PART II

Aligning data governance with the social contract

Data infrastructure policy: Ensuring equitable access for poor people and poor countries

Main messages

1. As new mobile technologies emerge, policy makers should proactively facilitate their rollout by promoting service competition, where possible, and infrastructure sharing, where necessary.

2. Universal service policies should incorporate measures designed to ease the demand-side barriers often faced by those who do not seek data services even when they are locally available. These measures include programs to improve the affordability of handsets and data services, while enhancing the digital literacy of excluded groups.

3. To ensure high-speed, cost-effective data services, policy makers should facilitate development of domestic data infrastructure that allows local storage, processing, and exchange of data so that data need not travel through distant overseas facilities.

4. A competitive market and open governance arrangements are two policies that support the creation of internet exchange points. Establishment of colocation data centers will depend on a stable investment climate for private sector investors, combined with the availability of low-cost reliable sources of clean energy.

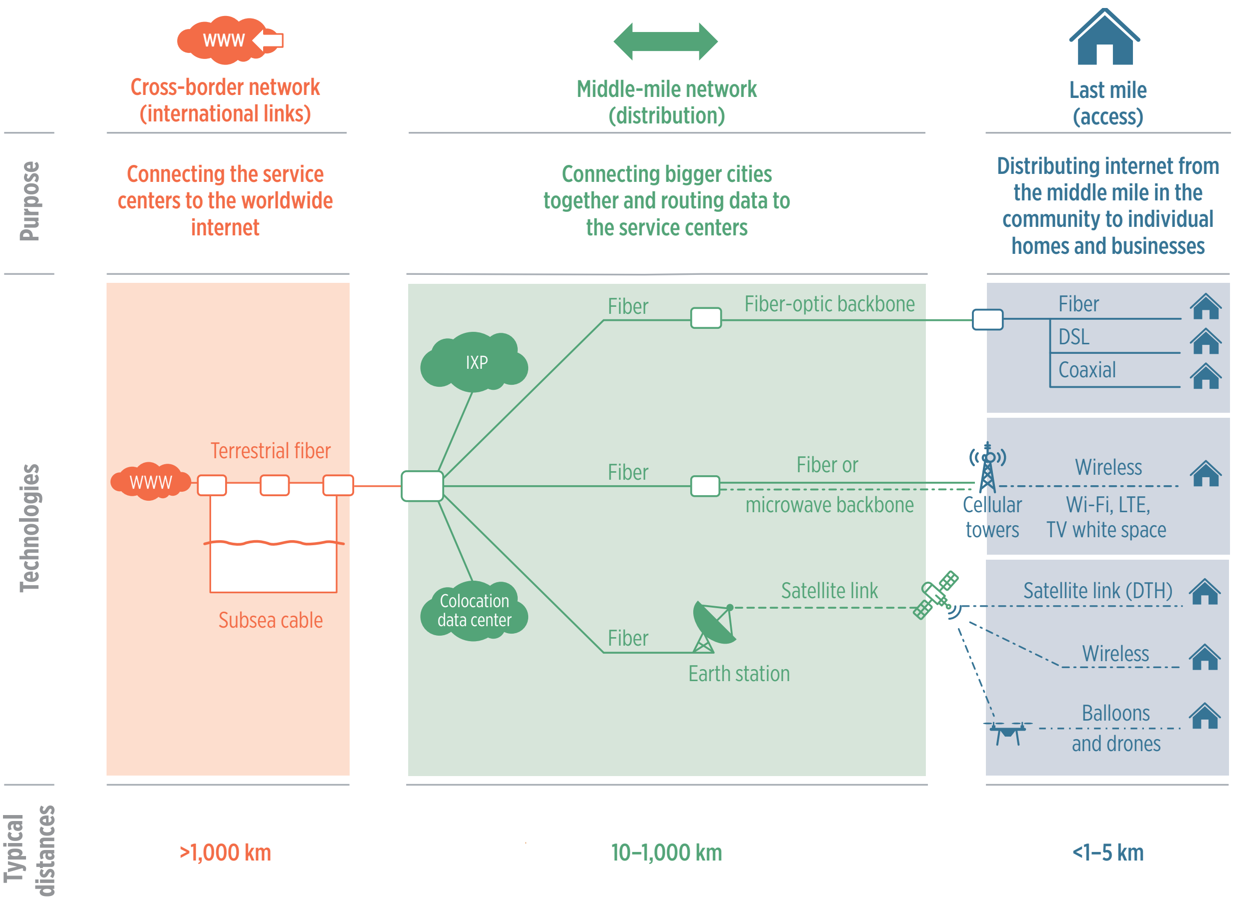
Data infrastructure as a source of inequity

Infrastructure is a prerequisite for collecting, exchanging, storing, processing, and distributing modern data because of its digital character. Harnessing the full economic and social value of modern data services calls for digital infrastructure that is universally accessible, while also offering adequate internet speed at affordable cost. Yet the developing world is lagging behind, with major gaps between rich and poor people on broadband connectivity, and a substantial divide emerging between rich and poor countries in the availability of data infrastructure. Well-designed infrastructure policies are needed to redress these adverse trends.

Concerns about inequities in access to data infrastructure stem from growing evidence of a link with economic activity. Numerous studies have found that broadband infrastructure boosts economic growth,[1] increasing productivity[2] and employment[3] while enabling digital enterprises. For example, the arrival of fiber-optic submarine cables in Africa has had positive effects on employment from the entry of new firms, greater productivity, and higher exports.[4] More broadly, a 10 percent increase in data centers results in an expansion of exports in data-related services of about 1.6 percent.[5] As a growing share of economic activity becomes data-enabled, it is important to ensure that poor people and poor countries are not excluded from such opportunities by the absence of suitable data infrastructure.

Data infrastructure forms a supply chain that originates in global data storage centers and data processing facilities known as cloud computing platforms (figure 5.1). From there, data pass through

Figure 5.1 The data infrastructure supply chain



Source: Adapted from World Bank (2019c).

Note: DSL = digital subscriber line; DTH = direct-to-home; IXP = internet exchange point; km = kilometers; LTE = Long-Term Evolution; WWW = World Wide Web (internet).

internet exchange points (IXPs) for transfer to users. Data then flow in and out of countries through an intercontinental network of submarine cables. Once on domestic soil, data are distributed through national fiber-optic and microwave backbone networks until they reach a proximate location for distribution to local communities, whether through wired connections, or wireless signals provided by mobile (or cellular) networks. Finally, data are exchanged with individuals, businesses, and public institutions through *fixed* lines or *wireless* signals from cellular towers**,** and increasingly with inanimate machines, cameras, and sensors connected to what is known as the Internet of Things (IoT). Data travel thousands of kilometers along this seamless infrastructure supply chain at breathtaking speeds of 200,000 kilometers per second—meaning that digital data can, in principle, circle the globe five times within a second.[6]

Data traffic is growing rapidly around the world. Internet data usage rose from 4.6 to 13 gigabytes per person per month between 2012 and 2017.[7] Four trends are driving the explosion in data traffic. First, the number of internet users is growing. More than half of the world's population is now online, up from less than one-third in 2010, and that share is forecast to reach two-thirds by 2023. Second, the number of connected devices on the IoT already exceeds the number of human users and is forecast to reach 25 billion by 2025 with the diffusion of 5G technology.[8] Third, internet speeds are continually increasing, which supports growing data volumes. By 2023 the speed of broadband service provided over fixed networks is expected to double from 2018 levels,[9] even as the speed of broadband service provided over fixed networks triples. Fourth, video accounts for three-fifths of internet traffic, and associated quality improvements are increasing video data traffic.[10] A two-hour movie in standard definition uses 1.4 gigabytes of data, whereas ultra-high definition uses 18 gigabytes.[11]

Although most data traffic is still carried over fixed networks, data traffic carried over wireless networks is forecast to rise to more than 20 percent of the global total by 2022, up from only 3 percent in 2012. This shift is driven by the greater prevalence of mobile traffic in emerging nations, with China and India alone accounting for more than 40 percent of the world's mobile data traffic as of 2018.

Both poor *people* and poor *countries* face fundamental inequities in their ability to access data infrastructure. To participate in the data-driven economy, *people* require internet connectivity. It entails both access to last-mile internet infrastructure—increasingly provided through a wireless signal—and ownership of a data-enabled mobile handset (also known as a smartphone)—or alternatively a full-blown fixed line connection. Such connectivity makes it possible for people to both have access to data about other people (and increasingly other things) and provide their own data to others. Large swathes of the population remain excluded from the internet, particularly the poor, the uneducated, the elderly, those living in rural areas, and—in some parts of the world—women. This complex situation reflects both the supply-side challenges entailed in rolling out coverage of the latest mobile technologies and the demand-side barriers preventing potential users from taking up the service even when it becomes available. Moreover, because of the growing volumes of data underpinning economic and social activity, connectivity is meaningful only if it can be provided at affordable cost and adequate speed.

Unless *countries* have access to modern data infrastructure, connectivity (even when available) will remain prohibitively expensive and slow. Such infrastructure begins with adequate international bandwidth to permit fluid and unconstrained access to the global internet commons. As traffic grows, local IXPs are needed to prevent domestic data transfers from being diverted across vast distances overseas. The addition of domestic colocation data centers—wholesale storage facilities that host other companies' data—allows substantial volumes of popular overseas content to be stored locally, further improving internet performance. It may also permit direct access to cloud computing platforms, greatly enhancing data processing capabilities. Although almost all countries now enjoy access to global internet submarine cables through either direct coastal access points or cross-border land connections, domestic data infrastructure—such as IXPs, colocation data centers, and cloud computing platforms—remain nascent across low- and middle-income nations, leaving them to contend with low internet speeds and high data charges.

This chapter unpacks the underlying issues that explain the data inequities faced by poor people and poor countries, with an emphasis on identifying appropriate policy responses. The chapter updates, complements, and extends the earlier treatment of related issues in *World Development Report 2016: Digital Dividends*. For this reason, coverage of supply-side issues is on a relatively high level, whereas the demand-side barriers, as well as the emerging challenges posed by development of domestic data infrastructure, receive more attention.

Connecting poor people

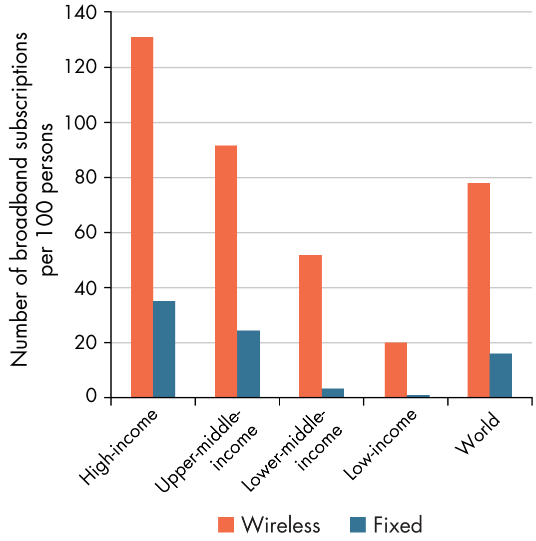
Many individuals in low- and middle-income nations use basic cellphones for applications such as text messaging and mobile money. These applications have had tremendous development impacts, even without using much data or requiring broadband internet access.[12] Beyond such basic telephony applications, access to broadband internet, in combination with ownership of a feature phone or smartphone, greatly enriches an individual's ability to use data for a better life. Social media connect family and friends; online government services and shopping websites save individuals time and money; online learning and telemedicine provide new, accessible, and inexpensive ways of delivering education and health. The COVID-19 pandemic is reinforcing the importance of access to broadband internet for remote learning and home working, as well as improving the overall resilience of economies to shocks of various kinds (see spotlight 5.1).

