries have almost as many PCs per capita as there are Internet users in developing countries, which have twice as many Internet users as PCs. The ratio rises as per capita incomes decline, with four times as many Internet users as PCs in the Middle East

Figure 2.5 The incidence of Internet use varies widely across countries



Sources: World Bank; World Development Indicators.

and North Africa and South Asia. The capacity to share an Internet connection, either formally through a commercial venture such as an Internet café or informally, makes Internet use much more affordable than owning a PC and lies at the root of this difference.

A lack of infrastructure helps explain weak penetration rates in some low-income countries. For example, even though Internet penetration rates rose by 41 percent in Sub-Saharan Africa from 1999 to 2005, Internet penetration in the region remains the lowest among developing regions, in part because no high-speed, low-cost backbone exists to connect eastern and central Africa to the rest of the world. As a result, Internet transactions must be made via satellite, which provides lower bandwidth at higher cost than fiber optics (Kenyan call center operators pay $7,000 per megabyte of bandwidth compared with around $500 for operators connected by fiber optic cable in India). As a result, prospects for Sub-Saharan Africa are expected to improve following the recent installation of a fiber optic backbone along the western coast of the continent and the expected completion of a similar backbone along the eastern coast in 2008.

Technology is also providing solutions for overcoming infrastructure costs. In a number of countries, wireless broadband connections are outpacing digital subscriber line (DSL) and cable as a mechanism for distributing Internet access to customers. So-called 3G mobile phones already provide reasonable bandwidth in many countries, while more advanced standards offer hope for even faster implementation and diffusion. Some 23 developing countries are planning to, or already have begun to, deploy WiMax systems, a wireless, broadband Internet standard touted as the successor to today's WiFi and 3G systems. Those with existing WiMax implementations include the Dominican Republic, Pakistan, South Africa, and Uganda.

The ability to share the fixed costs of a mobile phone and its monthly subscription costs, along with its portability, have facilitated the diffusion of this technology in developing countries. Although lack of competition and difficulties innovative entrepreneurs encountered in getting licenses slowed the initial diffusion of mobile phone technology, much has changed in recent years (Sullivan 2007). Mobile phone ownership rates in developing countries—even in the poorest countries—are rising rapidly, having almost doubled in low-income countries between 2000 and 2004. Indeed, new subscribers are signing up at such a fast pace that the data in table 2.7 are already broadly out of date.

Because the market is evolving so rapidly, with new applications for mobile phone technology being developed on a regular basis, evaluating its overall impact is difficult. Penetration rates in Europe and Central Asia and Latin America and the Caribbean are already high, rivaling those observed in high-income countries less than 10 years ago. Penetration rates in East Asia and the Pacific are somewhat lower on average; however, looking at only the middle-income countries in the region and excluding small island economies, the average penetration rate in East Asia and the Pacific is higher than in Latin America and the Caribbean. Penetration rates in low-income countries are much lower, on average, although some countries have reached levels comparable to those in middle-income countries. As of 2005, six Sub-Saharan African countries (Botswana, Gabon, Mauritius, the Seychelles, Sierra Leone, and South Africa) had mobile phone penetration rates above 30 percent. Although penetration rates in South Asia are also low, the large populations of these countries and the pace at which firms are adding customers means that globally, a substantial proportion of new mobile phone subscribers comes from developing countries.[11]

The rapid penetration of mobile phone technology reflects in part the process by which it has been financed. Unlike most fixed-wire telephone systems, railroads, and electrical grids, mobile phone technology has been introduced into most developing countries by well-funded private operators working within a relatively competitive environment. As a result, the creation of the necessary infrastructure for these systems has not been held back by the government financing and bureaucratic constraints that slowed the diffusion of older technologies. Moreover, microfinance techniques have facilitated expansion of the demand side of the business (Sullivan 2007).

The technological and economic implications of the rising penetration of mobile phones are only now being assessed. In poor, rural areas, where the transportation of goods and people is heavily constrained by poor infrastructure, the introduction of cheap, personal communications may be of great value both as a substitute for moving people and to assure that the movement of people or goods is worthwhile. In particular, the availability of relatively cheap and efficient communications has reduced informational asymmetries in a number of sectors, increasing producers' revenues and lowering consumers' costs (albeit at the expense of middlemen). In addition, this technology is increasingly being used to enable a degree of arm's-length financial intermediation that many argue is critical to development, but that has largely been unavailable in the past because of a lack of infrastructure (box 2.8).

The diffusion of new technologies has encouraged rapid growth in business services

The Internet, greater availability of computers, and faster communications have combined to greatly expand the potential for developing countries to supply services from a distance in a process called offshoring. Initially offshoring services were concentrated on lower-end software services and business

Box 2.8 Innovative use of communications technology is improving financial access for the poor

The poor confront considerable challenges in gaining access to well-functioning savings and payments services. Financial institutions do not exist in many rural areas, and those that do often impose high minimum balance requirements (reflecting high unit transaction costs for small accounts) that are well beyond the reach of poorer households. However, the adaptation of technology has allowed some innovative financial institutions in Sub-Saharan Africa to extend financial outreach to the poor.

For example, the Equity Bank in Kenya has outfitted a series of vans with laptops and telecommunications facilities to act as mobile banking units. It has also designed flexible savings mechanisms with emergency loan facilities. Teba Bank of South Africa has developed a smart card that uses existing mobile phone technology to provide low-cost, electronic banking services (savings and payments) for low-income customers. The program was originally developed to handle wage payments for migrant workers. The value of the cards can be topped up or the cards can be used to make purchases at any of the simple wireless terminals that have been placed in shops frequented by low-income clients. Remote Transaction Systems in Uganda is introducing a similar, but more sophisticated scheme. A system developed by Celpay allows clients in the Democratic Republic of Congo and Zambia to use their mobile phones to pay bills. The client establishes an account with Celpay and can then make purchases by texting a request to Celpay, which will transfer money to the merchant's account. Security is provided by the use of a personal identification number, which is needed to complete the transaction.

In a series of surveys of banking services in three middle-income and four low-income countries, Bankable Frontier Associates (2007) found that even though only 1.5 percent of the adult population in South Africa was using mobile phone banking, the potential for the service was large. Between 7 and 41 percent of the unbanked population of the countries surveyed (Botswana, Kenya, Namibia, South Africa, Tanzania, Uganda, and Zambia) has access (including shared access) to a mobile phone, and these penetration rates are rising.

Source: Bankable Frontier Associates 2007; World Bank 2007c.

processes as well as call centers. More recently, offshoring has moved into such areas as investment and financial services, human resources, health services, retail functions, logistics, and customer support functions (World Bank 2005). In addition to increasing demand for labor and boosting export revenues, offshoring of services to developing countries can improve their incentives to provide education and training, help improve the quality of services provided domestically, encourage technology and knowledge transfers, and minimize (compared with manufacturing) the environmental consequences of economic growth. By one account, the most attractive locations for offshoring global services (based on costs, the availability of workers with appropriate skills, and the overall business environment) include Brazil, Chile, China, the Czech Republic, India, Malaysia, the Philippines, and Thailand (A. T. Kearney 2007). As the complexity of services offshored increases, geographic proximity to major markets has become more important and has provided greater opportunities, for example, for the Czech Republic to supply Western Europe and for Mexico to supply Canada and the United States. The advantages of fluency in English and French, along with shared time zones, have increased the potential for African countries to supply services to the European market.[12]

While India has dominated the outsourcing market, rapid expansion of the business may be running into capacity constraints as the pool of unemployed and underemployed skilled workers dries up and wages are bid up.[13] Eventually, rising labor costs may partly erode the advantage of the current major offshore centers, providing greater room for competition from poorer countries. A recent survey found that the relative cost advantage of the leading offshore destinations fell in 2006 (A. T. Kearney 2007). However, partly because of learning by doing, these countries' scores along other dimensions, including people skills and the business environment, have increased. As a result, they have been able to move up the value added ladder by increasing the sophistication of the services they deliver even as their costs rise. This development underlines a major message for policy makers and businesses in developing countries: improving the skills of the labor force by devoting more resources to education and training, along with improving the overall climate for investment, is essential for competing in technologically sophisticated markets.

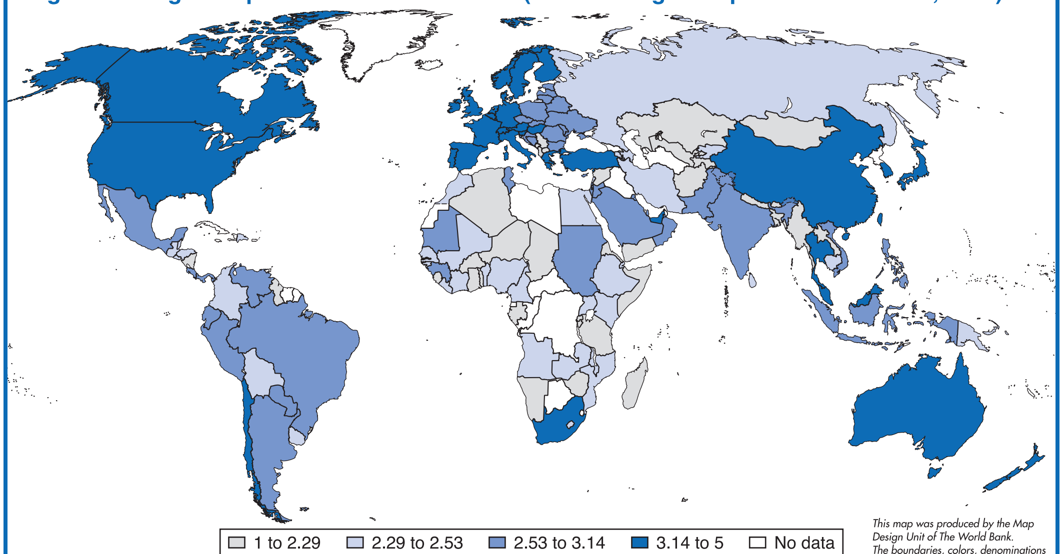
Logistics represent an important process technology

As noted earlier, the spread of modern communications technology and the diffusion of computers, coupled with quality improvements in transportation services, have combined to greatly improve the rapid and efficient delivery of goods and services, enabling just-in-time inventory processing and more efficient supply chain management (this subsection is based on Arvis and others 2007). The World Bank's logistics performance index provides an overall evaluation of the perceived sophistication with which countries are able to deliver goods and services (figure 2.6). It contains several subindexes that measure services critical to logistics, including customs, infrastructure, ability to track shipments, and business processes (competence) along with the timeliness and cost of deliveries of domestic logistics companies (table 2.9).

The overall quality of logistics services is clearly correlated with income. The top performers are high-income countries (Singapore, with an index of 4.19, ranks number 1), while the worst performers are the poorest countries that are landlocked or that suffer from severe governance problems or conflict (Afghanistan, with an index of 1.21, ranks last). On average, low-income countries score significantly lower than middle-income countries.

