McKinsey
Global Institute

Executive summary

Connected world

An evolution in connectivity
beyond the 5G revolution

February 2020

McKinsey Global Institute

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Discussion paper

Connected world: An evolution in connectivity beyond the 5G revolution

Executive summary

February 2020

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In brief

Connected world: An evolution in connectivity beyond the 5G revolution

The world's digital connections are about to become broader and faster, providing a platform for every industry to boost productivity and innovation. We have identified hundreds of use cases across more than 17 commercial domains that can run on an enhanced digital backbone. This research focuses on four of them: mobility, healthcare, manufacturing, and retail.

We find that implementing the most promising use cases we identified in these four areas alone could increase global GDP by $1.2 trillion to $2 trillion by 2030, with the countries that are most connected today capturing much of the value. These four domains represent roughly one-third of global GDP, implying that there are opportunities to create trillions of dollars in additional value across other sectors. On top of this, some two billion new users are set to come online worldwide, generating another $1.5 trillion to $2 trillion in GDP impact, mostly in the developing world.

However, although most of the needed technologies are already available and the opportunities have existed for some time, progress has yet to take off in many areas. Questions about who makes the required investments, who benefits, and how to coordinate multiple players still must be solved.

— The future of the connected world is not just about the newest frontier technologies, such as high-band 5G and low-earth orbit satellite constellations. Much of it will be defined by the expansion and evolution of existing advanced connectivity technologies, like fiber, low- to mid-band 5G, Wi-Fi 6, and various other long- and short-range solutions. The new architecture of connectivity also features cloud and edge computing that can be accessed with cheaper and more efficient "thin" devices. Computing power, storage, and sensors are all growing more powerful and more affordable. As these trends converge, the connectivity ecosystem will be populated with more technologies, services, and providers than ever before.

— While consumer demand for entertainment and internet applications will continue to drive most network usage, connectivity enables new capabilities across the economy. To illustrate the range of what is possible, we highlight a number of promising use cases in four commercial domains. In **mobility,** vehicles will communicate with infrastructure, other vehicles, and networks, improving safety and traffic flow. In **healthcare,** connectivity-enabled innovations can make it possible to monitor patients remotely, use AI-powered tools for more accurate diagnoses, and automate many tasks so that caregivers can spend more time with patients. **Manufacturers** and other industrial companies can run highly precise, high-output, and largely automated operations using low-latency commercial and private 5G networks. **Retailers** can offer a more seamless and personalized in-store experience while making inventory management and warehouse operations more efficient.

— Out of the $1.2 trillion to $2 trillion potential in these four domains, 70 to 80 percent can be achieved with existing advanced connectivity technologies. With its improved speed, efficiency, latency, and coverage, frontier connectivity can produce the remainder by taking many existing use cases to the next level—and paving the way for entirely new ones that we cannot foresee today. However, most providers and industry players are not bolting out of the starting gate. In many places, investment has yet to materialize at the scale of the opportunity.

— For this to happen, several issues clouding the market will need to be solved in each of the four domains. For one, coordination across value chains is a

critical challenge. Second, the potential value is fragmented across many use cases but lacking a clear aggregator to provide scale. In addition, incentives are often misaligned. The entity doing most of the heavy lifting of investment and implementation may not be the one who stands to benefit financially. Furthermore, many use cases introduce data complexities, in terms of privacy, security, and interoperability. Finally, deployment constraints in the form of regulatory barriers, capital availability, and long investment cycles are leading both connectivity providers and industry players to put upgrades on hold in many regions. These issues existed in the previous technology cycle, and they are carrying forward with greater urgency. Tackling them can potentially unlock trillions of dollars—not just in these four domains but in others as well.

– Apart from industry use cases, up to 2 billion additional users could come online by 2030, due to a combination of network expansions, growing affordability of devices and services, and other factors. Overall, the share of the global addressable population remaining wholly offline or limited to only the most basic connectivity (that is, not yet using 3G-capable data networks or better) could shrink by half, from 40 percent today down to 20 percent. The economic and social benefits would be profound, from improved access to mobile banking and credit to new educational opportunities.