In the context of low- and middle-income countries, wireless broadband networks have emerged as the most relevant technology for accessing data services. The impacts of wireless broadband are greater than those of wired broadband in these nations,[13] particularly because the expansion of fixed broadband is relatively limited and has yet to reach the minimum threshold to have a statistically significant effect on economic growth.[14] Even in upper-middle-and high-income nations, where fixed broadband is more prevalent users spend most of their time online on mobile phones. Among the poorest in these countries, many only use wireless networks to access the internet (figure 5.2).[15]

The world's political commitment to universal access for internet was most recently articulated in a 2019 report of the United Nations Broadband Commission for Sustainable Development, which calls for 75 percent access to broadband worldwide by 2025—65 percent in developing economies and 35 percent in least developed countries.[16] The United Nations also encourages all countries to adopt by 2025 a national plan for universal access to broadband. These targets reflect a reappraisal by the international community following the failure to reach Sustainable Development Goal (SDG) 9, Target 9.c, which called for "universal and affordable access to the internet in least developed countries by 2020."[17]

From an economic standpoint, public policy support for universal coverage of telecommunications and data services has hinged on positive network externalities. In other words, the economic value

Figure 5.2 The developing world overwhelmingly accesses data using wireless networks



Source: WDR 2021 team, based on data from International Telecommunication Union, Statistics (database), https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx. Data at http://bit.do/WDR2021-Fig-5_2.

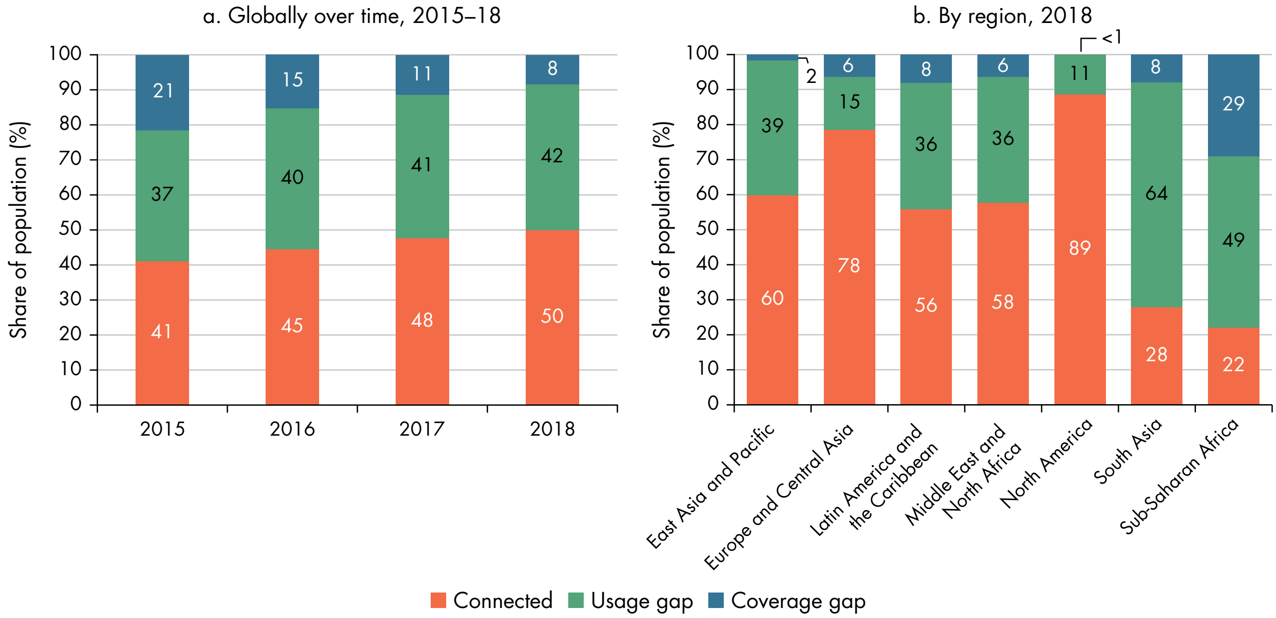
Note: Data are for 2019.

of communications infrastructure rises as more members of a society are connected because such growth exponentially increases the number of pairs of people who can communicate with each other.[18] Such positive externalities have underpinned the case for providing public subsidies to ensure that universal access can be achieved. Furthermore, as the internet becomes the central platform for much of social and economic life, providing all citizens with an opportunity to access this platform is increasingly a matter of social inclusion.

The shortfall of digital connectivity in the developing world can be understood in terms of three different types of gaps. The *coverage gap* refers to the fact that last-mile digital infrastructure has yet to reach all inhabited locales. The *usage gap* refers to the fact that, even when coverage becomes available, uptake of the service by the affected population will typically not be universal. The *consumption gap* refers to the fact that, even when people do take up the service, data consumption is typically too low to support basic economic and social functions. The discussion that follows focuses primarily on people, but small firms face many of the same barriers.

Although all but 8 percent of the world's population is covered by a wireless broadband network (figure 5.3, panel a), this overall figure hides significant

Figure 5.3 Gaps in 3G wireless broadband internet coverage have been shrinking, but usage gaps remain stubbornly high



Sources: WDR 2021 team, based on 2015 and 2018 data in ITU (2018a). Data at http://bit.do/WDR2021-Fig-5_3.

regional differences (figure 5.3, panel b). The *coverage gap* is less than 1 percent in North America, but as high as 29 percent in Sub-Saharan Africa. The *usage gap* encompassed 42 percent of the world's population in 2018, but as much as 64 percent of the population of South Asia, where more than 1 billion people are covered by a broadband signal without making use of the internet. Although the 3G coverage gap has shrunk by more than half over the last five years thanks to successful rollout of last-mile infrastructure on the supply side, the usage gap has remained remarkably stable, indicating the persistence of barriers on the demand side. Indeed, as of 2018 more than four in five of the unserved persons worldwide lived in areas where 3G signal coverage was already available.

Ultimately, the three gaps are interrelated because improving service uptake and data consumption also contribute to commercial viability, increasing the revenues generated by any particular investment in network coverage. Thus progress on closing the usage gap and narrowing the consumption gap will further help eliminate the coverage gap.

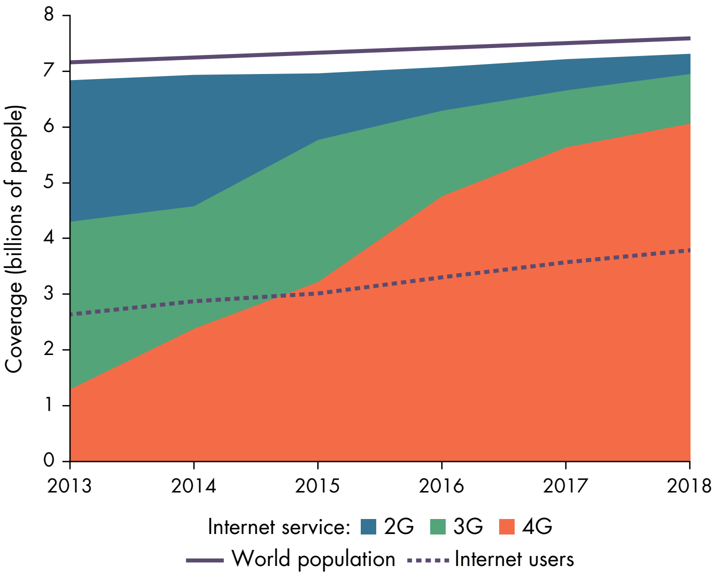
Closing the coverage gap

In 2018 more than 600 million people lived without access to the internet, a far cry from the United Nations' SDG target of universal and affordable access to the internet by 2020.[19] Most of those who are unconnected live in lower-income nations. Estimates suggest that achieving universal broadband internet access by 2030 will require an investment of approximately US$100 billion in Africa alone.[20]

The coverage gap is typically reported relative to 3G technology, which delivers speeds of 42 megabytes per second, making it the first generation able to support data-rich smartphone applications. However, rapid innovation in the mobile communications sector leads to a new generation of technology just about every decade, ushering in substantial improvements in speed and bandwidth and making universal coverage something of a moving target. In fact, 4G technology, offering speeds of 400 megabytes per second, is already widely available in the developing world (figure 5.4). If 4G were used as the relevant technological benchmark, the coverage gap would rise from 8 percent to 20 percent in 2018, and the problem of access would no longer be confined solely to Sub-Saharan Africa.

In 2019 5G technology became commercially available in 23 high-income economies and China, with a global coverage gap of 95 percent by the end of the first year. The new 5G technology is revolutionary because of both its exceptionally high speed of 1,000 megabytes per second, as well as its greatly enhanced

Figure 5.4 Globally, the coverage of wireless technologies reflects their constant upgrading



Source: WDR 2021 team, based on data in ITU (2018a). Data at http://bit.do/WDR2021-Fig-5_4.

capacity to transmit a large amount of sensor-based data from the IoT in near real time, offering numerous applications across different economic sectors. Forecasts suggest that one-third of mobile subscriptions could be 5G by 2025.[21]

This Report finds that under current conditions, 5G stand-alone technology (that is, technology not dependent on 4G for signaling) does not seem to be broadly viable across low- and middle-income countries, outside of major urban areas. However, developing 5G non–stand-alone technology as an incremental evolution of 4G greatly improves its viability. It could then become a cost-effective technology for meeting population coverage in densely populated middle-income countries once data traffic grows to the point that large numbers of users are demanding many gigabytes of data per month.[22] Viability could also be greatly improved by adopting regulations that promote sharing of infrastructure and policies that limit the burden of taxes and spectrum license fees on investors.[23]

Past investments in fiber-optic backbone networks and cellular towers (under 3G) have had a significant impact on the viability of the newer wireless technologies (such as 4G and 5G). Countries at an earlier stage of infrastructure development will find it challenging to leapfrog ahead, but for others investments in the fiber-optic backbone will continue to provide payoffs as countries upgrade to more advanced technologies.

The coverage gap reflects the lack of commercial viability associated with serving remote populations in the absence of any government intervention. Closing this gap calls for concerted efforts to drive down the cost of service provision, as well as better design of government policies on universal service access. Among the main policy measures to cut costs are those aimed at strengthening competition in the sector, enabling the sharing of infrastructure, improving the availability and affordability of the wireless spectrum, and exploiting new technologies.

Reducing retail costs. Individuals' access to reliable high-speed data services depends on both extensive last-mile coverage and proximity to the national fiber-optic backbone infrastructure. Limited retail competition can lead to high profit margins inflating charges to customers for last-mile access.[24] In addition, costs may be relatively high due to limited electricity coverage in outlying areas, forcing operators to rely on their own higher-cost diesel power generation for base stations instead of being able to draw energy from the public grid.[25] Meanwhile, recent innovations in wireless cellular technologies may reduce the cost of last-mile rollout. For example, in Japan Rakuten recently achieved 40 percent reductions in the cost of traditional cellular networks through migration to a cloud-based, software-driven environment.[26]

Introducing fiber-optic backbone competition. The greater the proximity of users to backbone infrastructure, the stronger are the mobile signals and the faster the data download speeds. In Africa, 45 percent of the population lives more than 10 kilometers away from fiber-optic network infrastructure—more than in any other region.[27] Relative to microwave links, fiber-optic backbones offer greater carrying capacity at higher speeds. Yet many countries in Africa still need to upgrade from microwave to fiber-optic technology—an estimated 250,000 kilometers of fiber-optic cable are needed across the continent.[28] Deployment of fiber-optic cable can cost as much as US$70,000 per kilometer[29]—a high entry barrier for building national fiber-optic backbones.

As a result, competition is often limited, and, in the absence of regulation, high wholesale prices and limited network development may result. Lack of competition is further exacerbated when backbone infrastructure operators are vertically integrated, providing both wholesale and retail services.[30] In the absence of robust competition, some countries have opted for state-owned backbone development, based on vendor financing, but this approach crowds out private investment and unnecessarily adds to the public debt. A competitive backbone market may be a

preferable alternative policy, with government taking on a coordinating role, inviting multiple operators to participate, enforcing open access and cost-based pricing, and offering incentives to existing or new operators to invest in less lucrative areas to complete the infrastructure backbone.