Nevertheless, index levels show considerable dispersion among countries with similar income levels. Countries where trade has played a significant role in promoting growth (for example, Chile, China, India, Malaysia, South Africa, Thailand, and Vietnam) tend to score high relative to their income level.

Figure 2.6 Logistics performance in the world (score on logistics performance index, 2005)



This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

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Source: Arvis and others 2007.

Note: The maximum score attainable is 5; the minimum is 1.

Vietnam, a low-income country, ranks 53rd among 150 countries, or slightly above the average for upper-middle-income countries. In contrast, countries where growth has been generated by oil and mineral assets, for example, Algeria, Bahrain, and Saudi Arabia, score low relative to income. The absence of a strong manufacturing sector in these latter countries tends to reduce the political impetus for the reforms that would improve logistics. Ultimately, countries that achieve high scores on the logistics performance index are those that have vigorously pursued reforms to improve the effectiveness of public sector institutions and to

Table 2.9 The quality of logistics services in 2005 varies by income

(score on logistics performance index)

	Overall	Customs	Infrastructure	International shipments	Logistics competence	Tracking and tracing	Domestic logistics costs	Timeliness
Regions					*(Index)*			
East Asia and the Pacific	2.58	2.41	2.37	2.64	2.54	2.53	3.04	3.01
Europe and Central Asia	2.59	2.39	2.39	2.61	2.53	2.55	2.97	3.04
Latin America and the Caribbean	2.57	2.38	2.38	2.55	2.52	2.58	2.97	3.02
Middle East and North Africa	2.42	2.24	2.27	2.44	2.33	2.35	2.95	2.88
Sub-Saharan Africa	2.35	2.21	2.11	2.36	2.33	2.31	2.98	2.77
South Asia	2.30	2.06	2.07	2.28	2.32	2.32	3.12	2.73
Income groups								
High-income countries	3.67	3.45	3.66	3.52	3.64	3.71	2.58	4.05
Upper-middle-income countries	2.85	2.64	2.70	2.84	2.80	2.83	2.94	3.31
Lower-middle-income countries	2.47	2.31	2.27	2.48	2.40	2.45	3.01	2.93
Low-income countries	2.29	2.12	2.06	2.32	2.29	2.25	2.99	2.71

Source: Arvis and others 2007.
Note: The maximum score attainable is 5; the minimum is 1.

encourage the efficiency of private sector institutions through competition.[14]

Among the components of the index, assessments of the quality of infrastructure, the quality of services, and the ease of customs clearance processes are highly correlated across countries. In contrast, the cost of services varies less across countries (with the exception of markedly high road freight rates in Sub-Saharan Africa) and thus makes a more limited contribution to cross-country differences in the overall index. This highlights the importance of the speed and reliability of shipping in globally integrated production networks. Interestingly, the gap between the best and worst performers in relation to the overall assessment of the reliability of the supply chain is twice the average gap across various dimensions of supply chain performance. The reliability of the supply chain tends to be determined by its weakest link.

Evaluating overall technological progress

The preceding sections of this chapter have discussed technological achievement in developing countries along three dimensions: scientific innovation and invention, the diffusion of old technologies, and the diffusion of new technologies. In this section we calculate summary indexes of technological achievement along each of these dimensions, as well as an overall index that combines these subindexes with additional information about the extent to which countries are exposed to technology through trade and FDI, issues that are discussed in more detail in chapter 3.

Summary indicators for scientific innovation and technology penetration

A statistical approach to summarizing technological progress

In creating the summary indexes, a statistical technique, principal components analysis, is used to combine subindicators in a flexible manner.[15] This approach has been widely used in health economics (Gwatkin and others 2000a, 2000b, 2000c; McKenzie 2003; Montgomery and others 2000; Vyas and Kumaranayake 2006), in poverty analysis (Sricharoen and Buchenrieder 2005), in regulatory policy analysis (Nicoletti, Scarpetta, and Boylaud 1999), in constructing cross-country measures of capital controls (Chinn and Ito 2006) and in the analysis of e-readiness in India (Government of India 2006). It contrasts with most existing efforts to construct overall indexes of technological achievement, which tend to aggregate subindexes using arbitrary weights with a weak theoretical or empirical basis, by using the statistical properties of the underlying data to determine the weights used in calculating the summary and overall indexes. Principal components analysis is used to generate aggregate indexes at two points in time, the early 1990s and the early 2000s,[16] for scientific innovation and invention, the penetration of older technologies, and the penetration of newer technologies. These summary indexes are then combined with an index of the extent to which countries are exposed to foreign technologies (through trade and FDI), which is developed in chapter 3, to generate an aggregate index of technological achievement. Table 2.10 lists the indicators that are summarized in both the overall index and each of the summary subindexes. The technical annex to this chapter explains the steps taken to calculate these weights in more detail.

The relationship between technological achievement and income varies depending on the dimension observed

Figure 2.7 reports the distribution of the summary subindex for each of the three dimensions of technological achievement discussed in this chapter (the summary index of the extent of exposure to foreign technologies is presented in chapter 3). A quick glance reinforces the earlier conclusion that, by and large, developing countries are not participating in scientific innovation at the technological frontier. Indeed, only a handful of countries, eight of which are former

Table 2.10 Indicators included in summary indexes of technological achievement

Indicator	Measure	Source
Scientific innovation and invention		
Scientific and technical journal articles	population	World Development Indicators
Patents granted by the U.S. Patent and Trademark Office	population	Lederman and Saenz 2005
Patents granted by the European Patent Office	population	Lederman and Saenz 2005
Penetration of older technologies		
Group A		
Electrical power consumption	kilowatt-hours/capita	World Development Indicators
International outgoing telephone traffic	minutes	World Development Indicators
Air transport, registered carrier departures worldwide	% of GDP	World Development Indicators
Agricultural machinery: tractors	per 100 hectares of arable land	World Development Indicators
Group B		
Main lines	per 100 inhabitants	World Development Indicators
Exports of manufactures	% of merchandise exports	World Development Indicators
Medium-tech exports	% of merchandise exports	CEPII BACI database
Penetration of recent technologies		
Internet users	per 1,000 people	World Development Indicators
Personal computers	per 1,000 people	World Development Indicators
Cellular subscribers	per 100 inhabitants	World Development Indicators
Percentage of digital mainlines		World Development Indicators
High-tech exports	% of total exports	CEPII BACI database
Exposure to external technology		
FDI net inflows	% of GDP	World Development Indicators
Royalties and license fee payments	% of GDP	World Development Indicators
Imports of high-tech goods	% of GDP	CEPII BACI database
Imports of capital goods	% of GDP	CEPII BACI database
Imports of intermediary goods	% of GDP	CEPII BACI database

Source: World Bank.
Note: BACI = Banque analytique de commerce internationale, CEPII = Centre d'Etudes Prospectives et d'Informations Internationales, EPO = European Patent Office, FDI = foreign direct investment, GDP = gross domestic product, USPTO = United States Patent and Trademark Office.

Soviet bloc countries, have anything like the same level of at-the-frontier scientific activity as the high-income countries. While this may reflect an innate bias in the indicators used (number of journal citations and patent applications), the results are consistent with the view that most technical progress in developing countries occurs through the adaptation and adoption of new-to-the-market or new-to-the-firm technologies rather than through the creation of new-to-the-world technologies. Moreover, notwithstanding that some firms—and even some cities—in developing countries do participate actively at the technological frontier, when viewed from the national level, not even the most advanced developing countries participate at levels comparable to those prevalent in high-income countries.

The distribution of technological achievement across the other indicators (diffusion of old innovations and of new innovations) is also skewed toward high-income countries, but much less so. Thus the intensity with which upper-middle-income countries exploit both older and newer technologies is between 50 and 60 percent of the level in high-income countries. This ratio is between 30 and 40 percent for lower-middle-income countries and is about 23 percent for low-income countries (table 2.11). However, the dispersion of the summary indicator of the penetration of older technologies within income groups is very wide. Many low-income countries report higher utilization rates for older technologies than do many upper-middle income countries. This report suggests that other factors—such as

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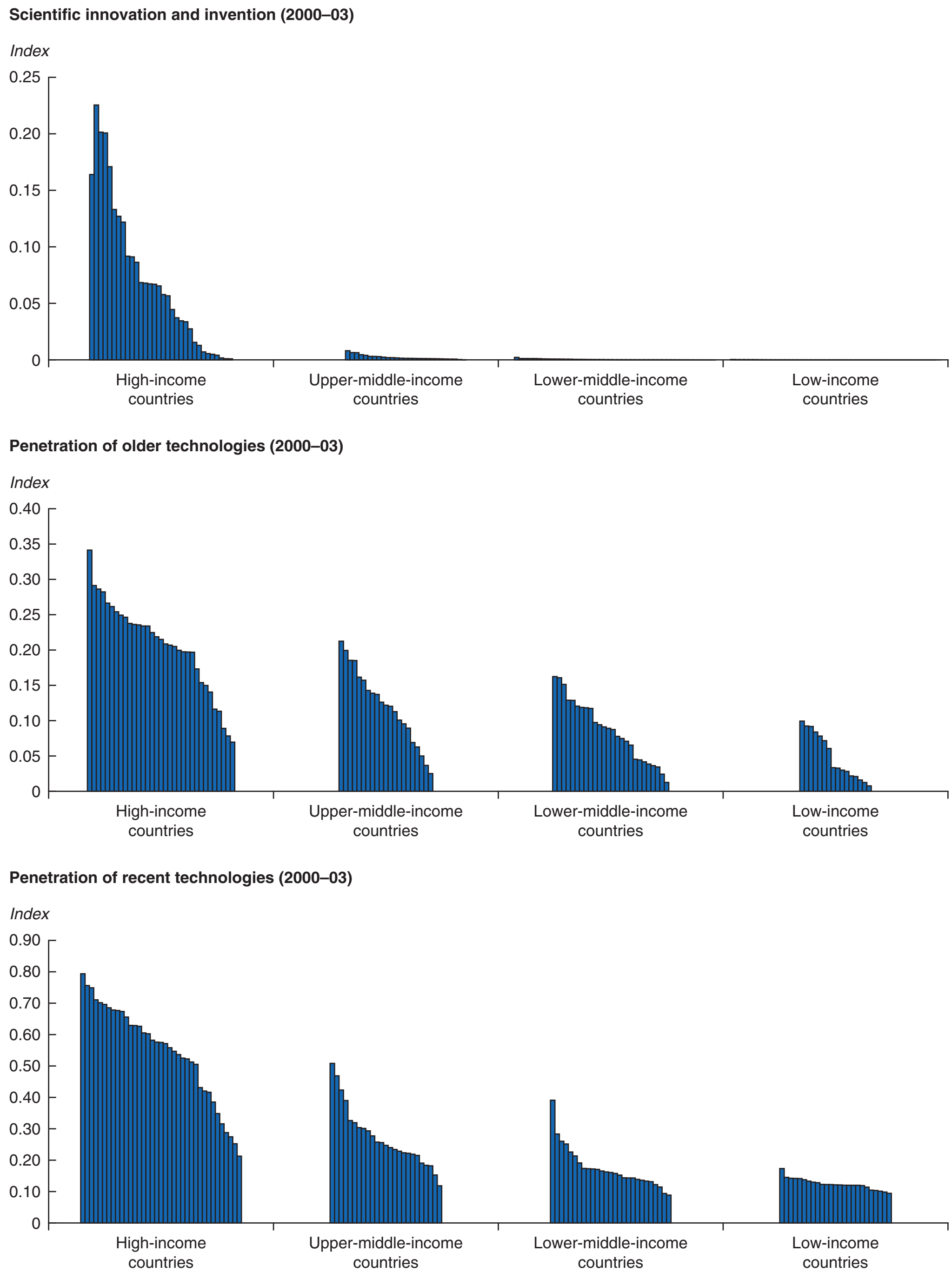
Figure 2.7 Distribution of technological achievement by dimension



Source: World Bank.