– Delivering connectivity enhancements will come at a cost. We estimate that by decade's end networks can be expanded and upgraded to cover approximately 80 percent of the global population with advanced connectivity, at a cost of some $400 billion to $500 billion. However, connectivity providers are unlikely to have sufficient incentive to offer frontier coverage in most of the world. Only a quarter of the global population is likely to gain high-band 5G coverage by 2030, with rollout costing some $700 billion to $900 billion. Given the magnitude of the investment required, connectivity providers will continue to face a tough road. Many of them are already struggling to meet shareholder demands while considering capital investments to enhance their networks.

– Despite the promise of a more inclusive connected world, disparities between countries could persist. Analyzing revenue potential, cost factors, and market dynamics, we see four country archetypes progressing along the connectivity continuum at varying speeds, as well as two countries that stand apart. **Pioneer countries** (including the United States, Japan, and South Korea) **and China** are ahead on the connectivity continuum; they are already deploying the first high-band 5G networks in select major cities. **Leader markets** such as France and Canada will be close behind. **Followers,** such as Brazil and Poland, are a few years back; their near- to medium-term focus is likely to be on fiber and mid-band 5G. **Trailing countries** such as Pakistan and Bolivia are unlikely to gain widespread advanced connectivity, let alone frontier connectivity, in the near term. **India** has modernized its mobile networks at breakneck speed, but frontier connectivity will likely be limited to its major urban centers. In addition to the gaps across these archetypes, the urban-rural connectivity gap within countries could widen. These patterns of deployment will affect how the value from domain use cases is ultimately distributed, favoring pioneer countries and China.

– A number of questions remain open. Can providers capture long-term economic value by partnering with businesses in other domains? What will the connectivity ecosystem look like in a decade's time, and what new competitors and players might enter? Will companies opt to build their own private networks rather than relying on public services? To what extent will processing migrate to the edge? Will providers continue to struggle with monetizing consumer entertainment and internet applications, or will new applications change this dynamic? How much more value potential exists in other commercial domains, and do they have their own unique barriers to adoption that need to be addressed? Lastly, the role policy makers will take in shaping the connected world of the future remains unclear. The actions governments choose to take in areas such as regulation, spectrum, infrastructure access, R&D funding, and even subsidies will have major implications for where, when, and how the world connects. We plan to explore some of these issues in future research.

Executive summary

The promise of 5G has captured the attention of business leaders, policy makers, and the media. But how much of that promise is likely to be realized anytime soon?

With the first true high-band 5G networks already live, we set out to take a realistic view of how and where connectivity could be deployed and what it can enable over the next 10 years. But 5G is not appearing in isolation. This research takes a more expansive view of connectivity to include other technologies, ranging from fiber and satellites to Wi-Fi and short-range technologies.

Despite the hype about remote surgery and *Star Trek*–style holodecks in everyone's living rooms, the future is not solely happening on the frontier. Existing connectivity technologies are expanding and evolving, with new standards that boost network performance—and they are much less capital-intensive. We have identified an enormous array of use cases that can run on this type of upgraded backbone. Companies do not have to wait for high-band 5G to implement new systems and go after the resulting productivity gains.

To illustrate what is possible, this research looks at how connectivity could be deployed in mobility, healthcare, manufacturing, and retail. The use cases we identified in these four commercial domains alone could boost global GDP by $1.2 trillion to $2 trillion by 2030. This implies that the value at stake will ultimately run trillions of dollars higher across the entire global economy.

Most of this value can be captured with advanced connectivity, using technologies that have been available for some time now. This raises a puzzling question: Why is so much potential still sitting on the table, and will new technologies alone be enough to realize it? This research looks at the issues holding back the market, with the aim of starting a broader conversation about what it will take to create momentum. It is part of an ongoing body of work that will continue exploring connectivity, including its possibilities in other sectors and its impact across broader economies.

Beyond the implications for industry, connectivity also has ramifications for equity and society. A picture of today's digital networks superimposed on the planet would confirm that the World Wide Web is not actually worldwide today. There are dark gaps as well as regions of unusual density. In the decade ahead, many of those blank spaces will light up, and billions of new users will come online.

Enabling more people to plug into global flows of information, communication, and services could add another $1.5 trillion to $2 trillion to GDP, above and beyond the economic value of the use cases identified in the four commercial domains highlighted in this research. Although gaps will remain, this trend could unlock greater human potential and prosperity in many developing nations.