Enabling sharing of infrastructure. Another way to increase coverage by keeping costs down is to create a regulatory environment that facilitates the sharing of infrastructure both across sectors and within digital infrastructure markets.[31] The cost of broadband transmission and core network deployment can be reduced by using existing railway lines, power transmission grids, and pipelines, or by coordinating with road construction to lay ducts along highways. In emerging markets, and particularly in the poorest countries where demand may be thin and infrastructure costs and the associated risks relatively high, operators could be allowed to share backhaul infrastructure (such as fiber-optic cable) or local facilities (such as communication towers). Sharing of infrastructure has great potential to accelerate digital connectivity. Recent estimates suggest that the cost of deploying 5G mobile network technology could be reduced by more than 40 percent by sharing antenna sites.[32] However, the tensions between promoting competition and enabling cooperation in the market for digital infrastructure must be carefully balanced, with cooperation encouraged only in market segments that cannot efficiently support more than one operator.

Improving the availability and affordability of the spectrum. Making adequate spectrum available at relatively low cost is important for reducing coverage gaps. A low-frequency spectrum is attractive for rural areas because it provides wider coverage, requiring a lower density of cellular towers to cover a given area and reducing investment costs. Governments have often delayed the migration from analog to digital television, which releases coveted low-frequency spectrum for wireless broadband use. Some governments auction frequencies with elevated reserve prices that raise investment costs and are then passed on to users through higher prices. For example, in Senegal operators boycotted the 4G spectrum auction because of the high reserve price—CFAF 30 billion (US$49.86 million).[33] Other governments charge recurring fees for the use of spectrum, raising the cost of deploying infrastructure in rural areas.

Exploiting new technologies. Emerging niche technologies—such as TV white space (TVWS), hot air balloons, and low-orbit satellites—promise to significantly reduce last-mile deployment costs in remote areas, although many have yet to scale up commercially. TVWS uses the buffer frequencies between TV channels to provide broadband internet access. It is already being used successfully in Colombia to connect rural schools and coffee plantations in geographically challenging locations such as mountainous rainforests.[34] Two innovative solutions that have been proposed to reach remote rural areas are high-altitude platform station (HAPS) systems, which use a network of hot air balloons to provide unserved locations with connectivity,[35] and low-Earth orbiting (LEO) satellites. Iridium—which in 1998 became the first LEO to launch—today has slightly more than 1 million subscribers, mainly in niche markets such as the maritime aviation sectors and emergency services, as well as oil and gas.[36] Yet neither HAPS nor LEO satellites have proved they can provide direct consumer broadband access in rural areas on a sustainable basis at an affordable price.

Reforming universal service funds. Adopting these approaches to driving down costs can substantially expand the coverage attainable on a commercially viable basis. Nonetheless, some remote pockets will not reach universal access without some form of state support. Many countries have created universal service funds to harness public resources to subsidize infrastructure rollout in unserved areas. These funds are typically financed by obligatory levies charged on operators. However, for a variety of reasons many of these funds have proven to be unsuccessful (Kenya is one of the few exceptions in Africa).[37] Funds often suffer from poor design, lack of spatial planning to guide fund allocations, a mismatch between funds collected and disbursed, political interference, and failure to incorporate sustainability factors such as training and education, maintenance, and energy supply.[38] For example, in Africa more than US$400 million worth of universal service funds have not been disbursed.[39] A study of countries with universal service funds in the Asia-Pacific region found that they did not experience higher internet growth than countries without funds—except Malaysia and Pakistan, where the funds were transparent, efficient, and targeted extension of the national fiber-optic backbones.[40]

Tackling the usage gap

Of the 3.8 billion people not using the internet in 2018, 3.1 billion lived within range of a wireless broadband signal.[41] Government efforts to provide universal service access have traditionally focused on eliminating the coverage gap through rolling out the supply of infrastructure, but such policies should increasingly be oriented toward addressing the demand-side barriers that limit service uptake, thereby creating such a sizable usage gap.

Targeting the most critical underserved segments. Although traditional universal service policies have largely focused on directing public support to underserved rural *communities*, there is considerable scope to target demand-side policy measures to particular categories of under-served *individuals* irrespective of their location. A suite of large sample household surveys conducted in 22 developing countries in 2017/18 reveal that people who do not connect to broadband service even when it is available are significantly more likely to be poor (in the bottom 40 percent of the national income distribution), less educated (having only a primary education), elderly (over 50 years old), and female.[42] Of these, the largest effect is associated with education: completion of primary education adds 35 percentage points to the likelihood of internet uptake.

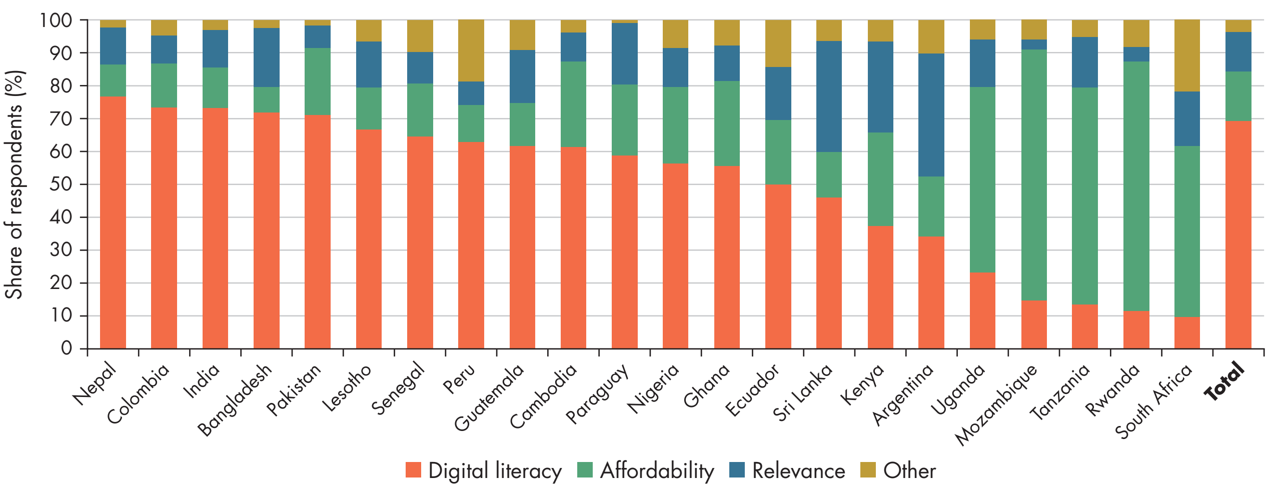
Also noteworthy is the significant gender digital divide. Globally, some 250 million fewer women than men use the internet. In low-income countries, only one in seven women is online, compared with one in five men.[43] Women are somewhat more likely than men to be challenged by digital literacy issues and to face additional obstacles to being online. For example, in many countries lack of family approval for women owning a cellphone is a major barrier.[44]

Broadly, three reasons have been put forward to explain the usage gap in low- and middle-income countries. First, people find it difficult to afford a mobile device or data services. Second, they lack the digital literacy needed to use the internet.[45] Or, third, they do not see internet services offering any content or application of relevance to their lives. The household surveys conducted in 22 developing countries in 2017/18 found that the reasons most frequently cited by people for not taking up data services are related to digital literacy (69 percent), followed by affordability concerns (15 percent) and relevance issues (12 percent)—see figure 5.5.[46] Digital literacy limitations appear to dominate in South Asia, whereas affordability concerns are more prominent in some African countries. These different constraints are not, however, mutually exclusive. A person who becomes digitally literate and therefore more motivated to access the internet may then face affordability challenges not relevant before.

Individuals are also attracted to using the internet when family members or friends do so, particularly when it comes to social media. Analysis conducted for this Report found that social network effects have a significant positive impact on the usage of wireless internet in low- and middle-income countries. Individuals whose five closest friends are using an online social network are 63 percent more likely to use the internet than those whose closest friends are not already active on social media.[47]

Addressing the widespread problem of digital literacy. In the 2017/18 household surveys, digital literacy was the most fundamental reason given for not using the internet. More than 84 percent of those surveyed who

Figure 5.5 In low- and middle-income countries, nearly 70 percent of those who do not use the internet are held back by deficiencies in digital literacy



Source: Chen 2021. Data at http://bit.do/WDR2021-Fig-5_5.

Note: Respondents to the survey conducted for this Report had access to internet service. Responses to the digital literacy category included "Do not know what internet is" and "Do not know how to use internet." Responses to the affordability category included "No access device" and "Too expensive." Responses to the relevance category included "No interest/not useful" and "No relevant content in local language."

were either uneducated or had completed only a primary school education stated they "do not know what internet is" or "do not know how to use internet."[48]

Various initiatives are under way to teach basic digital skills. Mobile industry association GSMA has developed a Mobile Internet Skills Training Toolkit based on a "train the trainers" approach.[49] Results from a pilot project in Bangladesh found that mobile internet usage among the beneficiary group more than tripled, with 19 percent of group members becoming regular mobile data users.[50] In early 2017, the Rwandan government launched the Digital Ambassadors Program, which trained 5,000 youth posted to all 30 districts in the country to provide digital skills training to 5 million Rwandans over a four-year period.[51] Field studies conducted in Burkina Faso, Mali, Senegal, and Tanzania found that audio and icon-based interfaces and a stripped-down version of the internet ("internet lite") helped students overcome their digital literacy limitations.[52] Despite these examples, there is little evidence that digital literacy programs are operating at the scale needed to significantly improve the uptake of data services, or that they are being suitably integrated with efforts to address the more fundamental underlying problem of basic literacy.

Once people become digitally literate, a key determinant of using the internet is availability of local language content.[53] Social media usage grows rapidly as the relevant apps become available in local languages much sooner than internet content.[54]

Making digital devices more affordable. Poor people wishing to avail themselves of internet access must first be able to afford a mobile device. However, according to one study, the cost of even an entry-level device exceeds 20 percent of the monthly income in more than half of low- and middle-income nations.[55] Another study found that the cost of a low-end US$42 smartphone is more than 80 percent of the monthly income in low-income countries.[56]

Efforts are under way to make entry-level internet devices more affordable. Mobile operators are creating partnerships to obtain inexpensive handsets or are bundling mobile phones with subscriptions. Pan-African operator MTN collaborated with China Mobile to launch a US$20 smartphone targeted at 10 million first-time users.[57] In India, Jio offers an internet-enabled phone for Rs 699 (US$9.21), provided the customer spends at least Rs 1,500 (US$19.77) a year on service charges.[58] Although most branded phones are manufactured in East Asia, several countries have created reassembly plants to manufacture inexpensive mobile phones locally. In Ethiopia, a Chinese company is assembling about 1 million phones a year for export throughout the region.[59] In Costa Rica and Malaysia, universal service funds have been used to subsidize internet devices for low-income users.[60]

Taxes, import duties, and other fees also affect device affordability. Despite the low purchasing power of their populations, low-income countries on average impose the highest customs duties on mobile phones, adding 7 percent to prices on average. One study found that several mainly low- and middle-income countries applied handset excise taxes (beyond the regular sales tax) and activation fees.[61] Ownership is also affected by substantial gender gaps in low- and middle-income countries; the share of men owning mobile devices is 20 percentage points higher than the share of women.[62]