Table 2.11 Technological achievement in developing countries relative to that in high-income countries

(percent of level in high-income countries)

	Scientific innovation and invention	Penetration of older technologies	Penetration of recent technologies
High-income countries	100.0	100.0	100.0
Upper-middle-income countries	3.3	58.4	49.6
Lower-middle-income countries	0.6	41.6	31.8
Low-income countries	0.1	23.7	22.7

Source: World Bank.

Table 2.12 Increase in technological achievement in developing countries relative to that in high-income countries

(index, percent increase in high-income countries = 100)

	Scientific innovation and invention	Penetration of older technologies	Penetration of recent technologies
High-income countries	100.0	100.0	100.0
Upper-middle-income countries	191.6	220.8	162.3
Lower-middle-income countries	157.1	251.8	145.8
Low-income countries	63.7	480.4	411.3

Source: World Bank.

history, effectiveness with which governments have delivered some public sector technological services, and past turmoil—may have had a greater influence than income in explaining the integration of these technologies into their economies.[17] In contrast, the diffusion of recent technologies is more correlated with income and shows both much less variation and less overlap across income groups. These results are consistent with the view that nonfinancial impediments to technological diffusion have constrained the diffusion of more recent technologies by less than they have for older ones.

In terms of scientific innovation and invention, middle-income countries have been catching up, at least in relative terms, but as already noted, the gap between them and high-income countries remains large. In addition, the gap between most low-income countries and the technological frontier has widened further both in relative and in absolute terms.

The story on the diffusion of technology is more encouraging. On average, in middle-income countries older technologies are diffusing at 2.5 times the rate as in high-income countries and more than four times as fast as in low-income countries (table 2.12). While this result appears to be robust for middle-income countries (figure 2.8), the variance is much higher among low-income countries. Several low-income countries have recorded substantial increases in technological progress, for example Benin, Ghana, and Togo record more than 100 percent improvements. In many others, however, progress has been slower than in high- and middle-income countries, implying that the technology gap for these countries is either stable or widening.

Not surprisingly, the most rapid increases in technological achievement recorded over the past decade or so are for more recent technologies, whose starting points are relatively low even in high-income countries (figure 2.8). Clear indications of catch-up are evident for newer technologies, with the penetration rates in upper-middle-income countries increasing 1.5 times as quickly as in high-income countries. The pace of increase among low-income countries was more than four times as rapid, but this reflects, to a significant degree, very large percentage improvements in a few countries that started off with very low levels. Notwithstanding these caveats, most developing countries are maintaining pace with high-income countries and many, especially among the upper-middle-income countries, are gaining ground.

New technologies are not as diffused as old technologies, but the gap between income groups is smaller

Overall, the penetration of recent technologies in the economic life of developing countries is less extensive than for older technologies, which is entirely understandable given the length of time that has passed since the older technologies were introduced. Nevertheless, the gap between countries at different income levels is not as striking as one might expect. Many upper-middle-income countries have achieved levels of technological achievement

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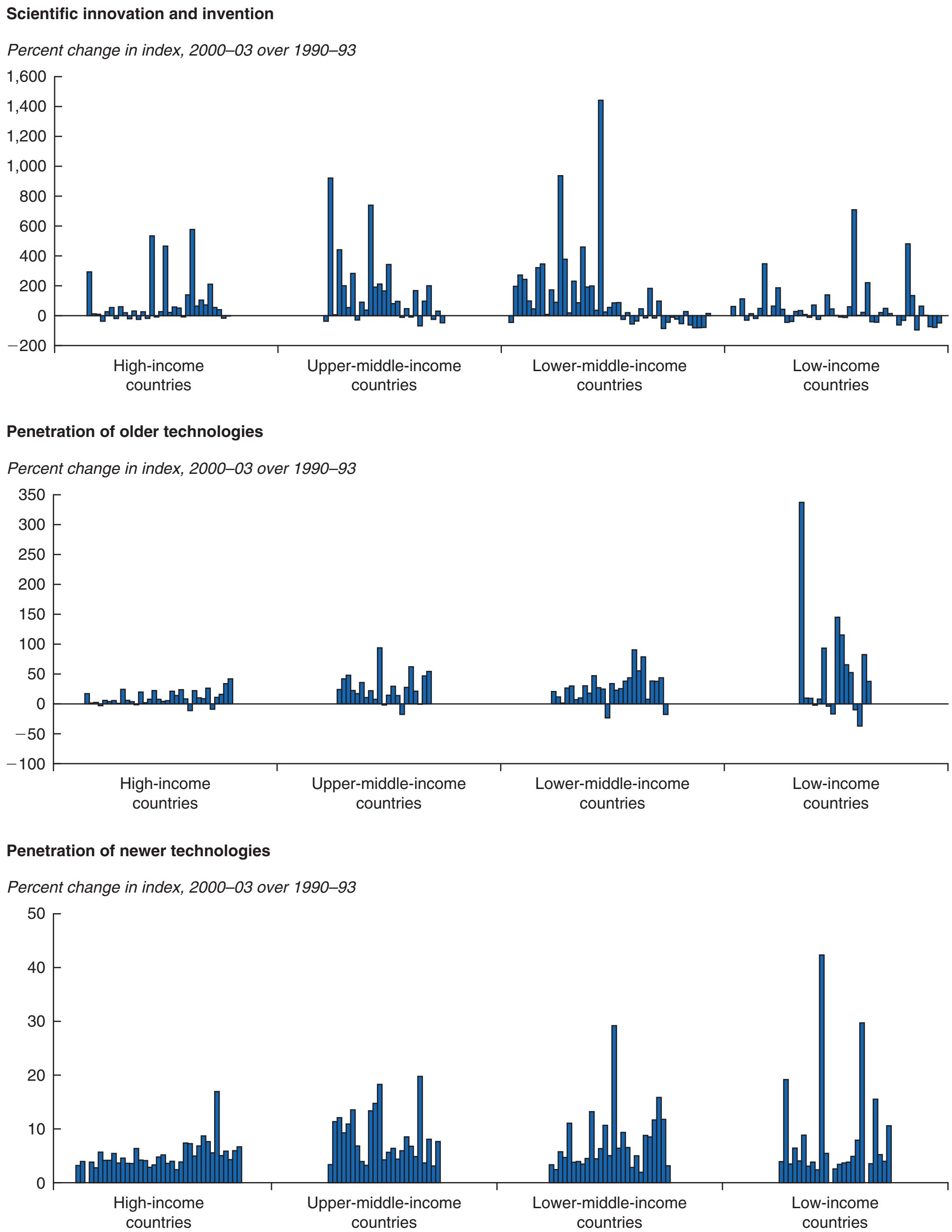
Figure 2.8 Increase in summary technological achievement subindexes, 1990s–2000s



Source: World Bank.

Note: Countries are ranked according to the level of technological achievement in 2000.

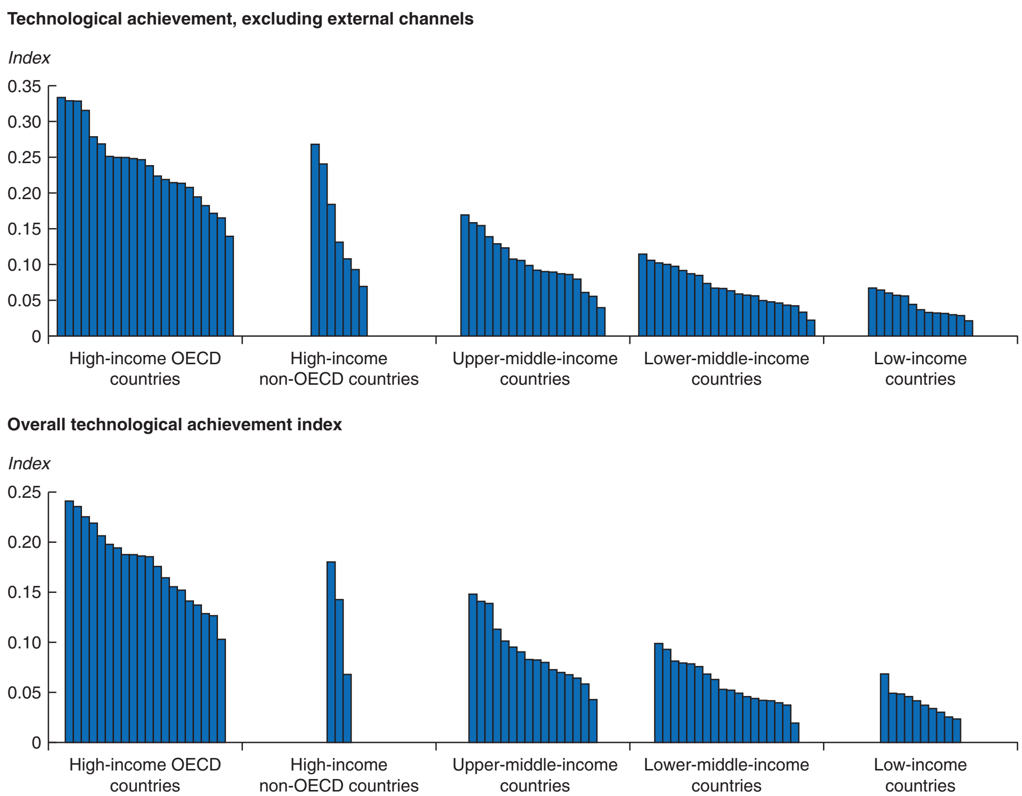
similar to those in high-income countries, and substantial overlap is apparent between upper- and lower-middle-income countries and between lower-middle-income and low-income countries. Interestingly, the clear advantage countries in Europe and Central Asia enjoy along other dimensions of technological achievement is less marked here, with East Asian countries performing better than might be expected.