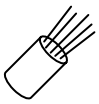
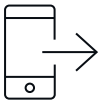
In the decade ahead, a combination of technologies will take important strides forward

Connectivity is undergoing evolutionary change in most parts of the world—and, in select areas, a genuine leap into the frontier.

Existing connectivity technologies are expanding their reach as networks are built out and adoption grows. At the same time, the next generations of these technologies are appearing, with upgraded standards (Exhibit E1). Both of these trends are expanding and improving what we refer to as "advanced connectivity." In addition, a new type of more revolutionary (and more capital-intensive) "frontier connectivity" is emerging, although it is likely to have a more limited geographic footprint in the decade ahead, barring the mass-market deployment of satellite coverage.

Exhibit E1

Connectivity technologies are taking strides forward.

	Connectivity spectrum		Value proposition
Frontier		LEO constellation	Global coverage with significantly reduced latency vs. existing satellite offerings
		High-band 5G (ie, millimeter wave)	Highest speed, low latency, and highly secure cellular connectivity
Advanced		Low- to mid-band 5G	High-speed, low-latency cellular connectivity overlay on existing 4G infrastructure
		Wi-Fi 6	Next-generation Wi-Fi with improved speed, device density, and features to increase device efficiency
		Fiber/DOCSIS 3.x	High-speed, low-latency fixed networks that support other connectivity
		LPWAN (e.g., NB-IoT, Sigfox, LoRa)[1]	Low-power and low-maintenance networks that support high densities of connected devices
		Short range (eg, RFID/Bluetooth)	Short-range and efficient device-to-device connectivity, storage, and identification

1. LPWAN are low-power, wide-area networks; NB-IoT refers to narrow-band Internet of Things.
Source: McKinsey Global Institute analysis

— **Advanced connectivity:** Existing connectivity technologies continue to proliferate and evolve, from backbone networks to the last mile that meets the end user. In networks, for instance, providers are upgrading existing 4G infrastructure with low- to mid-frequency

"non-standalone" 5G network overlay.[1] The results of these upgrades will vary significantly depending on the spectrum used and density of supporting infrastructure such as cell towers. But in general, these low- to mid-frequency 5G networks can offer significant improvements in speed and latency while supporting a greater density of connected devices. Meanwhile, fiber optic networks continue to expand, and the introduction of the new DOCSIS 3.x standard promises to bring the performance of cable broadband closer to that of fiber—and to do so over existing infrastructure. In the last mile of access, the next generation of Wi-Fi (Wi-Fi 6) will improve speeds while supporting many more connected devices. Technologies that use radio signals for tagging, tracking, and contactless short-range communication between devices (such as Bluetooth, NFC, and RFID sensors) are becoming more sophisticated. Low-power wide-area networks (LPWANs, with competing standards such as LoRa, NB-IoT, and SigFox) provide connectivity over broader areas and longer ranges. All of these technologies continue to improve in terms of affordability, functionality, and adoption.

— **Frontier connectivity:** Frontier technologies like high-band 5G and low-earth orbit satellite constellations represent a more radical departure.[2] Designed to be the most ultra-fast mobile option, high-band 5G (often in the form of standalone 5G) promises to put the speed, latency, reliability, and security of fiber in the air, expanding what mobile devices can do. It offers a significant step change in overall network performance from low- to mid-band 5G. Low-earth orbit (LEO) satellites could also deliver a breakthrough—not necessarily in network performance but in breadth of coverage. By essentially beaming broadband down from space, they could bring coverage to remote parts of the world where the economics do not work for laying fiber or building cellular towers. However, providing ubiquitous coverage requires a constellation of many satellites orbiting at once, making viability uncertain. OneWeb and SpaceX are the only companies to launch test satellites (as of this writing), and no commercial services are yet available.

The advances described above are occurring alongside an expansion of hardware and software capabilities.[3] Cloud computing will provide a processing backbone and storage capacity for use cases that require significant computational power. Edge computing will do the same while removing latency limitations. The new architecture of connectivity will also include private corporate networks. These connectivity and computing advances will enable cheaper and much more efficient "thin" devices connecting with the cloud and localized servers; they could become mainstream at the end of the decade for both consumers and businesses.