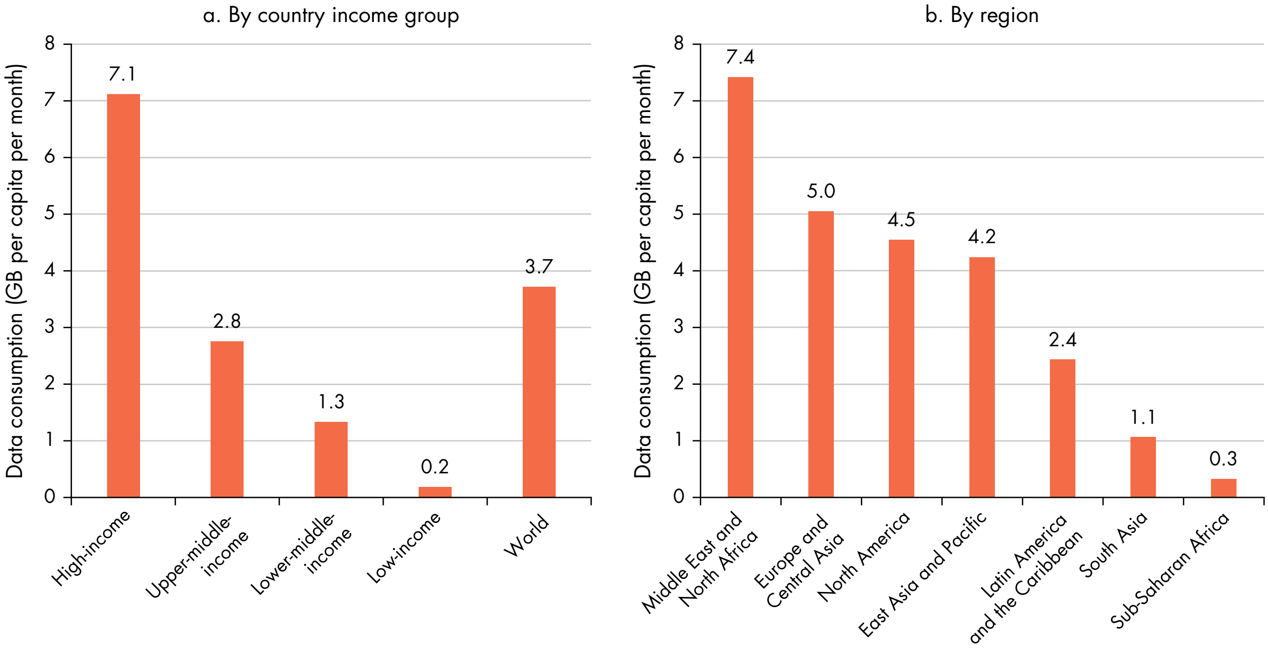
Narrowing the consumption gap

Even among people who connect to the internet and subscribe to data services, a wide consumption gap remains in *wireless* data usage across country income levels and regions, with the data usage per capita in high-income countries more than 30 times higher than that in low-income countries (figure 5.6). The consumption gap is even wider if *fixed* broadband is considered. The number of fixed broadband subscriptions is much higher in high-income economies, and because of more favorable data plans, these subscriptions support much higher levels of consumption than mobile subscriptions—potentially as much as 100 times more.[63]

The consumption gap raises questions about how much data are "enough" to meet basic social and economic needs. In 2019 the Alliance for Affordable Internet (A4AI) stated that 1 gigabyte of data per month was sufficient to benefit from the internet in a meaningful way,[64] but later it revised its estimate of "meaningful connectivity" to unlimited access as a result of the burgeoning use of data during the COVID-19 pandemic.[65] Based on a detailed empirical examination of data consumption patterns, this Report estimates that 660 megabytes per month is adequate to meet basic needs for e-government services, online shopping, browsing news, medical and educational information, and the like, rising steeply toward 6 gigabytes per month if a certain amount of social media and video-related usage is also included.[66]

Two fundamental drivers of low data consumption are the struggle to afford data usage charges and the technical constraints on network performance. These two drivers can be related. Problems with affordability translate into lower usage, which, in turn, means lower revenue streams and weaker incentives to invest in better network performance.

Figure 5.6 Inequities in mobile data consumption across country income groups and regions are huge



Source: WDR 2021 team. Data at http://bit.do/WDR2021-Fig-5_6.

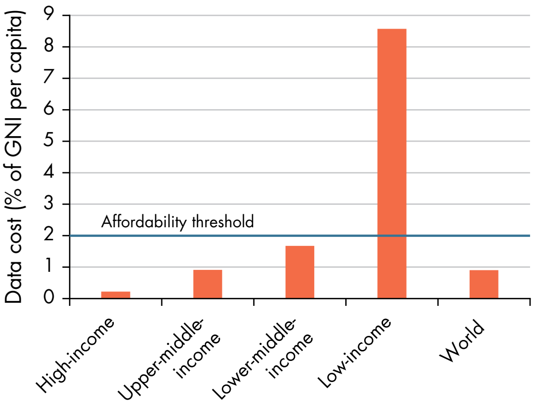
Note: Data are for 2018. Figures include averages of 119 economies with data. GB = gigabytes.

Tackling affordability constraints. Many internet users in low- and middle-income nations limit their mobile data usage because of affordability constraints (figure 5.7). A survey carried out in 11 emerging countries found that a median of 48 percent of respondents had difficulty paying for their mobile data usage, and 42 percent frequently or occasionally restrict the amount of data they use.[67] Instead of purchasing large amounts of data on a monthly basis, users buy it in small amounts when they have the money. Many mobile operators offer a variety of data bundles to cater to this pattern. MTN Zambia, for example, has 17 prepaid data plans, ranging from one-hour plans, including 5 megabytes of data, to weekly bundles offering unlimited access to popular social media applications.[68]

What is an affordable level of expenditure on data services has been the subject of some debate. The Alliance for Affordable Internet established a normative affordability threshold of 2 percent of monthly income linked to a normative consumption threshold of 1 gigabyte per month.[69] This threshold was subsequently adopted by the UN Broadband Commission.[70] According to these norms, data services could be considered generally affordable to the average consumer, except in low-income countries. The reality is that the actual expenditure on data services (known as average revenue per user or ARPU) and the associated data consumption levels both fall well below these norms. In fact, it is only when the cost per gigabyte of data drops below 0.5 percent of gross national income (GNI) per capita that data consumption reaches and eventually exceeds the 1 gigabyte threshold (figure 5.8).

The amount of data that people can afford to consume is itself a function of the prices that operators offer across different markets, as well as over time. In India, rapid entry of mobile operators offering 4G service in 2016 boosted coverage from 4 percent in 2015 to 94 percent in 2018.[71] Intensifying competition led to a dramatic price drop from US$4.41 to US$0.17 per gigabyte per month from 2014 to 2018 and a surge in consumption per subscriber from 0.3 to 7.7 gigabytes per month over the same period.[72] Similarly, in Cambodia intense competition has brought down the cost per gigabyte of data from US$4.56 in 2013 to one of the world's lowest at US$0.13 in 2019, driving up data consumption to 6.9 gigabytes per capita per month—the highest mobile data usage per capita of any low- or lower-middle-income nation. This increase was achieved through a combination of measures such as migrating spectrum and users to 4G to achieve lower operating costs, outsourcing construction work, and moving software to the cloud.[73] As a result of the low data charges, Cambodian consumers devote

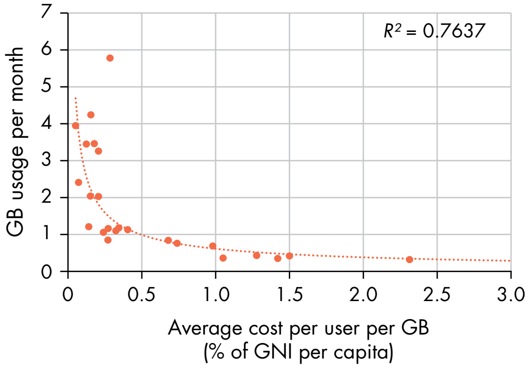
Figure 5.7 The monthly price for 1 gigabyte of data is unaffordable in low-income countries



Source: Cable.co.uk, Worldwide Mobile Data Pricing 2020: The Cost of 1GB of Mobile Data in 228 Countries (dashboard), https://www.cable.co.uk/mobiles/worldwide-data-pricing/. Data at http://bit.do/WDR2021-Fig-5_7.

Note: Data are as of 2018. The affordability threshold is 2 percent of monthly income. Prices are the median prices of the economies in the group. GNI = gross national income.

Figure 5.8 Data consumption is very sensitive to market prices and service affordability



Source: WDR 2021 team. Data at http://bit.do/WDR2021-Fig-5_8.

Note: Each circle represents a country. GB = gigabyte; GNI = gross national income.

96 percent of their information and communication technology (ICT) spending to data services, having largely moved away from voice and text.

Interestingly, users in low-income countries typically spend much more on voice and text services—between 2 and 4 percent of monthly income—than they do on data services. Because traditional voice and text can alternatively be provided on over-the-top (OTT) data-based services, which bypass traditional distribution and use only a small amount of data, users could substantially reduce their overall ICT expenditure by substituting data for voice and text services.

Addressing technical constraints. Slow speeds also discourage consumers from using more data. Downloading 250 megabytes takes 17 seconds at a speed of 100 megabytes per second, but as long as three minutes at a speed of 10 megabytes per second.[74] The speed dividends arising from migration to the next generation of mobile technology clearly drive higher levels of data consumption. For example, in India during 2018 a 2G subscriber consumed just 0.5 gigabytes per month, rising to 5.3 gigabytes per month for a 3G subscriber and 9.7 gigabytes per month for a 4G subscriber.[75]

Regulatory policies and retail competition drive migration to higher-generation mobile technologies. Transitions to next generations can be encouraged by early release of competitively priced spectrum. The auction of 3G spectrum in Thailand in 2012 was designed to support rapid upgrade from 2G by incorporating license conditions for coverage, pricing, and quality. Within two years, all license conditions were exceeded, with nearly universal 3G coverage, upgrading of three-quarters of subscriptions, lower prices, and service speeds exceeding license requirements by tenfold.[76]

Allowing operators to "refarm" their spectrum holdings can also accelerate migration to next-generation mobile. In contrast to regulatory policies that tie new mobile technologies to specific frequencies that are then auctioned, refarming allows operators to launch new mobile technology using their own spectrum. This encourages them not only to be more efficient in their use of spectrum, but also to rapidly upgrade their existing subscribers to reclaim the spectrum used for the older technology. About three-quarters of the spectrum used for 4G around the world has been refarmed: 25 percent from switching from analog to digital television broadcasting and 50 percent from operators using their own spectrum.[77]

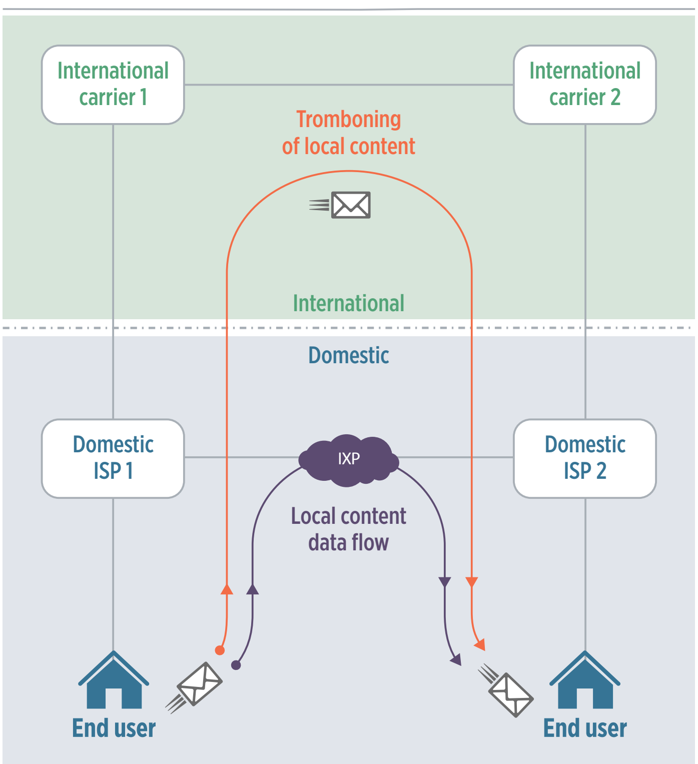
Nonetheless, many operators try to recapture their original capital expenditure before upgrading to a new generation of wireless technology.[78] To overcome this issue, Rwanda created a public-private partnership to roll out a 4G/LTE (Long-Term Evolution) network that covered almost 99 percent of the population by the end of 2019—the highest level in the world. However, because of the high cost of obtaining a 4G/LTE–compatible device, as well as technical challenges with the migration of voice services, service uptake has been modest, with most Rwandans continuing to use slow 2G technology for mobile data.[79]

Connecting poor countries

The high cost and low speed of internet services have emerged as key drivers of data consumption in the developing world. One reason is that many low-income countries lack their own domestic data infrastructure, relying instead on overseas facilities to exchange data (via internet exchange points), store data (at colocation data centers), and process data (on cloud platforms). This reliance requires them to transfer large volumes of data in and out of the country (see "tromboning" in figure 5.9), for which they pay a substantial penalty: prices that are several times higher than those in countries with their own infrastructure. They also experience slower speeds that can be an order of magnitude lower. This situation can be avoided by creating IXP infrastructure at the national level, eventually complemented by colocation data centers.