Overall technological achievement

To understand overall technological achievement, two alternative summary indexes were generated. The first combines the three summary subindicators of achievement discussed earlier, while the second includes an additional summary indicator that measures the extent to which economies are using imported technology in their production processes. The underlying components and their recent evolution are discussed in more detail in chapter 3 in the context of the channels by which external technology is transmitted to developing countries. These overall summary indexes are calculated using the same basic technique used to calculate the subindicators (see the technical annex to this chapter for details), with one difference: rather than using the raw data as inputs, the previously calculated summary indicators are used.

Figure 2.9 reports levels of technological achievement in 2000 according to these two summary indicators. The country coverage differs somewhat between the two indexes. To

Figure 2.9 Alternative summary indexes of technological achievement (2000s)



Source: World Bank.

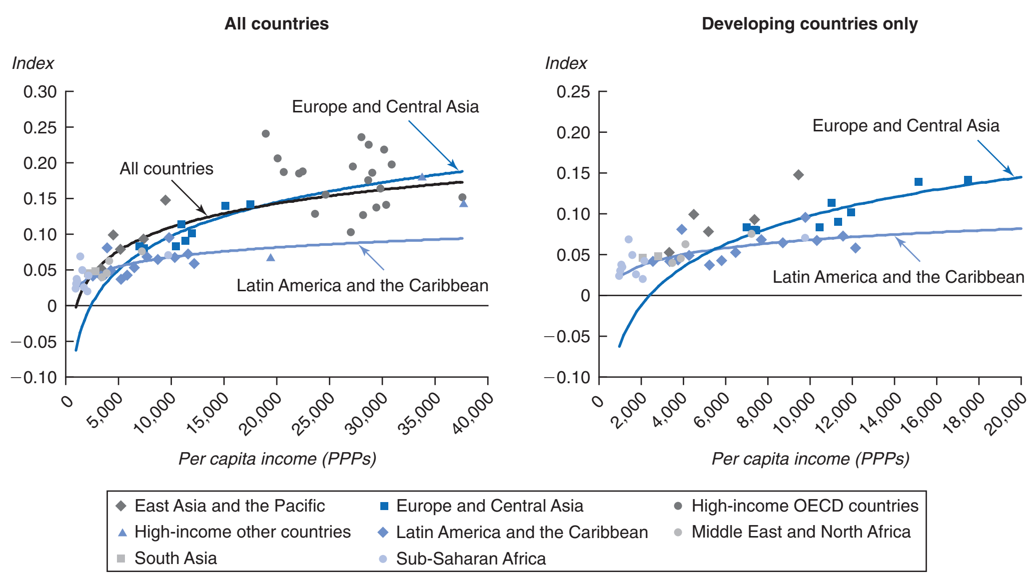
be included, each country must have data for all variables, and as additional variables are added, some countries are lost from the sample. Reflecting this requirement, only 20 low-income countries are included in the first index and 16 in the second, down from 46 in the case of the subindicator with the best coverage.[18] Although these are relatively diverse groups of countries, they cannot be considered representative of all developing countries. Particular care should be taken in extrapolating results derived from these countries to all low-income countries.

Countries with similar income levels can have very different levels of technological achievement

While the influence of income on technological achievement is well established, considerable variation occurs within income groups (figure 2.10). The top performers within developing country income groups achieve a technology rating about equal to that of the median country in the next highest income group, and scores for countries at roughly the same income level show substantial dispersion. Overall, the relationship between technological achievement and income per capita is nonlinear, with the rise in technological achievement tending to flatten out for countries with per capita incomes between $10,000 and $25,000, a group that includes upper-middle-income countries and some of the less wealthy high-income countries such as Greece and Portugal. Countries in Latin America have weak technology scores given their income levels. Despite the perceived technological prowess of countries in East Asia, except for Malaysia, the highest-scoring country in the region, the developing countries in the region do not particularly distinguish themselves, in part because technological diffusion in these countries remains concentrated in a few urban centers and has not diffused widely elsewhere.

Focusing only on developing countries in the second panel of figure 2.10, the correlation with income remains, but the same

Figure 2.10 Technological achievement rises with income levels



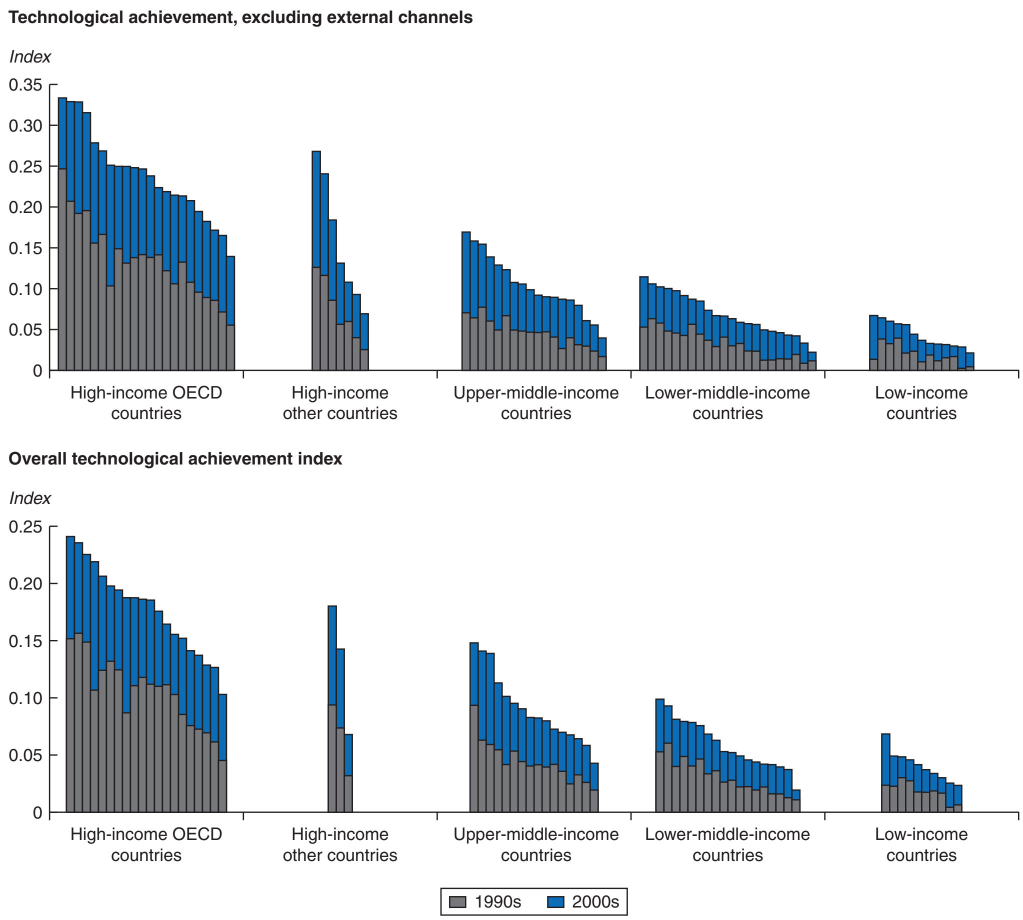
Source: World Bank.

tendency for a flattening in the relationship is still observable. For countries in Latin America and the Caribbean, the relationship between technological achievement and income per capita flattens out at even lower income levels, while for countries in Europe and Central Asia, the pattern follows more closely that of the overall sample, which includes high-income countries. Among developing countries (excluding those in the Europe and Central Asia region), technological achievement flattens out at an index level of around 0.15 for countries with per capita incomes around $5,500. While not conclusive, these results are consistent with a view that other factors, such as technological absorptive capacity (see chapter 3) limit the level of technological achievement that some developing countries can attain even as incomes continue to rise.

Technological convergence appears to be constrained by weak absorptive capacity in some regions

Figure 2.11 reports values for the two overall summary indexes at two points in time,

Figure 2.11 Comparison of levels of technological achievement, early 1990s and early 2000s



Source: World Bank.

roughly the early 1990s and the early 2000s. Both indexes offer a broadly consistent view of technological achievement. They both confirm that the absolute size of the increases in technological progress over the decade is larger among higher-income countries than lower-income countries, but that the relative improvement in developing countries has outpaced that in high-income countries, implying that catch-up is occurring.

The extent of apparent catch-up is strongest when considering the narrower definition of technological achievement that includes only scientific inputs and the penetration of old and new technologies. According to this measure, low-income countries for which data are available have shown the largest percentage improvement. If changes in the extent to which countries are making use of external technologies through imports and FDI are included, the extent of convergence declines for all developing country groups except the upper-middle-income countries. This finding reflects that high-income countries have also increased their imports of high-tech goods and have also benefited technologically from the operation of technologically sophisticated foreign-owned firms on their soil. However, trade may contribute more to technological improvement in the South than in the North (Lumenga-Neso, Olarreaga, and Schiff 2005).

Among upper-middle-income countries, catch-up is particularly strong in Chile, Hungary, and Poland, where the level of technological achievement rose by more than 125 percent during the 1990s. For most countries the pace of convergence was much slower. As indicated earlier, relatively weak data coverage across low-income countries makes generalizing about their progress difficult. Only 16 low-income countries (10 in the case of the summary index that includes imports of technology and FDI) have sufficient data for both the early 1990s and the early 2000s to permit an estimate of their rate of technological progress. Although generalizations to all low-income countries are not possible, some commonalities do emerge from this subsample, namely:

- The absolute increase in the overall index of technological achievement for low-income countries is about the same as for lower-middle-income countries (and thus the percentage increase in low-income countries is much greater), strongly suggesting a catch-up effect relative to the lower-middle-income countries (table 2.13).
- The percentage increase in achievement along the scientific innovation and invention dimension for all eight Sub-Saharan African countries for which data are available, along with Bangladesh and India, lies well below the average for middle-income countries. Only Vietnam approaches the performance of middle-income countries.
- The picture for the diffusion of old innovations is decidedly more mixed, with 5 of

Table 2.13 Overall technological progress in absolute and relative terms

	Technological achievement excluding external channels	Overall technological achievement
	(Percent change in the index)	
High-income	94	77
Upper-middle-income	127	109
Lower-middle-income	137	103
Low-income	227	161
Low-income (excluding Sudan)	160	124
	(Percent change relative to high-income countries)	
High-income	100	100
Upper-middle-income	135	141
Lower-middle-income	146	133
Low-income	241	208
Low-income (excluding Sudan)	170	160
	(Absolute change in the index)	
High-income	0.096	0.068
Upper-middle-income	0.057	0.046
Lower-middle-income	0.036	0.028
Low-income	0.024	0.022
Low-income (excluding Sudan)	0.024	0.022

Source: World Bank.