Advanced and frontier connectivity will enable new capabilities in major commercial domains

Today consumers still power the internet. Online video accounts for some 70 percent of the world's internet traffic, with only small differences across regions. By 2030, we expect that share to exceed 80 percent. By some estimates the world will consume 20 times more data than it does today, with much of this growth driven by new users, more time spent watching video, and higher-definition content.[4]

Connectivity will enable businesses to do more in the next decade as well.[5] Enhanced broadband will make streaming, downloads, and data exchange lightning fast. Because they

1 "Low- to mid-band" refers to the use of frequencies between 600 MHz and 6 GHz, which offer a good balance of throughput, capacity, and coverage. "Non-standalone" 5G refers to the use of an existing LTE network for signaling and network-control functions, with the 5G component exclusively focused on user traffic. In contrast, "standalone" 5G refers to a network that uses 5G cells for both signaling and information transfer.

2 "High-band" refers to the use of frequencies above 24 GHz (also referred to as millimeter-wave spectrum), which offer the ultra-high broadband speed envisioned for 5G.

3 "New demand, new markets: What edge computing means for hardware companies," McKinsey.com, November 2018.

4 Based on Cisco's projections through 2022, and extended to 2030. For Cisco's 2022 projection, see *Cisco Visual Networking Index: Global mobile data traffic forecast update,* Cisco, February 2019.

5 "Are you ready for 5G?," McKinsey.com, February 2018.

require less power, LPWANs can extend the battery life of the devices and sensors they connect, making it viable for the Internet of Things to scale up like never before. Ultra-low latency and strong security will create the confidence to run "mission-critical" applications that demand absolute reliability and responsiveness—even in vital infrastructure systems and in matters of life and death. LEO satellites could provide true global coverage.

Based on industry-specific research and expert interviews, we have identified hundreds of use cases in commercial domains that would run on both advanced and frontier networks. These are independent of the many consumer-driven entertainment and internet applications that are possible. To convey the sheer diversity of use cases, as well as some of the opportunities and implementation challenges, we profile four commercial domains with some of the largest potential to capture higher revenues or cost efficiencies.[6] The use cases we describe in this research are meant to be illustrative rather than exhaustive, and others will likely emerge over time.

— Connectivity will be the foundation for increasingly intelligent **mobility** systems.[7] While the automotive industry is at the heart, mobility is a broader concept that includes car-sharing services, public transit, infrastructure, hardware and software, and more—in short, all of the actors and enablers involving in moving people (and goods) from one point to another on the ground. Connectivity could open up new revenue streams through preventive maintenance, improved navigation and carpooling services, and personalized "infotainment" offerings. Vehicle-to-infrastructure and vehicle-to-vehicle communications can prevent collisions, enable various levels of vehicle autonomy, and improve traffic flow. We estimate the GDP impact of connectivity in mobility to be $170 billion to $280 billion by 2030.