Consider a user who wants to view an educational video online. The request is uploaded as a small packet of data with address information and goes from the user's device to the national backbone and onward to the internet service provider (ISP). Often in lower-income countries, the video is not available domestically, obliging the ISP to route the request overseas, where it finds its destination—say, in California. The video is then downloaded back to the user. Such a circuitous process for accessing content incurs significant charges from international carriers while prejudicing service quality. This same operation would be much faster and cheaper if a replica of this content were stored at a local colocation data center that could be accessed via a local IXP.

Figure 5.9 The presence of domestic data infrastructure facilitates national data exchanges



Source: WDR 2021 team.

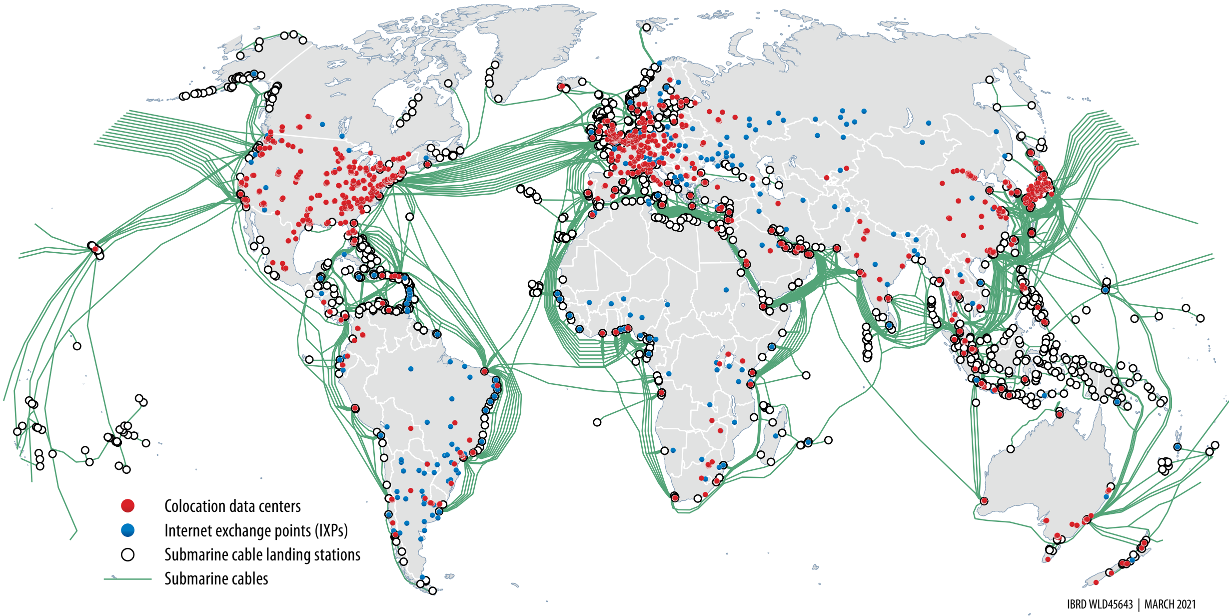
Note: ISP = internet service provider; IXP = internet exchange point.

This example illustrates how international bandwidth is a critical part of the data infrastructure, enabling data to be sent to and retrieved from anywhere in the world. The global internet bandwidth stood at 463 terabytes per second in 2019, almost tripling from 2015. Sub-Saharan Africa had the fastest growth in bandwidth of any region over the 2015–19 period. It grew by 53 percent a year, reflecting a large increase in capacity because of the deployment of new submarine cables. However, Sub-Saharan Africa continues to lag other regions in total capacity.

Most international internet traffic is carried over the world's dense web of some 400 undersea fiber-optic cables, spanning more than 1 million kilometers.[80] Almost all coastal economies are now connected to undersea cables (map 5.1). Submarine cable ownership has diversified from consortiums of telecommunication operators to include wholesale operators and increasingly big content providers such as Amazon, Google, and Microsoft.[81] Notably, Facebook recently announced plans to lay the 2Africa submarine cable around Africa. It will have nearly three times the capacity of all the undersea cables currently serving the continent.[82] The growing convergence of content provision and carriage of content will require greater regulatory oversight to ensure that carriage is provided in an open, nondiscriminatory manner.

Before establishing a submarine cable connection, countries used costly, low-capacity satellite links**.** Connection to submarine cables has dramatically lowered wholesale international bandwidth prices. Results in Africa over the last decade have been dramatic, with the price of 1 megabit per second dropping from US$3,500 to US$29 in Mauritania and from US$1,174 to US$73 in Togo.[83] In Tonga, the submarine cable increased capacity by more than 100 times, while prices dropped from US$495 to US$155 per megabit per second.[84] Nonetheless, restrictive policies for access to submarine cable landing stations may

Map 5.1 The global fiber-optic cable submarine network reaches all corners of the world, but data infrastructure is unevenly developed



Sources: PeeringDB, Interconnection Database, https://www.peeringdb.com/; PCH Packet Clearing House, Packet Clearing House Report on Internet Exchange Point Locations (database), accessed December 14, 2020, https://www.pch.net/ixp/summary; TeleGeography, Submarine Cables (database), https://www.submarinecablemap.com/. Data at http://bit.do/WDR2021-Map-5_1.

prevent the full benefits of this reduction in wholesale prices to feed through into retail tariffs.

Despite such progress, huge price differences persist for the exchange of data traffic. For example, the cost of exchanging data is around US$0.45 per megabyte per second in North America and US$0.62 per megabyte per second in London, compared with US$2.38 in São Paulo and US$5.00 in Johannesburg.[85] These stark differences in costs may in part reflect the limited development of domestic data infrastructure in low- and middle-income countries.

Strengthening data infrastructure

Without a domestic capability to exchange data, countries are totally reliant on international bandwidth. As noted, such bandwidth is expensive and slower than exchanging traffic locally. Such reliance also affects service resilience, since a country is completely shut off from the internet if there is any disruption to international bandwidth. For example, after a trawler snapped a submarine cable in 2018, Mauritania was offline for two days, and nine other West African countries experienced internet outages.[86] Although there will always be a need for international bandwidth, an appropriate balance is needed between relying on overseas infrastructure and developing domestic facilities.[87]

The economic case for domestic data infrastructure hinges on whether the present value of the resulting cost savings and speed improvements for data transactions over the life of such infrastructure exceeds the associated immediate up-front investment in facilities. The cost of developing IXPs is relatively modest and likely can be supported even in nascent markets so long as the sector is not monopolistic. As for colocation data centers, the investments are more sizable. There are also significant scale economies associated with the development of the associated power infrastructure that may account for as much as 40 percent of investment costs. The operating expenses are also largely fixed; about half of them are related to energy for cooling the facilities. Because exceptionally high levels of reliability and security are needed for colocation data centers, market dynamics favor hyperscale service providers with established reputations. This requirement further reinforces the case for larger-scale facilities in countries that have a relatively stable investment climate, including low levels of disaster risk, and the availability of clean, reliable, and cost-effective

sources of energy or natural sources of cooling such as water bodies.

Creating internet exchange points. By keeping data traffic in the country, IXPs can reduce reliance on international bandwidth, lowering costs and improving performance. One study covering Latin America noted that "local bits" are cheaper than "exported bits," finding that the region spent around US$2 billion a year for international bandwidth—a sum that could be reduced by one-third through greater use of IXPs.[88] IXPs reduce the time it takes to retrieve data, enhancing user engagement. In Rwanda, it is 40 times faster to access a locally hosted website (<5 milliseconds) than one hosted in the United States or Europe (>200 milliseconds).[89]

As of June 2020, there were 556 IXPs across the globe.[90] Europe, with the largest number, accounts for 37 percent of the world total, while Africa has just 9 percent and accounts for less than 2 percent of global IXP traffic, although that traffic is growing rapidly.[91] Stark differences in the availability of IXPs are evident across country income groups, particularly when population differences are taken into account.

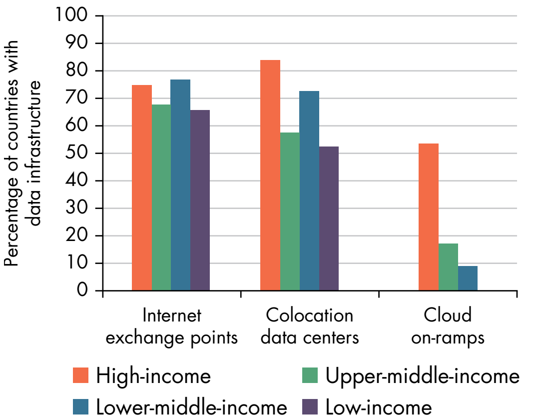
IXPs are often established initially by universities or as nonprofit associations of ISPs, located in small server rooms with technical tasks carried out by volunteers. As greater volumes of traffic are exchanged and new participants join, a more sustainable technical and operational environment is needed. Governance arrangements are then formalized, staff hired, and equipment upgraded. Eventually, the IXP grows to the point where many participants want to join without having to deploy a physical connection to the exchange. This leads to the creation of multiple IXPs in different locations, with the central IXP relocated to a colocation data center. For example, DE-CIX, an IXP in Frankfurt, Germany, began operations 25 years ago in an old post office when three ISPs interconnected their networks.[92] Today, it is the world's leading IXP, spread over more than three dozen data centers and linking almost 1,000 participants, with average traffic of more than 6 terabytes per second.

Developing colocation data centers. Data centers have emerged as a vital component of the digital infrastructure ecosystem. In a data center, networked computers provide remote storage, processing, and distribution of data. The centers are mainly operated by global information technology (IT) companies, governments, and enterprises that host other companies' data (colocation data centers). Data centers range from small rooms in organizations where data are kept on storage devices connected to computer servers to giant warehouse-like facilities where thousands of servers are arranged on racks. Colocation data centers offer companies multiple advantages, including the physical space to store a growing amount of data, the security associated with high industry reliability standards (as they almost never shut down), and easy internet access due to their growing association with IXPs.[93]

Globally, some 3,700 data centers are connected to the internet.[94] The disparities in data center penetration among country income levels are wide, particularly when taking population differences into account (figure 5.10). Although there are more than three data centers per million inhabitants in North America, the ratio is only 0.8 per million in South Asia and Sub-Saharan Africa. In fact, there are more data centers in the state of California than in all of Sub-Saharan Africa. These disparities may be related to lower income and thus demand, but they also reflect shortcomings in the investment climate.

Major colocation data center companies have largely shunned investing in low- and middle-income economies. This lack of investment is often attributed to a lack of demand, as well as an aversion to a country's perceived high risk of natural disasters, unpredictable political environment, barriers to doing business, and unreliable energy and internet infrastructure.[95] However, certain large businesses in low-income countries, such as those in the financial

Figure 5.10 Data infrastructure is relatively scarce in low- and middle-income countries



Source: WDR 2021 team, adapted from PeeringDB, https://www.peeringdb.com/. Data at http://bit.do/WDR2021-Fig-5_10.

Note: The figure depicts data centers connected to the internet. Data were extracted in June 2020.

sector and other service industries, already have in-house data storage systems that, if aggregated, could create the scale necessary for colocation data centers.