16 low-income countries showing stagnation or declines in the index between the early 1990s and early 2000s, while 6 recorded large percentage increases, comparable to those displayed by the more successful middle-income countries.

- Even for the diffusion of recent innovations, where successful examples of mobile phone and Internet diffusion have been much publicized, only 5 of 25 low-income countries (Guinea, Mongolia, Pakistan, Sudan, and Zimbabwe) achieved increases in the index that exceeded the middle-income average. However, low-income countries did increase penetration rates for recent innovations more quickly than high-income countries.[19] Given that new technologies sometimes substitute for older technologies, such as mobile phones for fixed-line telephones, transmission of information over the Internet for transmission involving travel and telephones, the previous finding suggests that the overall pace of convergence in low-income countries may be accelerating, particularly as data for 2005 and 2006 suggest continued high growth in the diffusion of mobile telecommunications and Internet technologies.[20]

Econometric evidence supports the view that the relationship between income and technological diffusion follows an S-curve: technological diffusion is slow at very low incomes, in part because of difficulties in affording new technologies, in part because low levels of human capital severely constrain technological progress. As incomes rise, technological diffusion increases rapidly, particularly in percentage terms, because of the low base level. At some level of income, however, the pace of technological diffusion slows. One explanation for this slowdown at higher income levels is the slow pace of improvement in an economy's ability to absorb new technologies (its technological adaptive capacity), as determined by the level of human capital, the governance structure, and the infrastructure (Howitt and Mayer-Foulkes 2005; Klenow and Rodriques-Clare 2004; Lederman and Saenz 2005). According to this view, technology in a country tends to converge toward a level consistent with the country's technological adaptive capacity. As a result, countries may experience relatively rapid technological progress for a period, but may subsequently stagnate at a given level unless they take steps to further raise their technological adaptive capacity. Chapter 3 develops the components of technological adaptive capacity and describes trends in developing countries.

Technological diffusion over the long term

So far, we have emphasized the technological performance of countries at different income levels over the recent past. Thanks to a new data set developed by Comin and Hobijn (2004), we can now analyze the process of technological diffusion over the longer term. This data set traces the extent of diffusion of some 100 technologies in 157 countries during the period 1750–2003.[21] For each technology, only countries for which published data exist are included, implicitly restricting the sample to countries (and technologies) where a significant degree of diffusion has occurred. The data analyzed here are further restricted to include only those country-technology pairs (a data set with one country and data for 7 technologies would have 7 country-technology pairs) where the intensity of use has reached at least 5 percent of the average level of the 10 countries with the highest recorded level of diffusion. Under this restriction, there are 1,181 country-technology pairs, 699 of which correspond to developing countries, heavily weighted to technologies discovered in the late 19th or early 20th centuries.[22]

Two important points emerge from this analysis. First, the diffusion of technology across the globe has accelerated over time.

Table 2.14 Successful diffusion has accelerated

	Period technology was initially discovered				
Technology	1750–1900	1900–50	1950–75	1975–2000	Number of countries
	(years following discovery until technology reached 80 percent of reporting countries)				
Transportation					
Shipping (steam)	83				21
Shipping (steam motor)	180				57
Rail (passenger)	126				93
Rail (freight)	124				99
Vehicles (private)	96				153
Vehicles (commercial)	63				123
Aviation (passenger)		60			109
Aviation (freight)		60			103
Communications					
Telegram	91				77
Telephone	99				156
Radio		69			154
Television		59			156
Cable television		50			98
PC			24		134
Internet use			23		151
Mobile phone				16	150
Manufacturing					
Spindle (ring)	111				50
Steel (open hearth furnace)	125				50
Electrification	78				155
Steel (electric arc furnace)		92			91
Synthetic textiles		36			75
Medical (OECD only)					
Cataract surgery	251				19
X-ray		93			27
Dialysis		33			29
Mammography			33		18
Liver transplant			28		29
Heart transplant			28		27
Computerized axial tomography (CAT) scan			18		29
Lithotriptor				15	26
Average (excluding medical)	106.9	60.9	23.5	16.0	
Average (including medical)	118.9	61.3	25.7	15.5	

Source: Calculations from CHAT database (Comin and Hobijn 2004).

Table 2.14 reports, for several old and new technologies, the number of years that elapsed between the discovery of the technology and the time it reached 80 percent of the countries currently reporting data for that technology.[23] The acceleration in the pace at which technologies spread across countries is particularly striking in the communications field, for which data are relatively good and country coverage is extensive. Thus telephone and telegram services were invented in the middle of the 19th century, and more than 90 years passed before those services reached 80 percent of the countries that currently report data

Table 2.15 The pace at which technology diffuses has picked up among successful adaptors

	1800–99		1900–50		1950–75		1975–2000	
	Threshold		Threshold		Threshold		Threshold	
	5%	25%	5%	25%	5%	25%	5%	25%
	(years from discovery until threshold reached)							
Regions								
East Asia and the Pacific			60	69	23	28	18	21
Europe and Central Asia	91	117	47	57	25	30	18	21
Latin America and the Caribbean	71	105	54	72	30	35	18	21
Middle East and North Africa	97	118	58	67	25	29	18	21
South Asia			52	62	—	—	—	—
Sub-Saharan Africa	85	109	56	69	—	—	18	21
Income groups								
High-income OECD countries	63	91	46	60	20	24	13	17
Other high-income countries	95	112	57	65	20	25	15	18
Upper-middle income countries	83	110	51	64	26	31	18	21
Lower-middle-income countries	86	114	57	69	—	—	20	22
Low-income countries			56	68	—	—		
World	76	102	52	65	22	26	16	19
Developing countries	84	111	54	67	26	31	18	21

Source: World Bank calculations using the CHAT database (Comin and Hobijn 2004).
Note: The sample is restricted to only those 567 country-technology pairings where the 25 percent threshold was reached and that were below 10 percent when they appeared in the database; — = no data.

for them. In contrast, mobile phones, computers, and cable television reached 80 percent of the countries that currently report data in less than 25 years. The same sort of acceleration can be observed for the dissemination of transportation, manufacturing, and medical technology.

Second, and consistent with the first point, technological diffusion appears to accelerate above a certain threshold. Table 2.15 considers only those country-technology pairs that have reached a level of penetration equal to 25 percent of the average level observed in the 10 countries where the technology is employed most intensively. Looking at the results for the world as a whole, the amount of time required to go from the 5 percent level to the 25 percent level (averaged across country-technology pairs) is much smaller than the time required to reach the 5 percent level. For example, in the first half of the 20th century, for a technology to reach the 5 percent threshold took, on average, 52 years, but only an additional 13 years to reach 25 percent. Moreover, the pace of acceleration has increased over time. For technologies introduced since 1975, a group dominated by electronics and information technologies, on average, it took 16 years from its invention for a technology to reach the 5 percent threshold in a given country, but only another 3 years to reach the 25 percent threshold. Although the pace of diffusion was somewhat slower in developing countries than in high-income countries, it too follows the same pattern. Because table 2.15 excludes country-technology pairs where the 5 percent threshold has been reached, but not the 25 percent threshold, the recorded diffusion times are probably lower-bound estimates.[24] This pattern is consistent with the existence of significant economies of scale and barriers to entry among these technologies, such that once the barriers are overcome and the technology is in place, scaling up occurs relatively quickly.

While diffusion has occurred relatively rapidly among successful diffusers, successful

Table 2.16 Slow diffusion means that many developing countries never reach the 25 or 50 percent threshold

	1800s			1900–50			1950–75			1975–2000		
	Threshold			Threshold			Threshold			Threshold		
	5%	25%	50%	5%	25%	50%	5%	25%	50%	5%	25%	50%
	(number of country-technology pairs that have reached threshold)											
Regions												
East Asia and the Pacific	18	0	0	38	9	3	7	2	1	6	2	0
Europe and Central Asia	56	19	6	47	23	6	40	18	3	23	13	6
Latin America and the Caribbean	80	11	1	95	34	8	31	3	0	19	4	0
Middle East and North Africa	28	4	1	44	16	6	9	1	0	6	2	0
South Asia	7	0	0	11	3	3	0	0	0	1	0	0
Sub-Saharan Africa	27	4	0	83	21	8	11	0	0	12	3	0
Income groups												
High-income OECD countries	150	114	75	134	93	55	96	87	75	28	26	23
Other high-income countries	25	16	7	28	23	14	14	10	8	7	6	6
Upper-middle-income countries	90	30	6	112	53	16	61	24	4	29	19	6
Lower-middle-income countries	109	8	2	130	38	12	33	0	0	33	5	0
Low-income countries	17	0	0	76	15	6	4	0	0	5	0	0
Total number of country-technology pairs												
World	391	168	90	480	222	103	208	121	87	102	56	35
Developing countries	216	38	8	318	106	34	98	24	4	67	24	6

Source: World Bank calculations using the CHAT database (Comin and Hobijn 2004).
Note: Sample restricted to only those 1951 country-technology pairings that were below 10 percent when they appeared in the database.

diffusion is the exception rather than the rule. For example, of 102 country-technology pairings first recorded in 1975–2000, only 56 (55 percent) have reached the 25 percent threshold and only about 35 (34 percent) have reached the 50 percent threshold (table 2.16). For developing countries, the pace (and extent) of diffusion is significantly slower (lower) than in high-income countries, with only 24 (36 percent) developing countries having reached the 25 percent threshold and only 6 (9 percent) having reached the 50 percent threshold. This slower diffusion is true even for extremely old technologies, a result consistent with the idea that affordability and competency issues are binding constraints on the further diffusion of technologies in these countries. This result is broadly consistent with the observation that for some groups of countries, overall technological achievement appears to stop increasing after a given level is reached, and many developing countries may thus face severe barriers to achieving accelerated technological progress.

Slow diffusion within countries reflects a nonlinear process

As noted earlier, the surprisingly low level of overall technological achievement in countries such as China and India contrasts with popular perceptions, which are based on the relative technological sophistication of some of the two countries' major cities and trading centers. However, the same kind of technological diversity observed across countries is visible within countries as well (see box 2.9 for the case of India). For example, although one might have expected India to have scored substantially better than many Sub-Saharan African countries in overall technological diffusion, in fact, it does not. Several technologically advanced cities in India notwithstanding, technologies have not penetrated deeply in many parts of the Indian countryside. Here the challenge is to put in place a basic infrastructure in the countryside that can support the kind of sophisticated technologies that the elites in the country are capable of supporting. As one observer put it, an energy technology revolution must precede

Box 2.9 The technological divide within India

Large segments of the Indian economy are technology sophisticated. Its high-tech industries are important global players, its premier education and R&D institutions are recognized internationally. Along with China, it has the largest pool of skilled manpower, including those with degrees in engineering and other technical disciplines. Moreover, India has become one of the world's largest markets for telecommunications technology, is a leader among developing countries in exports of software and information technology-enabled services, and has demonstrated its potential to be a major player in biotechnology-pharmaceuticals and the automobile and engineering sectors, with Bangalore having emerged as a major international center for technological production and innovation.