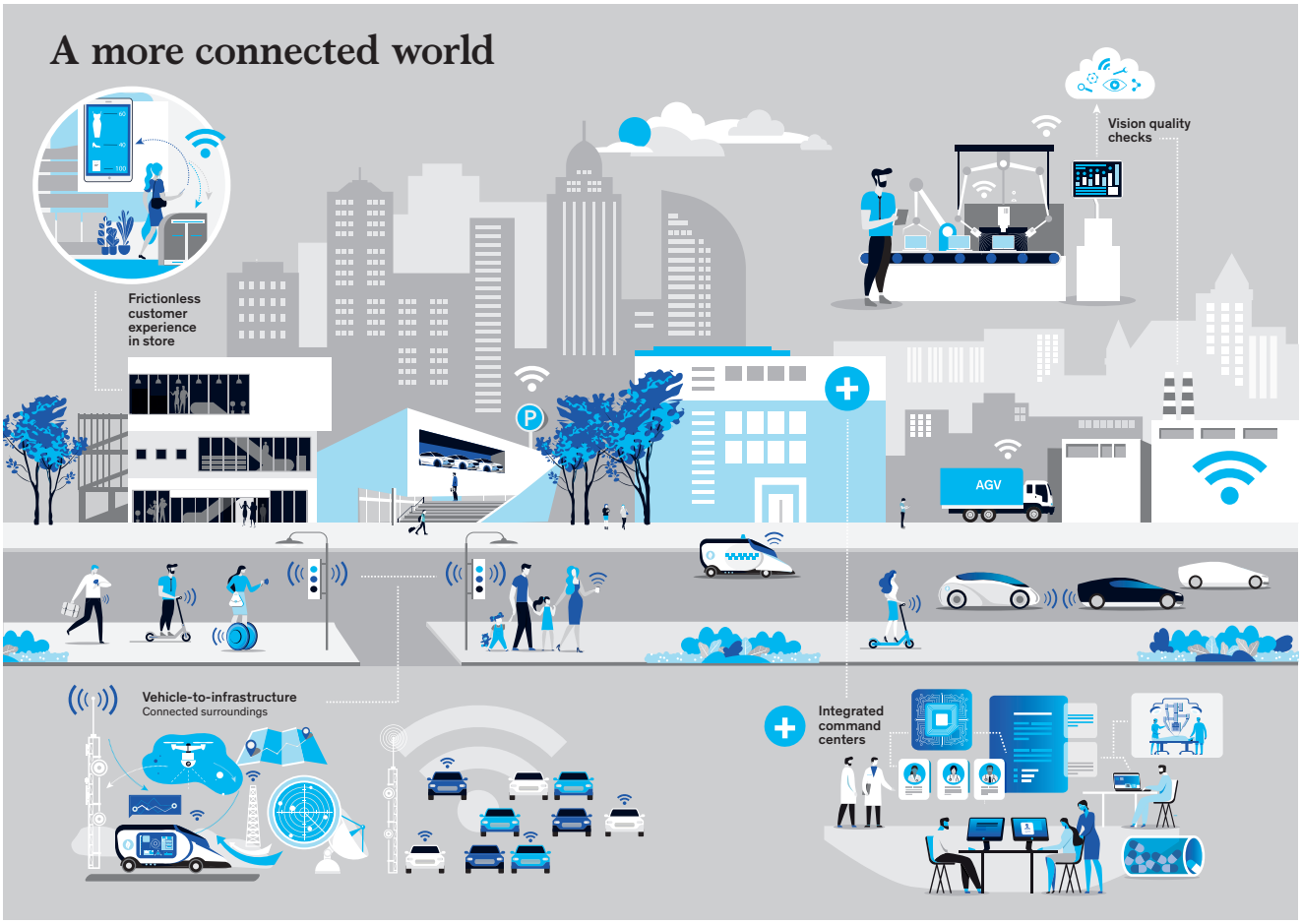
— Connected devices and advanced networks could transform **healthcare.**[8] Low-latency networks and high densities of connected devices and sensors make it possible to monitor patients at home in real time, which could be a major boon in the treatment of chronic diseases. Data can flow seamlessly throughout entire medical systems to smooth operations and coordinate care. AI-powered decision support tools can make faster and more accurate diagnoses, and many tasks can be automated so that caregivers can spend more time with patients. The ability to aggregate and analyze enormous data sets could yield new treatments. Together these use cases could free up additional investment capacity in healthcare and generate $250 billion to $420 billion in global GDP impact by 2030.

— **Manufacturing and other advanced industries** can run highly precise operations using low-latency and private 5G networks.[9] Smart factories powered by analytics, artificial intelligence, and advanced robotics can run at maximum efficiency, optimizing and adjusting processes in real time—not only on select assembly lines but across multiple plants. A growing number of factories will incorporate features such as automated guided vehicles and computer-vision-enhanced bin picking and quality control; these functions require the kind of speeds and ultra-low latency that high-band 5G networks provide. The GDP impact of connectivity in manufacturing could reach $400 billion to $650 billion by the decade's end.

— **Retailers** can use sensors, trackers, and computer vision to manage inventory, improve warehouse operations, and coordinate along the supply chain. Connectivity can support frictionless in-store experiences—for example, eliminating checkout and adding augmented reality for better product information. Real-time personalized

6 In addition to illustrating the range of use cases, these domains were chosen as a large, representative cross-section of the economy. They include both industrial and consumer-facing businesses, with a diverse mix of assets, occupations, and geographic footprints, and they span many different supply chains.
7 "The trends transforming mobility's future," *McKinsey Quarterly,* March 2019.
8 "The era of exponential improvement in healthcare?," McKinsey.com, May 2019.
9 "Five ways that 5G will revolutionize manufacturing," Operations blog, McKinsey.com, October 2019.

recommendations and promotions can increase sales. Some innovative retailers have already begun experimenting with and implementing some of these use cases, and advances in technology and affordability should lead to broader adoption by the decade's end. These use cases in retail could boost GDP by $420 billion to $700 billion.