Regional players are filling the void left by the large global data center providers. For example, Africa Data Centres (part of the Liquid Telecom Group) has colocation facilities in Kenya, Rwanda, South Africa, and Zimbabwe. Although some of the scale issues associated with developing colocation data centers could potentially be overcome through regional collaboration around shared facilities, the case for such an approach hinges on the existence of strong regional fiber-optic network connectivity to ensure that data can be transferred rapidly and reliably to any shared regional data facility; competitive pricing of such data transfers; and regional harmonization of the regulatory framework to support agile cross-border data transfers (as discussed in chapter 7).

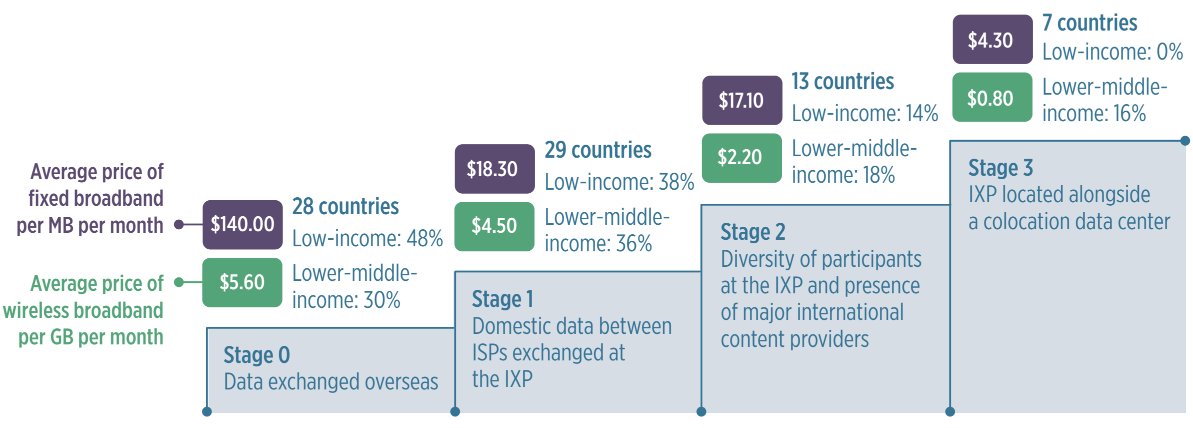
Despite mounting concerns about the environmental impact of data centers, there is evidence that the industry is taking aggressive action to curtail emissions and that availability of renewable energy is a factor in attracting investment (see spotlight 5.2).

Climbing the data infrastructure ladder. A country's development of data infrastructure can be envisioned as a series of stages that over time lower costs and improve performance (figure 5.11).[96] The stages progress from having no domestic IXP (stage 0), to establishing an IXP (stage 1), to attracting content providers and deploying data centers that host a diverse group of participants (stage 2), to locating the IXP alongside a colocation data center (stage 3). As countries move up the ladder, more data are exchanged nationally, and reliance on costly international bandwidth is consequently reduced, lowering retail prices, raising speed, and allowing higher data consumption.

Drawing on industry registries capturing the availability of data infrastructure globally in 2020, it is possible to build a comprehensive picture of domestic data infrastructure in the developing world. At stage 0 are 28 of the countries surveyed for this Report, none of which has an IXP, and these include almost half of the low-income country group. Underlying barriers are often responsible for the lack of an IXP: 10 of these countries are small island states where the scale of traffic is insufficient; four are in fragile and conflict-affected situations that impede the development of the data ecosystem; and five are monopolies where the sole national telecom operator is also in effect the IXP.

At stage 1 are 29 countries in which IXPs connect local ISPs. These include more than a third of low- and lower-middle-income countries. These IXPs are often located on the premises of government agencies or at academic institutions, typically in a small server room and in some cases using equipment provided through development assistance. For example, the African Internet Exchange System (AXIS) project, financed by the European Union, established IXPs in 14 African nations.[97] The IXPs in this group of nations often generate limited amounts of traffic, sometimes because not all ISPs participate in the IXP. In some

Figure 5.11 Countries develop domestic data infrastructure in stages



Source: Comini, Srinivasan, and Minges, forthcoming.

Note: Data provide close to global coverage for the year 2020 and are compiled from a variety of industry sources, including Packet Clearing House, CAIDA, PeeringDB, EURO-IX, and AF-IX. Amounts are in US dollars. GB = gigabyte; ISP = internet service provider; IXP = internet exchange point; MB = megabit.

countries, regulatory restrictions forbid participants that are not ISPs from joining the IXP.

The 13 countries at stage 2 have IXPs with non-ISP participants. Less than one-fifth of low- and lower-middle-income countries fall into this group. This group generally has numerous and diverse participants in the IXP, including all ISPs, as well as government agencies, local cloud providers, and national content companies, among others. Often, they have a Google Global Cache, a subset of Google's most popular content,[98] as well as content delivery networks (CDNs). However, large international content and cloud providers do not always use the IXP either because it is not located in a neutral data center or because its governance is not organized according to an open multistakeholder model.

At stage 3 are seven countries with IXPs colocated in data centers with international content participants. There are no low-income countries in this category, and only a minority of lower-middle-income countries. These arrangements often include multiple IXPs located in several data centers to facilitate participation. The Kenya Internet Exchange Point (KIXP) illustrates how this results in a dense network, enabling many participants to exchange data. KIXP is operated by a nonprofit organization representing technology companies, and its board follows international IXP best practices. KIXP has no restrictions on the types of organization that can connect to the exchange. It is located in colocation data centers in Kenya's two largest cities, Nairobi and Mombasa. Participants include national, regional, and international ISPs; government agencies; financial companies; and international content and cloud providers such as Amazon, Facebook, Google, and Microsoft.

Empirical evidence suggests that the benefits to countries of moving up the data infrastructure ladder are substantial. The average cost per gigabyte of wireless data per month drops from US$5.60 in countries at stage 0 to US$0.80 in countries at stage 3, while the corresponding cost per megabit for fixed data drops from US$140.00 to US$4.30 per month.

Nonetheless, the full benefits of developing domestic data infrastructure become apparent only when the local market is sufficiently competitive. For example, because of its strategic geographic location on the Horn of Africa, Djibouti's DjIX is a regional hub handling the exchange of considerable volumes of internet traffic. However, even though Djibouti's data infrastructure provides valuable services to neighboring countries, the monopolistic market structure of the national telecommunications sector does not allow these advantages to be passed on to domestic consumers, who face some of the most unaffordable internet charges in the world.[99]

Policy makers have an important role to play in shepherding IXPs through these various stages of development. In the early stages, demand remains incipient, and it is not possible to benefit from scale economies in infrastructure development. Governments and academic institutions can help initially with nascent IXPs by providing facilities and resources for training. Encouraging ISPs to exchange traffic locally helps boost demand for data services by reducing the cost of exchange. If needed, governments may have to mandate participation, particularly where dominant operators have been resistant. As their IXPs grow, governments can reduce their role, encouraging IXPs to become self-sustaining. Open IXP policies and multistakeholder governance are important for attracting non-ISPs to the membership, including large content providers. Government insistence on control over IXP practices discourages private sector investment in the data ecosystem.[100] A supportive regulatory environment for IXPs, as well as attention to sound governance practices, should ensure that multiple ISPs as well as universities, large enterprises, and other significant users make full use of the available IXP infrastructure. For example, in 2011 Bolivia legally mandated the creation of a national IXP requiring the participation of local ISPs. However, traffic growth was limited until 2018, when improved governance arrangements incentivized greater reliance on the IXP by local market players.[101]

Accessing cloud platforms

Just as there is growing reliance on colocation data centers to store data, the processing of data is being handled increasingly by cloud platforms. Cloud platforms essentially enable users to access scalable data storage and computing resources across the internet or other digital networks as and when required. Continual enhancements in cutting-edge computing capabilities, combined with significant improvements in the capacity and speed of processing, transmitting, and storing data, are making cloud computing increasingly important in the delivery of public and private services.[102]

Cloud platforms offer significant benefits in terms of security, resilience, scale, and flexibility. Security is arguably better on large cloud computing platforms than what many businesses or governments could achieve in-house.[103] Strong security features include ongoing data backups, redundant sites, and industry certifications, as well as adherence to national data protection regulations. However, moving data to the

cloud environment also presents new vulnerabilities such as reduced visibility of assets and operations, or the possibility that applications used to access cloud services could be compromised. IT infrastructure becomes more resilient as digital data and computing power become geographically distributed. This resiliency is enhanced by classifying services by region and availability zones and connecting data centers in the same geographic area. Cloud computing is attractive because it is often cheaper to share resources on a common platform than to replicate hardware, software, and storage requirements on individual company sites. Small enterprises can then outsource IT activities that they otherwise would not be able to provide internally, while benefiting from the flexibility of immediate upgrades to the most recent analytics and storage technology.

As broadband connectivity has become more widely available around the world, cloud computing has been growing rapidly, with industry revenues exceeding US$180 billion in 2018, up 27 percent over the previous year.[104] A few large companies dominate the cloud space, with almost all software and IT services firms based in the United States. These hyperscale providers operate cloud data centers mainly in high-income countries, with just a handful in large middle-income nations such as Brazil and South Africa, though not elsewhere in the developing world.

Free cloud services funded by advertising, such as webmail and online social networks, are already widely used in low- and middle-income nations. Google Docs provides word processing, spreadsheet, and presentation software used by millions around the world.[105] IBM offers several free services on its cloud.[106] However, sophisticated cloud services such as storage and analysis of vast amounts of data can be costly for developing economies because of the cost of moving data internationally and the resulting sacrifice in terms of speed.

One potential solution is to develop cloud platforms at the regional level by aggregating demand to achieve economies of scale. Regional harmonization of regulations for data security, data protection,[107] and data sovereignty could further reduce compliance costs and help induce major cloud providers to locate closer to low- and middle-income countries. For example, in March 2019 Microsoft launched the first data centers from a large cloud provider in Africa, with locations in Cape Town and Johannesburg, South Africa, and potential wider relevance to southern Africa.[108]

Another approach is for countries with colocation data centers to encourage the creation of "on-ramps" to cloud computing services. These are prevalent in some 80 percent of high-income countries but only in about 10 percent of middle-income countries such as India and Indonesia, and not at all in low-income countries.

Cloud on-ramps are private connections between data centers and cloud providers. They allow clients to interact directly with overseas cloud providers through domestic IXPs located in colocation data centers without needing to use the internet to access cloud services.[109] This process provides greater security and reliability because data are not transmitted to the cloud over public infrastructure but rather directly via the on-ramp. Performance in terms of speed is also greatly improved and costs are significantly lowered because the cloud provider is responsible for managing and routing the data traffic from the domestic colocation data center to its cloud data center overseas using the on-ramp. At the same time, cloud services create demand for data centers because some applications require very high speed, which can only be achieved when computational power is located close to the user at the network's "edge."[110] This description underscores the complementarities between different types of data infrastructure, such as IXPs, colocation data centers, and cloud computing.