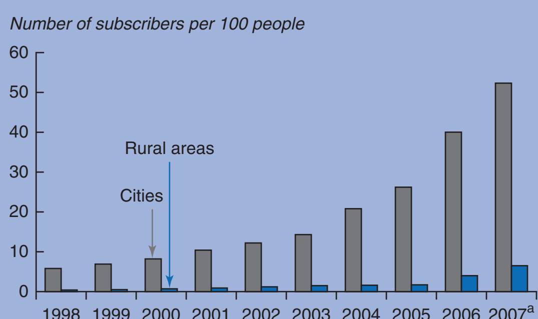
Nevertheless, on a per capita basis, India continues to lag behind middle-income countries in the rate of technological diffusion, R&D expenditures, attainment levels of basic and higher education, availability and quality of logistics services, and size of revenues and employment in software and other high-tech industries. In addition, India does not score substantially better than many Sub-Saharan African countries in terms of the overall penetration of technologies.

The juxtaposition of India's increasing technological prowess and relatively poor access to technology in per capita terms largely reflects the limited penetration of technology in rural areas, which account for more than 70 percent of the population, but less than 30 percent of GDP. For example, in June 2007 tele-density—the number of subscribers (wired and wireless combined) per 100 individuals—was 52.3 percent for urban dwellers compared with 6.5 for rural inhabitants (see the box figure). Although the gap remains large (especially in terms of quality and reliability), and indeed, has widened, a surge in rural mobile phone access means that by mid-2007, tele-density in rural India was equal to the level recorded for urban areas in 1998. Older technologies, such as radio, television, bicycles, and motorized two-wheelers, tend to be more evenly diffused than newer ones, such as mobile phones, computers, and the Internet, given the longer time since the former were introduced.

The digital divide between rural and urban areas promises to narrow over the long term, particularly in high-income states and near major cities. However, in some states, in the more remote rural areas, and among tribal and other linguistic groups that lag behind in economic development, the gap may well increase over time.

Source: Mitra 2007.

Urban and rural teledensity (fixed and mobile), India, 1998–2007



Source: Telecommunications and Regulatory Authority of India.
a. Estimated.

any information technology revolution (Friedman 2007). The rise in China's index of diffusion of new technologies is almost double that of India, in part because the more technologically backward regions in China have made progress in closing the gap with the more technologically advanced regions on the coast (Jefferson, Rawski, and Zhang 2007).

The technology employed by firms within sectors in individual countries also exhibits tremendous variation. In India, most firms, especially small ones, tend to use low levels of technology, and only a few operate near the national technological frontier. In most sectors, productivity at the national technological frontier is about five times the mean level for all firms (Dutz 2007). For small formal enterprises, average productivity is even lower: about one-sixth of the level at the technological frontier for each sector and only one-eighth that of top local performers. Smaller informal enterprises are likely to be even less productive.

The skewed distribution of enterprise productivity implies potentially huge productivity and output increases are possible, if already existing within-country knowledge were to diffuse from top performers to the rest of the economy. Assuming that domestic competencies were available (or created) to efficiently use the technologies employed by enterprises at the national frontier, Indian GDP could be 4.8 times higher if those technologies were successfully applied by their less productive rivals. Similarly, in Brazil, the productivity of innovative firms with more than 10 employees, which account for 26 percent of total sales, is, on average, 6.5 times higher than that of similarly sized firms classified as weakly innovative (which account for 11 percent of sales, but 38 per percent of employment).

Conclusion

All told, the evidence reviewed in this chapter suggests that for most developing countries technological progress is mainly a process of adaptation and adoption of technologies from abroad rather than the creation of new-to-the-world technologies. The pace of technology dissemination across countries has picked up considerably over the past 100 years, and most technologies are available at some level in most countries, but the extent to which technologies are available differs enormously. Many developing countries made progress in closing the technology gap with advanced countries during the 1990s. However, despite more rapid improvement in technological achievement among the poorest countries, enormous gaps in technological achievement remain. Even upper-middle-income countries have less than one-third of the level of TFP of high-income OECD countries, and low-income countries have only 7 percent. The gap in TFP levels between high-income countries and Latin America and the Caribbean, the Middle East and North Africa, and Sub-Saharan Africa has widened since 1990. Moreover, the gap between major centers and lesser cities and rural economies remains large even in the most successful countries.

At the same time, income is not the only determinant of technological progress. Although innovation at the technological frontier (as measured by patents and scientific journal articles) drops off quite sharply as income levels decline across countries, considerable overlap among income groups exists in the extent of diffusion of old technologies. Thus the most advanced middle-income countries demonstrate greater technological achievement in old technologies than the least sophisticated high-income countries, while the more advanced low-income countries rate higher than the lowest-ranking middle-income countries.

The technological gap between high-income and developing countries is more pronounced for new technologies; however, many developing countries are acquiring new technologies at a more rapid pace than older technologies. Given that some new technologies, such as mobile phones and to some extent computers, are substitutes for old technologies, the rapid diffusion of new technologies holds promise for a substantial, widespread advance in technological achievement. This progress likely reflects several factors: the reduction of regulatory constraints on economic activity that has occurred over the past 15 years in many developing countries; the enabling of private sector investors, who are free of local government budget constraints), to take the lead in implanting many of these technologies; the growing incomes in developing countries that have improved the affordability of new technologies; and the improvements in the technological absorptive capacity of developing countries and the increased exposure to international technology through trade flows, FDI, and a growing international diaspora. This last issue is the subject of chapter 3.

Technical Annex: Construction of the summary indexes

The summary indexes, the overall index of technological achievement, and the technological adaptive capacity index reported in chapter 3 were calculated by aggregating some

34 separate variables, with the weights used in the aggregation calculated by principal components analysis (see below). This approach distinguishes these indexes from most of those reported in the literature, which even though they are based on similar underlying base data, use arbitrary weighting schemes with limited theoretical or empirical bases (see Archibugi and Coco 2005 for a review).

A number of existing measures of technological achievement or technological progress emphasize inputs into technological advancement (numbers of scientists and engineers, R&D expenditure, or levels of R&D personnel), including, in some cases, even more indirect inputs, such as the general level of education of the population and governance factors that facilitate the absorption of technology (see, for instance, UNCTAD 2005). Other measures focus on outputs, that is, on indicators of technological performance, such as the shares of high-tech industries in exports and in manufacturing value added (UNIDO 2002). Still others focus more on the mechanisms by which technological progress is achieved (Sagasti 2003) or technological learning occurs (Soubattina 2006). A noncomprehensive list of prominent technology indicators includes the following:

- The index of innovation capability is published by the United Nations Conference on Trade and Development (UNCTAD 2005) and consists of an unweighted average of an index of human capital (calculated as a weighted average of tertiary and secondary school enrollment rates and the literacy rate) and a technological activity index (calculated as an unweighted average of three indicators: R&D personnel, U.S. patents granted, and scientific publications, all per million population).
- The index of competitive industrial performance is published by the United Nations Industrial Development Organization (UNIDO 2002) and is calculated as a simple average of four basic indicators: manufacturing value added per capita, manufactured exports per capita, share of medium- and high-tech activities in manufacturing value added, and share of medium- and high-tech products in manufactured exports;
- The technology achievement index is published by the United Nations Development Programme (UNDP 2001) and combines (a) the indicators of human skills (mean years of schooling in the population age 15 and older and enrollment ratio for tertiary-level science programs); (b) the diffusion of old innovations (electricity consumption per capita and telephones per capita) and of recent innovations (Internet hosts per capita and high- and medium-tech exports as a share of all exports); and (c) the creation of technology (patents granted to residents per capita and receipts of royalties and license fees from abroad). The index is constructed as simple averages of these indicators within subgroups and then across groups.
- The national innovative capacity index (Porter and Stern 2003) focuses on government- and firm-level policies associated with successful innovation. It is composed of four subindexes: proportion of scientists and engineers in the population, innovation policy, innovation linkages and what they call the cluster innovation environment. The overall index is calculated as an unweighted sum of the four subindexes, but the weights assigned to each indicator in the subindexes are determined by the coefficients obtained from a regression of the number of U.S. Patent and Trademark Office patents on the relevant indicators controlling for total population, the proportion of scientists and engineers employed, and the stock of international patents generated by the country between 1985 and 1994.

Estimating weights for variables using principal components

All the measures discussed above assign essentially arbitrary weights to the different indicators included in the indexes, or in the case of regression analysis, use weights derived from specific assumptions about functional forms and the data generating process. This report has followed a statistical approach, principal components analysis, to weighting variables. This approach is widely used in health economics (Gwatkin and others 2000a, 2000b, 2000c; McKenzie 2003; Montgomery and others 2000; Yvas and Kumaranayake 2006) and in poverty analysis (Sricharoen and Buchenrieder 2005). It has also been used in regulatory policy analysis (Nicoletti, Scarpetta, and Boylaud 1999) and in construction of cross country measures of capital controls (Chinn and Ito 2006). Most recently in the technology field, it has been used in a government of India study of e-readiness (Government of India 2006). Principal components analysis permits the calculation of weights for each indicator included in the overall index in an objective manner, with the weights being determined by the data—not by subjective judgment.

Principal components analysis is a statistical technique for reducing the dimensionality of data, thereby summarizing the informational content in a large set of data by calculating orthogonal linear combinations of the original data series. Essentially, it is a procedure that helps to reduce the number of variables in the analysis by calculating combinations of the underlying series that contain most of the information in the larger data set. It involves an examination of the correlation matrix for the variables and the extraction of the principal components of the data obtained from the eigenvectors of the correlation matrix whose eigenvalues are largest.

Intuitively, the procedure followed here is akin to an unobserved variable problem. It is assumed that there is some unobserved variable called *T* (technology), and that this variable is correlated with a number of other variables (***X***), such as R&D expenditures, share of high-tech goods in total manufacturing, and so on. These correlated variables are grouped together into a single data set and the eigenvalues of its correlation matrix are examined to identify a limited number of linear combinations (principal components) of the originating data that explain most of the variance in the original data set (at the limit, if all the eigenvalues were used, all the variance would be explained).

The first principal component is the linear combination of the underlying data that accounts for the largest amount of variability in the sample, the second principal component is the one that accounts for the next largest amount of variance, and so on successively until all the variance is explained. All components are orthogonal to (uncorrelated with) each other; therefore each can be interpreted as an underlying force (visible in varying degrees in each original variable). By selecting the n eigenvectors that explain a large share of the total variance, the overall dimensionality of the data set can be reduced to n.