Building a more connected world could create substantial economic value, mostly enabled by advanced connectivity

The use cases we identified in the four commercial domains described above could boost global GDP by an estimated $1.2 trillion to $2 trillion by 2030 (Exhibit E2). This would be equivalent to 3.5 to 5.5 percent of the expected GDP in these domains.

These use cases (and the capabilities related to enhanced broadband, the IoT, and mission-critical applications) are relevant in other domains as well.[10] Next-generation inventory management, for example, has applicability beyond retail; it also has value for logistics and consumer goods companies. Use cases that improve equipment utilization in factories also apply in mining, oil and gas, and commercial real estate operations. Over and above the value generated in the four domains described in this research, use cases running on advanced and frontier connectivity could generate trillions of dollars in value across the entire global economy.

There are additional economic benefits to businesses, consumers, and society that are not captured in this analysis. They include, for instance, the ability for businesses to differentiate themselves by creating a rich customer experience; the benefit of having better health

[10] On 5G specifically, several papers make the point that the economic potential is linked to business use cases and cross-industry relevance. See, for instance, *The road to 5G networks: Experience to date and future developments*, OECD Digital Economy Papers, No. 284, July 2019; and *The 5G economy: How 5G technology will contribute to the global economy*, IHS Economics and IHS Technology, January 2017.

outcomes and healthier, more productive citizens; and the ability to reduce waste and better manage capital and natural resources in production processes.

In the four domains we studied, advanced connectivity can enable some 70 to 80 percent of the economic potential. A great deal can be achieved without investing in frontier connectivity. This is because even in the wealthiest economies, only a relatively limited set of leading companies are deploying the most ambitious use cases that can run even on today's networks, from sensor-enabled inventory management to logistics tracking. As connectivity improves and hardware and applications become more affordable and mainstream, there is much more room for adoption to spread across domains, driving bigger productivity gains.

By contrast, use cases that require frontier connectivity such as high-band 5G could eventually generate some 20 to 30 percent of the potential impact, based on the use cases we have sized. High-band 5G will create greater network efficiency, boosting speeds and lowering latency even as providers accommodate more consumer-driven traffic and more devices. Existing use cases can run on a bigger scale while becoming more sophisticated and reliable. For example, these capabilities could open the doors to deploying tens of thousands of infrastructure sensors in a dense urban area, streaming data to consumer vehicles and public institutions securely in real time to enable safety features and faster emergency response.[11] It is possible that the value of use cases running on frontier connectivity could exceed our estimates, depending on whether some high-potential but still speculative use cases like augmented reality and self-driving vehicles reach mass adoption by decade's end. A stronger digital backbone can also support new applications we cannot predict today. The extent to which these developments—and the related demand—actually materialize will likely have a meaningful impact on the deployment and adoption of frontier connectivity.

In addition to the potential in these four commercial domains, advances in technology, coverage, and affordability can bring more of the world online. Aging or inadequate networks will be upgraded in future investment cycles, while new digital networks will reach some regions for the first time. Today 40 percent of the global addressable adult population is still under-connected (in other words, not yet using 3G-capable data networks or better) or altogether offline due to inadequate coverage, affordability barriers, or insufficient relevance (such as content in the local language). By 2030, that share could be cut in half. This will be enabled by a combination of trends, including not only wider network coverage but also the growing affordability of devices and data plans, the development of more relevant internet content, and demographic and social shifts (like increasing urbanization rates). This newly online population will benefit from intermediate connectivity via 3G or 4G/LTE cellular networks for basic web browsing, consumer mobile phone applications, e-commerce, and online video.[12] Global GDP could increase by another $1.5 trillion to $2 trillion as a billion people gain better access to digital information, tools, and services.

[11] *Smart cities: Digital solutions for a more livable future*, McKinsey Global Institute, June 2018.

[12] We use the term "intermediate connectivity" to refer to access to 3G and 4G/LTE cellular networks (with speeds of 1 to 50 Mbps and latency of ~50 milliseconds or more). Compared to advanced and frontier connectivity that we defined previously, intermediate connectivity features different technical capabilities, supported applications, and subscriber populations.