Big data analysis is increasingly taking place over distributed cloud networks because the considerable processing power needed is available only on the cloud. Data are stored in one or more places and processed in others. The cloud has also enabled a new collaborative environment for software development in which developers from around the world participate in modifying code. The world's largest open-source platform, GitHub, hosts more than 100 million repositories used by 50 million developers worldwide.[111] The growth in new software projects is mainly coming from low- and middle-income nations, with Africa expanding more rapidly than any other region. Open-source repositories in Africa created by software developers grew 40 percent in 2019.[112]

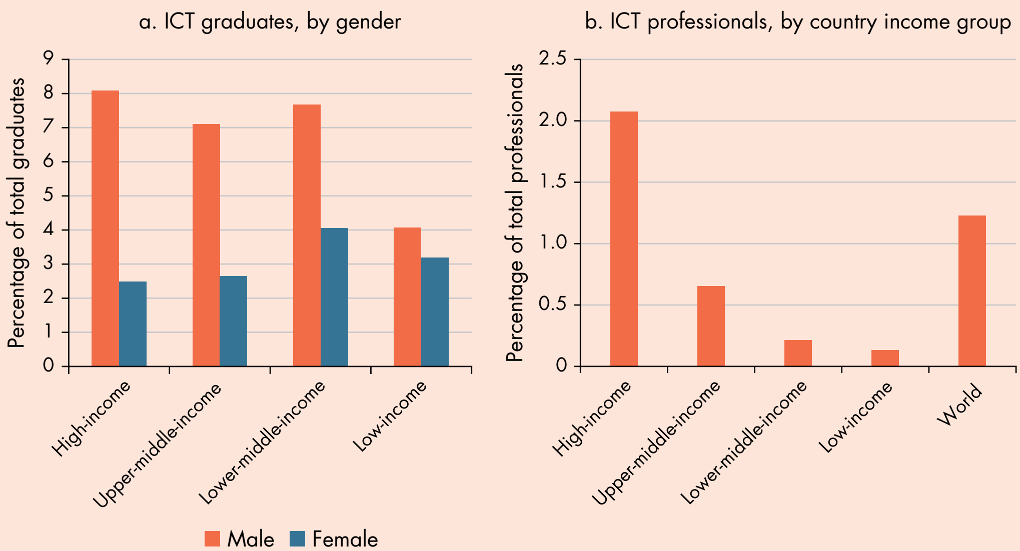
Without skilled human resources, countries will be limited in their ability to apply modern data infrastructure to achieving economic and social impacts. Workers are needed to create and maintain data infrastructure, as well as to collect, store, manage, and analyze large amounts of data. Although the skills needed to collect, store, and manage data are available in many parts of the world, those for analyzing big datasets are limited. Data scientists—specialists in math, computer, and analytical skills—who derive value from large datasets are in short supply, and low- and middle-income countries are at a disadvantage in the global market for technical skills (see box 5.1).

Box 5.1 The brain drain—ICT professionals

Available data on the supply of and demand for information and communication technology (ICT) skills paint two distinct pictures.[a] Among country income groups, there does not seem to be wide divergence in the proportion of students graduating with ICT degrees, which typically falls in the 7–8 percent range overall, yet with marked discrepancies between men and women (figure B5.1.1, panel a). However, employment of ICT professionals is strongly correlated with country income groups, since these workers account for 2.1 percent of total employment in high-income nations, dropping to 0.1 percent in low-income countries (figure B5.1.1, panel b).

The mismatch between supply and demand in low- and middle-income economies prompts outward migration toward better employment opportunities in countries where the digital sector is more developed. Evidence of this brain drain already exists: all countries except high-income are experiencing large outflows of skilled tech workers (figure B5.1.2, panel a). Even where skilled data workers have opportunities in low- and middle-income countries, wage differentials could be a driver of migration. The average wages for ICT employees are significantly higher in high-income nations (figure B5.1.2, panel b), and significant wage differentials exist across regions.

Figure B5.1.1 Low- and middle-income countries are educating ICT professionals but not retaining them



Sources: Institute for Statistics, United Nations Educational, Scientific, and Cultural Organization, Data of UIS.Stat (database), http://data.uis.unesco.org/; International Labour Organization, ILOSTAT Database, http://www.ilo.org/ilostat/. Data at http://bit.do/WDR2021-Fig-B5_1_1.

Note: For ICT graduates, panel a presents the latest available data between 2015 and 2018 for 120 economies. For ICT professionals, panel b plots the latest available data between 2016 and 2019 for 73 economies. Country income group percentages are collective country averages. ICT = information and communication technology.

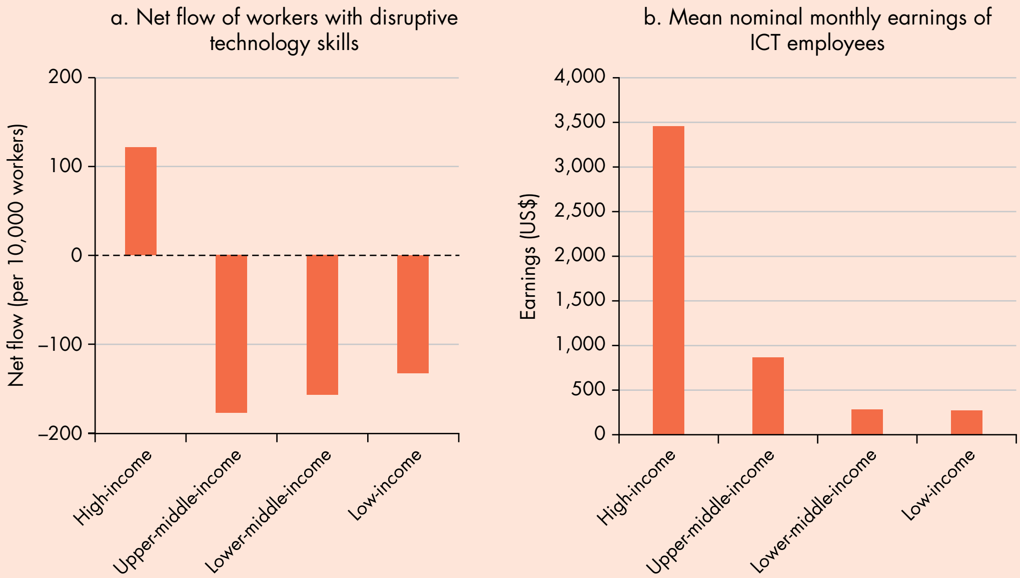
(Box continues next page)

Conclusions and recommendations

Low- and lower-middle-income countries continue to face major challenges in connecting themselves to the vital infrastructure that underpins the data-driven economy. Many have yet to develop their own IXPs and remain reliant on slow, expensive international data transfers to access the World Wide Web. Colocation data centers that allow further local storage and processing of data, as well as caching of internet content, are still not prevalent in low- and lower-middle-income countries, while global cloud computing resources are almost entirely concentrated in high-income countries, with a limited availability of on-ramps to facilitate access by the developing world.

Box 5.1 The brain drain—ICT professionals *(continued)*

Figure B5.1.2 Major wage differentials for ICT professionals create a brain drain, especially in low- and middle-income countries



Sources: International Labour Organization, ILOSTAT Database, http://www.ilo.org/ilostat/; LinkedIn data (2015–19). Data at http://bit.do/WDR2021-Fig-B5_1_2.

Note: According to LinkedIn dataset classification, "disruptive technology skills" include knowledge and skills in areas of materials science, aerospace engineering, development tools, data science, robotics, artificial intelligence, human computer interaction, genetic engineering, nanotechnology, and fintech. ICT = information and communication technology.

The relative penetration rate of data science skills—relevant to artificial intelligence—across comparable occupations is four times higher in high-income countries than in low-income countries.[b] Given salary differentials of 5–10 times between data scientists in low- and high-income countries, it is estimated that workers with these skills in low-income countries are 33 percent more likely to migrate than workers from high-income countries. There was a net outflow of at least 70,000 workers from low- and middle-income countries every year from 2015 to 2019.[c]

a. Data from the national statistical office on data skills are lacking in both availability and specificity, particularly for low- and middle-income countries. New sources of data, such as the professional networking platform LinkedIn, are emerging as sources of timely and granular information on the labor market, albeit with limited representativeness. The LinkedIn data used in this Report have been validated against international metrics where available to assess coverage and representativeness (Zhu, Fritzler, and Orlowski 2018).

b. Estimation based on the Skills Genome Benchmarking Methodology, using LinkedIn's Skills Genome Country-Occupation data. This method allows a fair comparison of the penetration of data science skills of all countries in the dataset with that of a chosen benchmark (low-income countries, in this case) by controlling for common occupations among each country and the benchmark.

c. WDR 2021 team calculations, based on Zhu, Fritzler, and Orlowski (2018).

At the same time, in poor countries large swathes of the poorest and most disadvantaged segments of society continue to be excluded from access to broadband data services. For low-income countries, particularly in Africa, the coverage gap for broadband signal remains significant, affecting 30 percent of the population. A major concern is the usage gap—the vast majority of those who do not have data access today live within range of a mobile signal, but they face either affordability or literacy challenges that prevent them from making use of the service. The COVID-19 pandemic has drawn growing attention to the consumption gap, which highlights the limited volumes of data usage in the developing world and

the implications for the population's ability to access data-based services such as tele-education.

Connecting poor people

When it comes to connecting people to data infrastructure, the following steps are recommended.

Keep costs down through competition. Governments should prioritize all measures to drive down the cost of service provision. Lower costs improve the commercial viability of services, thereby reducing coverage gaps and accelerating technology upgrades. They also help to improve service affordability, thereby reducing usage and consumption gaps. Governments have two possible levers for reducing costs. The most fundamental is creating competitive pressures along the supply chain, including both its wholesale and retail tiers, while addressing structural impediments such as vertical integration. In addition, governments could create a regulatory environment that supports sharing bottleneck infrastructures in areas with low data traffic that could not otherwise support competitive provision of data infrastructure.

Harness private sector investment. To develop digital infrastructure governments should rely on the private sector wherever possible. This calls for privatization of state-owned incumbents and a policy of avoiding state investment (such as through vendor-financed models) in segments such as the national fiber-optic backbone where the private sector is willing to invest. The entry of new market players is an important market trend, including the growing role of content providers in building backbone infrastructure, which will require careful consideration of competition and regulatory issues such as net neutrality.[113] With the advent of 5G, industrial players are also expected to become more active in the development of ICT infrastructure.

Rethink universal service policies. The underperformance of traditional universal service funds points to the need to rethink and modernize government policy measures to support universal service. Measures such as license coverage obligations should be considered. The role of innovative technologies (such as TV white space) and new entrants (such as content providers) in reaching remote populations are also relevant. Supply-side subsidies should be competitively awarded and carefully targeted to those pockets that cannot be reached effectively after considering all other available measures. Furthermore, universal service funds could be redirected to addressing the usage gap by funding digital literacy programs or supporting access to lower-cost mobile devices. This would entail targeting such resources more toward disadvantaged population segments than to underserved geographic areas.

Calibrate fiscal regimes carefully. The governments of poor countries have typically regarded digital infrastructure and associated data services as a potential fiscal cash cow (through taxes, fees, and other charges) in the context of low mobilization of public sector revenues. This view has led to relatively high indirect taxes on mobile devices and data services, significant import duties on equipment, and in some cases high reservation fees for spectrum access. However, there are important trade-offs between the fiscal revenues generated by the sector in the short term and the pace of digital infrastructure rollout and service uptake in the longer term, which also has implications for economic growth and associated tax revenues over time. The design of the fiscal regime for digital infrastructure and data services must therefore be carefully thought through to balance these competing policy objectives. There may be a case for giving lighter tax treatment to low-end mobile devices to support uptake by disadvantaged groups.

Support upgrades to new technologies. Governments need to create an environment that enables accelerated upgrades to higher-generation technologies. The fiber-optic backbone is a critical prerequisite for further upgrade of networks to 4G and 5G technologies. Thus measures to expand this network at any stage, in partnership with the private sector, would be a no-regrets strategy. In addition, allowing reform of the spectrum so that operators can repurpose existing spectrum allocations would be a helpful strategy. License conditions could also be used to package such regulatory allowances with obligations for data service providers to provide wide-ranging service coverage. Finally, the complexity of these new technologies will require adequate investments in cybersecurity protection.[114]

Connecting poor countries

When connecting countries to data infrastructure, the following steps are recommended.

Progressively develop domestic data infrastructure. Governments need to pay much more attention to the specific infrastructure required to support the sharing, storage, and processing of large volumes of data. To participate in the data-driven economy on a competitive basis, countries must be able to perform high-volume data operations at the greatest possible speed and lowest possible cost. The infrastructures that can meet these performance goals are internet exchange points, colocation data centers, and cloud computing.