It is assumed that the main correlate in the underlying data reflects some form of technology and therefore that the principal components can be used as an index of technology. This is essentially the same process as taking a simple average of several indicators, but with the attached weights being determined by the data rather than being imposed by the researcher.

As a large set of indicators are used that reflects a wide array of country characteristics, more than one principal component is required to adequately capture the information in the overall data set. One approach would be to calculate each of these purely data-driven, but necessarily arbitrary, components and use them to calculate the overall index. An alternative approach that uses a multistage procedure and subdivides the data into groups that are economically or statistically highly correlated or both was adopted. A principal components analysis on these subgroups can be used to create a subindex for those variables, which can then be used in a second stage to calculate an overall summary index.

Two methodologies for determining the subgroups were employed. The first was based on an ex ante grouping of the indicators following an economic rationale, and the second consisted of an ex post grouping of indicators based on an analysis of the correlation matrix and a graphical analysis of component loadings to identify groups of indicators that are highly correlated with each other. Because the overall technological achievement indexes obtained by these two methodologies are very similar, with correlation coefficients of 0.99, the remainder of the discussion is limited to the results obtained from the ex ante grouping given its more straightforward economic interpretation.

Data preparation

To maximize the economic comparability of the underlying cross-county data, all data were scaled, that is, expressed as a percentage of population, a percentage of GDP, a percentage of exports or imports, or a percentage of arable land, as relevant. So researchers could minimize the influence of outliers and one-off events, the scaled data were averaged over two time periods for each country: 1990–93 and 2000–03.[25] All data were converted into an index bound between 0 and 1 by subtracting from each variable the minimum observed value in the sample (across countries and time periods) and dividing by the difference between the maximum value in the sample and the minimum value.[26] Hence the value for indicator *j* for country *i* and time *t* is given by

$$x_{ijt} = (X_{ijt} - Min\ X_j)\ (Max\ X_j - Min\ X_j)$$

Applying principal components analysis to technology

For the purposes of this study, 34 variables were identified that bore an ex ante relationship with technology and for which adequate country coverage existed over the 1990–2006 period to support the calculation of two indexes, one for the early 1990s and the second for the early 2000s. The variables related to technological achievement and their sources are reported in table A2.1 and those related to technological absorptive capacity are reported in table A2.2.

Table A2.1 Indicators used to calculate the summary indexes and overall index related to technological achievement

Scientific innovation and invention	
Scientific and technical journal articles by population	World Development Indicators
Patents granted by the United States Patent and Trademark Office by population	Lederman and Saenz 2005
Patents granted by the European Patent Office by population	Lederman and Saenz 2005
Penetration of older technologies	
Electrical Power Consumption kilowatt-hours/capita	World Development Indicators
International outgoing telephone traffic percent of GDP per 1,000 people	World Development Indicators
Main lines per 100 inhabitants	World Development Indicators
Air transport, registered carrier departures worldwide percent of GDP per 1,000 people	World Development Indicators
Agricultural machinery: tractors per 100 hectares of arable land	World Development Indicators
Exports of manufactures percent of merchandise exports	World Development Indicators
Medium-tech exports percent of total exports	CEPII BACI database
Penetration of recent technologies	
Internet users per 1,000 people	World Development Indicators
Personal computers per 1,000 people	World Development Indicators
Cellular subscribers per 100 inhabitants	World Development Indicators
Percentage of digital mainlines	World Development Indicators
High-tech exports percent of total exports	CEPII BACI database
Exposure to external technology	
FDI net inflows percentage of GDP	World Development Indicators
Royalties and license fee payments percent of GDP	World Development Indicators
Imports of high-tech goods percent of GDP	CEPII BACI database
Imports of capital goods percent of GDP	CEPII BACI database
Imports of intermediary goods percent of GDP	CEPII BACI database

Source: World Bank.
Note: BACI = Banque analytique de commerce internationale, CEPII = Centre d'Etudes Prospectives et d'Informations Internationales, EPO = European Patent Office, FDI = foreign direct investment, GDP = gross domestic product, USPTO = United States Patent and Trademark Office.

Table A2.2 Indicators used to calculate the summary indexes and overall index of technological absorptive capacity

Macroeconomic environment	
General government balance as percentage of GDP	IMF/WEO and World Bank
Annual CPI inflation rate	Thomson Datastream and World Bank
Real exchange rate volatilty	J.P. Morgan, IMF and World Bank
Financial structure and intermediation	
Liquid liabilities percent of GDP	Beck, Demirgüç-Kunt, and Levine 2000
Private credit percent of GDP	Beck, Demirgüç-Kunt, and Levine 2000
Financial system deposits percent of GDP	Beck, Demirgüç-Kunt, and Levine 2000
Human capital	
Primary educational attainment percent of population aged 15 and over	Barro and Lee 2000
Secondary educational attainment percent of population aged 15 and over	Barro and Lee 2000
Tertiary educational attainment percent of population aged 15 and over	Barro and Lee 2000
Governance	
Voice and accountability	Kaufmann, Kraay, and Mastruzzi 2007
Political stability	Kaufmann, Kraay, and Mastruzzi 2007
Government effectiveness	Kaufmann, Kraay, and Mastruzzi 2007
Regulatory quality	Kaufmann, Kraay, and Mastruzzi 2007
Rule of law	Kaufmann, Kraay, and Mastruzzi 2007
Control of corruption	Kaufmann, Kraay, and Mastruzzi 2007

Source: World Bank.

An initial analysis of the two data sets revealed the existence of two principal components that explained 10 percent or more of the overall variance and three eigenvalues that exceeded 1—a widely used rule of thumb for determining the underlying dimensionality of a data set—in each of the data sets being used (tables A2.3 and A2.4). Bartlett's test for sphericity confirms that the basic indicators are correlated for both indexes, which confirms the meaningfulness of applying principal components analysis to this data. The Chi-square statistics are 1,520.88 (p-value of 0.00) and 1,572.10 (p-value of 0.00), respectively. Those statistics indicate a strong rejection of the null hypothesis that variables are not correlated.

Subsequently, as outlined earlier, principal components analysis was performed on ex ante economically motivated subgroups of the data for each summary index. In most cases, the first principal component from these subgroupings explained more than 60 percent of the total

Table A2.3 Share of total variance explained by principal components, technological achievement index

Technological achievement index (2000–03)

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
1	9.91	0.52	0.52
2	3.59	0.19	0.71
3	1.49	0.08	0.79
4	0.92	0.05	0.84
5	0.85	0.04	0.88
⋮	⋮	⋮	⋮
19	0.00	0.00	1.00
Bartlett's test: Chi-sq (171)	1520.88 (p-value 0.00)		

Source: World Bank.

Table A2.4 Share of total variance explained by principal components, technological absorptive capacity index

Technological absorptive capacity index (2000–03)

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
1	8.76	0.58	0.58
2	1.95	0.13	0.71
3	1.27	0.09	0.80
4	0.89	0.06	0.86
5	0.66	0.04	0.90
⋮	⋮	⋮	⋮
15	0.01	0.00	1.00
Bartlett's test: Chi-sq (105)	1572.09 (p-value 0.00)		

Source: World Bank.

variance for the subgroup,[27] suggesting that it adequately summarized the information in the overall grouping (table A2.5). Bartlett's test for sphericity rejects the null hypothesis of no correlation between variables in all cases at the 1 percent level.

Indicators of the penetration of old technologies constitute a notable exception. When all seven indicators were included, two eigenvalues exceeded unity. In addition, while the first principal component explained 55 percent of the variance, the second component

Table A2.5 Share of total variance explained by principal components for each sub-group of indicators

Technological achievement index (2000–03)

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
Scientific invention and innovation			
1	1.49	0.75	0.75
2	0.51	0.25	1.00
Bartlett's test:	Chi-sq (1)	126.58 (*p*-value 0.00)	
Penetration of recent innovations			
1	3.28	0.66	0.66
2	0.92	0.18	0.84
3	0.57	0.11	0.95
4	0.19	0.04	0.99
5	0.05	0.01	1.00
Bartlett's test:	Chi-sq (10)	605.16 (*p*-value 0.00)	

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
Penetration of old innovations			
1	1.46	0.73	0.73
2	0.54	0.27	1.00
Bartlett's test:	Chi-sq (1)	26.32 (*p*-value 0.00)	
Exposure to external technology			
1	3.43	0.69	0.69
2	0.80	0.16	0.85
3	0.54	0.11	0.96
4	0.22	0.04	1.00
5	0.01	0.00	1.00
Bartlett's test:	Chi-sq (10)	250.32 (*p*-value 0.00)	

Technological absorptive capacity index (2000–03)

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
Human capital			
1	1.87	0.62	0.62
2	0.77	0.26	0.88
3	0.37	0.12	1.00
Bartlett's test:	Chi-sq (3)	47.16 (*p*-value 0.00)	
Governance			
1	5.30	0.88	0.88
2	0.33	0.05	0.93
3	0.23	0.04	0.97
4	0.09	0.02	0.99
5	0.03	0.01	1.00
6	0.02	0.00	1.00
Bartlett's test:	Chi-sq (15)	2077.61 (*p*-value 0.00)	

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
Macroeconomic environment			
1	2.36	0.79	0.79
2	0.55	0.18	0.97
3	0.09	0.03	1.00
Bartlett's test:	Chi-sq (3)	25.53 (*p*-value 0.00)	
Financial structure and intermediation			
1	2.69	0.90	0.90
2	0.30	0.09	0.99
3	0.02	0.01	1.00
Bartlett's test:	Chi-sq (3)	633.96 (*p*-value 0.00)	

Source: World Bank.

accounted for a non-negligible 22 percent of the variance. The group was therefore further divided into two subgroups: industrialization and penetration of other old innovations. For each subgroup only the first principal component presented an eigenvalue greater than 1 and accounted for more than 70 percent of the variance in both instances. Subsequently, another stage of principal component analysis was performed to calculate an aggregate subindex for the penetration of old innovations, and the results are presented in the table A2.9 on the following page.[28] The overall conclusions obtained do not change substantially when the two groups are entered separately into the overall technological achievement index (rather than combined into one subindex).[29]

As expected, the principal components analysis assigned each subindex unequal weights in the overall index. Table A2.6 summarizes the weights assigned to each indicator series in the summary subindex of technological achievement for each of the economic variables. Table A2.7 reports the same data for the components used to calculate the overall index of technological absorptive capacity.

In a second stage, we conducted a principal components analysis on the subindexes. In the case of the technological achievement and the technological absorptive capacity indexes, the first principal component explained 79 percent and 65 percent, respectively, of the overall variance (table A2.8), suggesting that the first eigenvector of the correlation matrix provided a satisfactory summary of the information included in each of the subindexes.