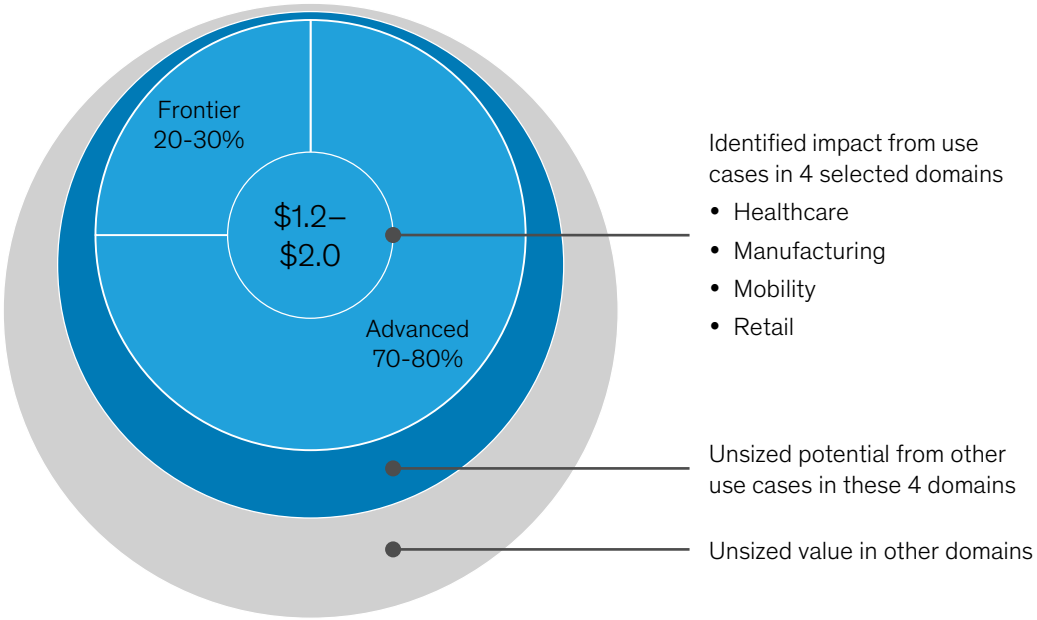
Exhibit E2

We analyzed use cases across four domains.

Connectivity will unlock value in these domains and beyond

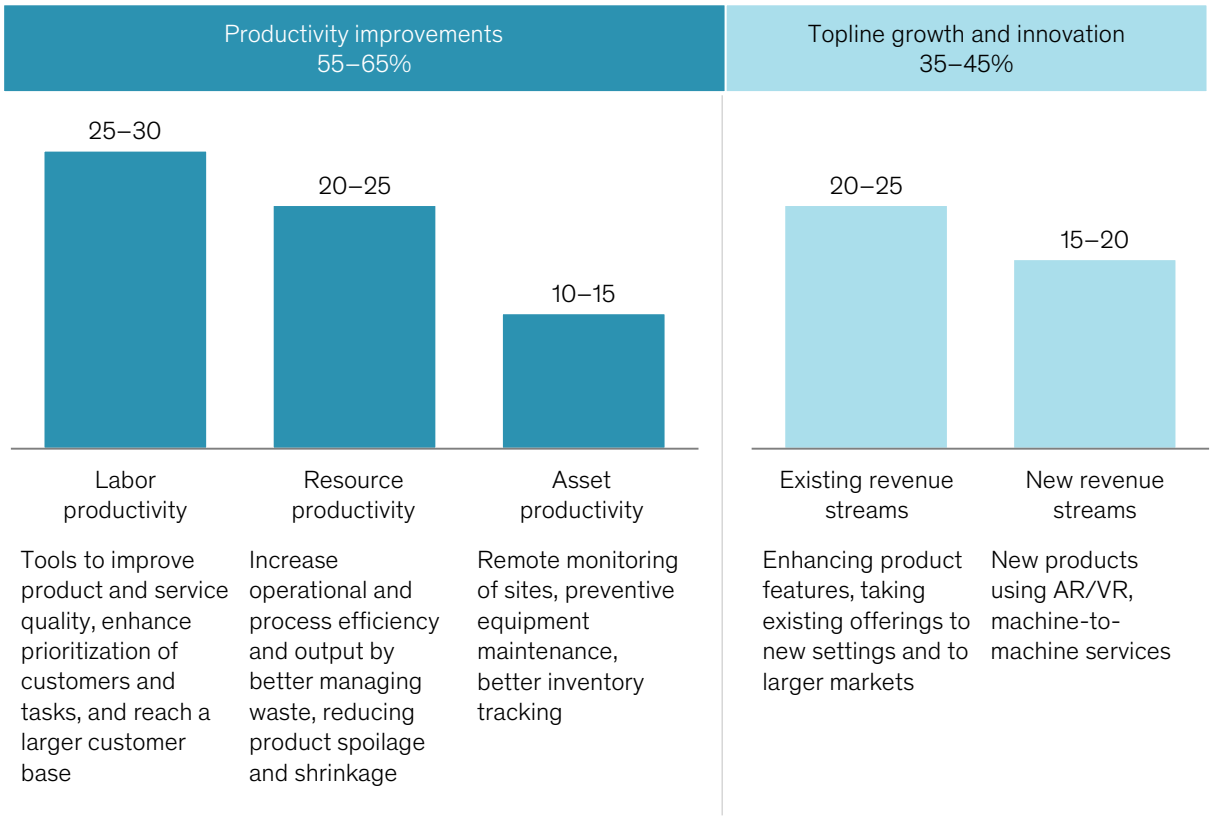
Projected GDP impact from enhanced connectivity, 2030