Promote creation of internet exchange points. IXPs remain scarce across the developing world, and even where they do exist they often fail to achieve their potential. Governments have a role in creating the enabling conditions for such institutions to emerge and be widely utilized. Better governance models are needed so that IXPs can develop and become sustainable. Collaboration between IXPs and key stakeholders such as ISPs, government entities, research networks, and content providers can help to raise awareness, expand skills, and create the trust essential for IXPs to be successful.

Create a favorable environment for colocation data centers. Neutral, privately owned colocation data centers are an essential part of data infrastructure and critical for promoting the digital economy. They are a secure venue in which local and international companies can store their data and help support the local hosting industry. The willingness of private investors to install such facilities in low- and middle-income countries is affected by concerns about the enabling environment—in particular, the availability of clean and secure energy sources, as well as relative political stability and ease of doing business. Governments can catalyze the market by moving their online services to data centers and by encouraging businesses to host locally to create economies of scale, while establishing a solid data protection framework to build trust.

Secure on-ramps to the cloud. Cloud computing creates tremendous opportunities for low- and middle-income nations to gain remote access to advanced computing facilities for data management and analytics. The cloud also enables collaborative creation of software, thereby giving software developers around the world opportunities to participate. However, cloud data centers and on-ramps are mainly located in upper-middle- and high-income nations. Low-income countries could induce the major cloud providers to locate closer through a regional approach that aggregates demand and harmonizes compliance requirements for security, data protection, and sovereignty. Governments also need to foster an enabling environment that encourages cloud providers to locate in local data centers in order to provide an on-ramp to their services.

Invest in and retain human resources. Realization of the potential for data infrastructure to contribute to economic development depends on adequate human resources, particularly in frontier areas such as data science and artificial intelligence. Although there is an acute global scarcity of these skills, evidence suggests that low- and middle-income nations are producing some graduates in these fields. However, wage differentials in a highly competitive global market are leading to a powerful brain drain effect, preventing those countries from harnessing these skills. The brain drain is often exacerbated by the lack of opportunities arising from undeveloped local data infrastructure. Governments need to stimulate their digital economies by encouraging private investment in fiber-optic backbones and data centers that generate direct and indirect employment.

The recommendations presented here are organized within the maturity model framework in table 5.1, recognizing that different countries may be at different stages of developing data infrastructure.

Table 5.1 Recommendations for data infrastructure improvements sequenced according to a maturity model

Stage of country	Connecting people	Connecting countries
Establishing fundamentals	Eliminate coverage gaps by reducing costs through wholesale and retail competition, as well as infrastructure sharing arrangements, and, where still required, providing well-crafted state support.	Ensure adequate international bandwidth. Create a competitive market environment for international gateways and internet service providers.
Initiating data flows	Narrow usage gaps through digital literacy campaigns, investment in basic education, lower taxation and import duties on low-end handsets, and support of local ventures for manufacturing handsets.	Encourage creation of the first domestic IXP and facilitate participation by all relevant domestic players. Allow additional IXPs to emerge and players to formalize and mature. Encourage arrangements to cache popular international internet content on local servers.
Optimizing the system	Upgrade digital networks to the latest generation to improve speed and efficiency and facilitate higher consumption.	Create a supportive environment in which colocation data centers can emerge, integrate with IXPs, and provide on-ramp access to cloud services.

Source: WDR 2021 team.

Note: IXPs = internet exchange points.

Notes

1. Briglauer and Gugler (2019); Czernich et al. (2011); Katz and Callorda (2018); Koutroumpis (2018); Minges (2015).
2. Bertschek and Niebel (2016).
3. Shapiro and Hassett (2012).
4. Hjort and Poulsen (2019).
5. van der Marel (2020).
6. See "How Does Data Travel on the Internet?" *Networking Guides*, https://networkingguides.com/how-does-data-travel-over-the-internet/.
7. Cisco (2018).
8. Ericsson (2020).
9. Cisco (2020).
10. Monash University (2020).
11. Sandvine (2019).
12. Text messages allow traders to check on agricultural prices, remind the sick when to take their medicine, and help nurses register births. Mobile money has unleashed add-on services in microinsurance, agriculture, and transportation, and it is facilitating the deployment of off-grid energy by allowing users to repay the cost of solar panels with micropayments. Development agencies can make conditional cash transfers to mobile money accounts, reducing costs and increasing security.
13. Katz and Callorda (2018).
14. Czernich et al. (2009).
15. Anderson and Kumar (2019).
16. Broadband Commission (2019).
17. For further details on Sustainable Development Goal 9, Target 9.c, see Department of Economic and Social Affairs, United Nations, "Goals: 9, Build Resilient Infrastructure, Promote Inclusive and Sustainable Industrialization and Foster Innovation," https://sdgs.un.org/goals/goal9.
18. See, for example, Michie (1997) or Madden (2010).
19. SDG Target 9.c states: "Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020" (Department of Economic and Social Affairs, United Nations, "Goals: 9, Build Resilient Infrastructure, Promote Inclusive and Sustainable Industrialization and Foster Innovation," https://sdgs.un.org/goals/goal9).
20. Broadband Commission (2019).
21. Ericsson (2020).
22. Oughton et al. (2018).
23. Oughton et al. (2018).
24. World Bank (2016).
25. GSMA (2019c).
26. Kapko (2020).
27. Broadband Commission (2019).
28. Broadband Commission (2019).
29. GSMA (2019b).
30. See World Bank (2019c). One example is Liquid Telecom, which has rolled out 70,000 kilometers of fiber-optic cable through several African nations. See Liquid Telecom, "Our Network," https://www.liquidtelecom.com/about-us/our_network.
31. For example, landlocked Mongolia's north-south fiber-optic backbone connecting it to China and the Russian Federation runs along the railway (Tsolmondelger 2019).
32. Strusani and Houngbonon (2020).
33. UN-OHRLLS (2017).
34. See the information on the Adopting TV White Spaces Project in Colombia (ITU 2018c, 33).
35. Loon (2020).
36. Iridium Communications (2020).
37. Intelecom Research and Consultancy (2016).
38. GSMA (2013).
39. World Wide Web Foundation and A4AI (2018).
40. ESCAP (2017).
41. ITU (2018a).
42. Chen (2021).
43. ITU (2018b).
44. GSMA (2020).
45. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) defines digital literacy as "the ability to access, manage, understand, integrate, communicate, evaluate and create information safely and appropriately through digital technologies for employment, decent jobs and entrepreneurship. It includes competences that are variously referred to as computer literacy, ICT literacy, information literacy and media literacy" (Law et al. 2018).
46. Chen (2021).
47. Chen (2021).
48. Chen (2021).
49. GSMA (2017).
50. GSMA (2019a).
51. See Ministry of ICT and Innovation, "Digital Ambassadors Programme," Kigali, Rwanda, https://www.minict.gov.rw/projects/digital-ambassadors-programme.
52. Radovanović et al. (2020).
53. Internet Society (2015).
54. Silver and Smith (2019).
55. GSMA (2019a).
56. A4AI (2020).
57. MTN (2020).
58. JioPhone, "Jio Digital Life," Reliance Jio Infocomm Ltd, Mumbai, India, https://www.jio.com/en-in/jiophone.
59. *New China* (2018).
60. A4AI (2020).
61. GSMA (2019d).
62. GSMA (2020).
63. Telefónica S.A., "Quarterly Results: 2020 January–September," https://www.telefonica.com/en/web/shareholders-investors/financial_reports/quarterly-reports/.
64. A4A1 (2019).
65. Sonia (2020).
66. Chen and Minges (2021).
67. Silver et al. (2019).
68. ITU (2018c).
69. See Alliance for Affordable Internet, "Affordable Internet Is '1 for 2'," https://a4ai.org/affordable-internet-is-1-for-2.

70. See “Advocacy Target 2” (Broadband Commission 2020).
71. BBC News (2019a).
72. BBC News (2019b).
73. Based on information provided by one of Cambodia’s seven mobile operators, Smart (Smart Axiata 2019).
74. See the speed graph provided by West Central Telephone Association, Sebeka, MN, https://www.wcta.net/speed-demo/.
75. TRAI (2019).
76. Malisuwan, Tiamnara, and Suriyakrai (2015).
77. Sanni (2016).
78. Capitel (2016).
79. RURA (2019).
80. TeleGeography, Submarine Cables (database), https://www.submarinecablemap.com/.
81. Miller (2019).
82. Ahmad and Salvadori (2020).
83. See World Bank, “West Africa Regional Communications Infrastructure Project, APL 2,” https://projects.worldbank.org/en/projects-operations/project-detail/P123093.
84. World Bank (2019a).
85. See TeleGeography, Submarine Cable Frequently Asked Questions, https://www2.telegeography.com/submarine-cable-faqs-frequently-asked-questions.
86. Baynes (2018).
87. The development of domestic data infrastructure should not be confounded with the question of data localization. Data localization, a regulatory issue discussed at some length under the trade section of chapter 7, concerns the adoption of government restrictions requiring that a country’s data be stored and sometimes processed on national territory, often with associated government controls on cross-border data transfers. Although domestic data infrastructure is a prerequisite for data localization, the development of domestic data infrastructure serves many other critical functions. In particular, it supports the cost-effective exchange of data among domestic parties and facilitates the access of country nationals to data from other jurisdictions by allowing copies of such data to be stored locally.
88. Agudelo et al. (2014).
89. Internet Society (2017).
90. The count of the number of IXPs in the world differs depending on the source. For example, PeeringDB (https://www.peeringdb.com/) reported 786 in June 2020. The variations are often due to differences in definitions (such as whether private peering facilities are included).
91. See Packet Clearing House, “Packet Clearing House Report on Internet Exchange Point Locations,” https://www.pch.net/ixp/summary.
92. DE-CIX (2015).
93. Dobran (2018). Colocation data centers are vulnerable to physical and cybersecurity threats. They may be an attractive target for cybercriminals because they host large amounts of data and private information, all in the same location. However, because they have more resources, colocation sites can invest in better security protections than what could be achieved in-house for a typical small or medium-size business.
94. PeeringDB, https://www.peeringdb.com/.
95. C&W (2016).
96. Comini, Srinivasan, and Minges (forthcoming).
97. EU-AITF (2018).
98. See Interconnect Help, Google, “Introduction to GGC,” https://support.google.com/interconnect/answer/9058809?hl=en.
99. Comini, Srinivasan, and Minges (forthcoming).
100. Balancing Act (2019).
101. Comini, Srinivasan, and Minges (forthcoming).
102. UNCTAD (2013).
103. All large cloud providers have International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 27000 certification compliant with regulatory and legal requirements that relate to the security of information (ISO/IEC, “Popular Standards: ISO/IEC 27001, Information Security Management,” https://www.iso.org/isoiec-27001-information-security.html).
104. IDC (2019).
105. See Google, “Google Docs,” https://www.google.com/docs/about/.
106. International Business Machines, “IBM Cloud: Free Tier,” https://www.ibm.com/cloud/free.
107. See chapter 7 for a discussion about data localization regulations.
108. Keane (2019).
109. See DP Facilities, “The Critical Role Data Centers Play in Today’s Enterprise Networks: Part 3, Why Cloud On-Ramps Are Key for an Enterprise Migrating to the Cloud,” https://www.dpfacilities.com/blog/cloud-onramps-are-key-to-migration/.
110. World Bank (2019b).
111. GitHub, “Where the World Builds Software,” https://github.com/.
112. GitHub, “The 2020 State of the OCTO–VERSE,” https://octoverse.github.com/.
113. Because of the complexity of the topic, this chapter does not address the issue of net neutrality and its impact on market regulation and competition.
114. With their distributed routing approach and software-driven design, 5G networks present an array of new cybersecurity challenges that must be addressed before these networks are widely deployed. Moreover, IoT devices are often manufactured without adequate cybersecurity protections, and they have security vulnerabilities. These vulnerabilities can be exploited by bad actors who can gain access to the network or harness the computational power of an IoT device for other malicious purposes, such as distributed denial of service attacks. A forthcoming World Bank 5G flagship report will address in detail the cybersecurity issues raised by the uptake of the 5G technology.

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