Table A2.6 Factor loadings and variable weights for technological achievement subgroups (2000–03)

	Factor loadings	Variable weights (%)
Scientific innovation and development		
Patents	0.7071	68.42
Scientific and technical articles	0.7071	31.58
Penetration of old innovations		
Industrialization	0.7071	67.43
Main telephone lines per 100 inhabitants	0.5815	30.82
Exports of manufactures	0.5597	42.67
Exports of medium-tech goods	0.5904	26.51
Other old innovations	0.7071	32.57
Electric power	0.4067	32.66
International telephone traffic	0.5137	21.00
Air transport	0.5396	20.06
Agricultural machinery	0.5288	26.28
Penetration of recent innovations		
Internet users	0.5282	25.45
Personal computers	0.5214	24.52
Cellular subscribers	0.5060	28.25
Percentage of digital mainlines	0.1846	6.39
Exports of high-tech goods	0.3987	15.40
Exposure to external technology		
Net FDI inflows	0.4969	28.55
Royalties and license fee payments	0.4384	16.35
Imports of high-tech goods	0.4624	17.59
Imports of capital goods	0.4914	28.20
Imports of intermediary goods	0.3248	9.30

Source: World Bank.
Note: FDI = foreign direct investment.

Table A2.7 Factor loadings and variable weights for technological absorptive capacity subgroups (2000–03)

	Factor loadings	Variable weights (%)
Human capital		
Primary educational attainment	0.4648	24.92
Secondary educational attainment	0.6153	39.27
Tertiary educational attainment	0.6367	35.82
Governance		
Voice and accountability	0.3918	19.14
Political stability	0.3760	15.42
Government effectiveness	0.4224	17.98
Regulatory quality	0.4140	11.85
Rule of law	0.4250	18.39
Control of corruption	0.4179	17.22
Macroeconomic stability		
General government balance	0.4990	28.95
Annual consumer price index inflation rate	0.6100	34.40
Real exchange rate volatility	0.6156	36.66
Financial structure and intermediation		
Liquid liabilities	0.5910	30.79
Private credit	0.5424	38.58
Financial system deposits	0.5971	30.63

Source: World Bank.

Table A2.8 Share of total variance explained by main principal components of technological achievement and technological absorptive capacity using the sub-indexes (2000–03)

Component	Eigenvalues	Share of variance explained	Cumulative share of variance explained
Technological achievement			
1	3.17	0.79	0.79
2	0.60	0.15	0.94
3	0.14	0.04	0.98
4	0.09	0.02	1.00
Bartlett's test: Chi-sq (6)	**332.49** (*p*-value 0.00)		
Technological absorptive capacity			
1	2.61	0.65	0.65
2	0.80	0.20	0.85
3	0.32	0.08	0.93
4	0.27	0.07	1.00
Bartlett's test: Chi-sq (6)	**138.31** (*p*-value 0.00)		

Source: World Bank.

Table A2.9 reports the implicit weights attached to each subindex in the two summary indexes.

A similar process was undertaken, with similar results, for the data from the 1990s. In calculating the percentage changes in each subindex and in the overall index, the factor loadings from the 2000s estimation procedure were used to ensure comparability of the data sets.

Table A2.9 Factor loadings and variable weights obtained from second-stage principal components analysis (2000–03)

	Scientific innovation and invention	Penetration of old innovations	Penetration of recent innovations	Exposure to external technology
Technological achievement				
Factor loadings	0.5272	0.5404	0.4409	0.4855
Subindex weights (%)	21.74	23.99	34.79	19.48
	Human capital	**Governance**	**Macroeconomic environment**	**Financial structure and intermediation**
Technological absorptive capacity				
Factor loadings	0.5392	0.5579	0.3493	0.5254
Subindex weights (%)	25.29	36.98	10.66	27.06

Source: World Bank.

Notes

1. TFP simply measures all influences on GDP growth other than increases in capital and labor. Thus changes in TFP could reflect changes in the composition of output (for example, a shift from agriculture to manufacturing), changes in the quality of labor or capital not reflected in the data (for example, education levels), or any other variable that is an important determinant of growth but whose influence is not explicitly accounted for in growth equations.

2. See http://www.itto.or.jp/live/PageDisplayHandler?pageId=217&id=280.

3. See, for example, Haskel and Slaughter (2002) and Krugman (2000). The rise in the global supply of goods produced by unskilled and semiskilled labor, and the influx of low-skilled immigrants, are also cited as contributing to earnings inequality in high-income countries.

4. This is an important conclusion of *Global Economic Prospects 2007*. Although intercountry inequality (where each country is accorded equal weight) has worsened, weighting country observations by population shows an improvement in income distribution. Taking into account within-country inequality, global inequality has remained roughly constant since the late 1980s.

5. Anecdotal evidence indicates that access to mobile phones improved returns to producers at the

expense of middlemen for fishermen in Porto da Manga, Brazil, and Moree, Ghana, and for farmers in a wholesale market in Sri Lanka (de Silva and Zainudeen 2007). The advent of the Internet and automated teller machines had a similar effect in the United States, overcoming the anticompetitive effects of state banking regulation and strong lobbying in state legislatures.

6. The focus on patents and scientific publications reflects academic research on technology. Patents have the advantage of being more clearly associated with processes rather than products (by definition, a patent is not granted on a product, but rather on the method by which it is produced). The disadvantage is that patents exclude a number of important forms of innovation, notably software (until recently) and processes for managing multinational production and distribution networks.

7. The definition of a high-tech export used here includes products with high R&D intensity, such as aerospace-related items, computers, pharmaceuticals, scientific instruments, and electrical machinery. As such, it excludes a number of services such as software engineering that may, by their nature, be even more technologically intensive.

8. For example, the correlation coefficient of the share of high-tech exports in total foreign sales with adult literacy was 43 percent in 2005 and with expected years of schooling was 22 percent.

9. Regional and income group data in table 2.7 are weighted averages of individual countries, with the weights given by their populations. The simple averages cited in the text give equal weight to every country independent of the size of its population.

10. The core technology for the Internet can trace its history back to the early 1960s and a network developed by the U.S. Defense Department's Advanced Research Projects Agency. However, the Internet as it is understood by most people today—the World Wide Web and HTML web pages—was first introduced in the early 1990s, with the first web browser, Mosaic, being released in 1993.

11. According to the Cellular Operators Association of India, the country had more than 121 million subscribers in March 2007.

12. For example, South Africa is beginning to attract companies for business process outsourcing. One British executive (Ranger 2006) noted that his U.K. customers were more comfortable with the South African accent than with the Indian accent and cited the advantages of working at similar times as the parent company.

13. A 2005 report from Gartner Inc. stated that India had captured 80 to 90 percent of total offshore outsourcing revenue (Tucci 2005).

14. The scores in large countries may be biased, better reflecting the scores in coastal trading cities and less the score in the interior. Thus the Russian Federation's weak overall score in comparison with China's may be explained by the relative absence of large port cities close to major Russian manufacturing centers, whereas in China, port cities and manufacturing centers tend to be in close proximity.

15. Principal components analysis involves examining the eigenvectors of the correlation matrix of a set of related data and extracting from it a weighting scheme that describes as much of the information contained within the data set as possible using a minimum number of orthogonal linear combinations of the original data. By construction, a data set that consists of 100 series will have 100 of these eigenvectors that fully describe all the information in the data set. However, the first five of these eigenvectors (five different linear combinations of the initial 100 series) may describe 90 percent of the total variance. In such a case, principal components analysis would involve calculating an overall index based on these five subindexes. In a two- or three-stage procedure such as the one used here, the data are divided into subgroups either based on the ex ante characteristics of the subindexes or on the basis of statistical correlations. Then a separate principal components analysis is done on each of these subindexes, which are subsequently combined in a second or third round to determine the overall index.

16. To minimize the influences of outliers, the component indicators of the subindexes for each time period are calculated as the four-year average of values for the period 1990–93 and 2000–03. To maximize country coverage, missing data are gap-filled by using more recent or older data generally from within the analytical period. For the transition economies of the former Soviet bloc, data as recent as 1995 are used for the early 1990s data point in cases where data do not exist or are unreliable.

17. The relationship between income and technological achievement is complex. The level of income affects the ability to gain access to technology, while the level of technology helps to determine income levels (see the earlier section on "The role of technology in development").

18. Low-income countries included in the first index are Bangladesh, Benin, Côte d'Ivoire, Ethiopia, Ghana, India, Kenya, the Kyrgyz Republic, Mozambique, Nepal, Nigeria, Pakistan, Senegal, Sudan, Tanzania, Togo, Vietnam, the Republic of Yemen, Zambia, and Zimbabwe. The second index includes all of these except Nepal, Vietnam, the Republic of Yemen, and Zimbabwe.

19. The penetration of new technologies during 1990–2000 increased by 102 percent in high-income OECD countries, 256 percent in upper-middle-income

countries, 219 percent in lower-middle-income countries, and 123 percent in low-income countries.

20. For low-income countries, the number of Internet users per 1,000 people rose by 172 percent between 1999 and 2005, the number of secure Internet servers per 1 million people increased by almost 30 percent a year between 2004 to 2006, and the number of mobile phone subscribers per 1,000 people rose by 92 percent between 1995 and 2005 (World Bank 2007d).

21. Measurements of the extent of diffusion differ by technology, but generally involve available statistics on technology flows per country scaled by income or population, whichever is more appropriate. For example, the diffusion of electricity is measured by kilowatt hours consumed per person and the diffusion of railroads is measured by tonnage moved divided by gross national product.

22. Of the 699 country-technology pairs related to developing countries, 216 refer to a technology that was first recorded in the 19th century, 318 date from the first half of the 20th century, 98 come from the third quarter of the 20th century, and 67 from the final quarter of the 20th century.

23. The data set includes an estimate of the date of discovery for each technology.

24. That is, there are country-technology pairs, not considered in this analysis, that have reached the 5 percent level but are taking a long time to reach the 25 percent level.

25. When missing data issues occurred over this time period, the earliest available observation for a given indicator in the period from 1988–96 and 1998–2006 was used so as to expand country coverage. The budget balance indicators and the real exchange rate volatility indicators were averaged over the periods 1990–96 and 2000–06 to purge out cyclical effects. The real exchange rate volatility series is the yearly average of the absolute value of monthly change in the real effective exchange rate.

26. For this operation the authors used a combined data set including observations from both the 1990s and 2000s to ensure that data for each period had the same underlying scaling.

27. Frequently more than 70 percent of the variance was explained by the first principal component.

28. A data-driven grouping of indicators was also conducted and used to generate a two-step index similar to the one reported in the main text. As the indexes derived from this procedure did not differ materially from the one reported here, they are not reported.

29. Furthermore, results for the overall technological achievement index remain unchanged when the entire old innovations indicator group is included, that is, when no division into subgroups is made and the second principal component is ignored.

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