%; $ trillion



Breakdown of impact category on selected use cases (healthcare, manufacturing, mobility, and retail)

% of total use cases selected



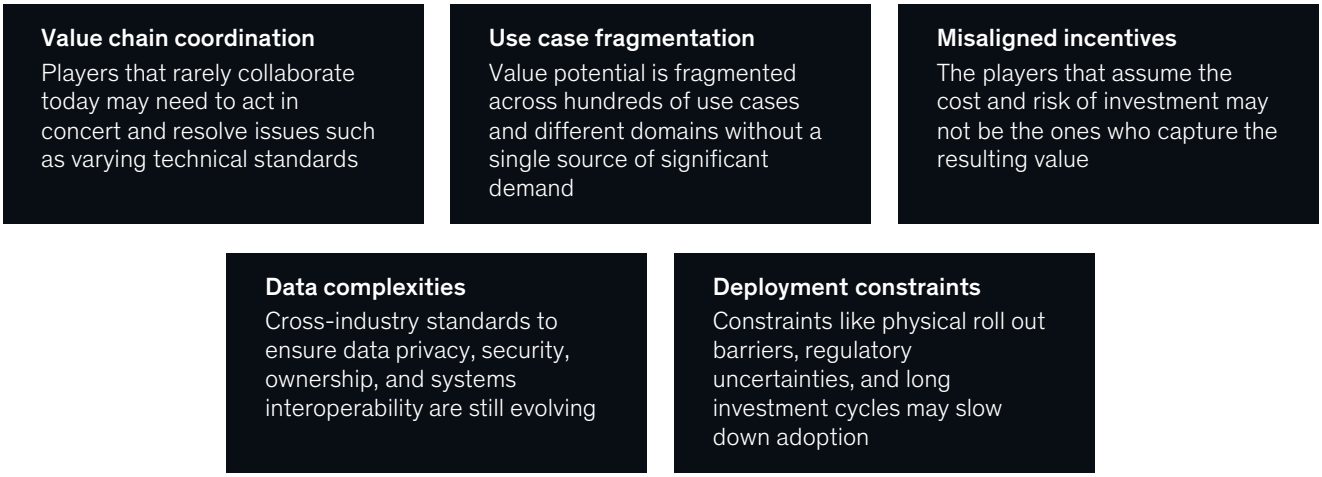
Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Global Institute analysis

To realize the full value at stake, persistent issues need to be solved

The growth of connectivity is a development with substantial promise—and as noted above, most of it can be achieved using technology that already exists today. While this is grounds for optimism, progress has yet to take off. In a world where future economic growth depends on improving productivity, the hurdles slowing both connectivity investment and the widespread adoption of use cases urgently need to be addressed. While the barriers vary somewhat in each commercial domain that we analyzed, many of the issues can be categorized into five groups (Exhibit E3).

Exhibit E3

Longstanding hurdles continue to hold back the promise of connectivity.



Source: McKinsey Global Institute analysis

— **Value chain coordination:** Multiple players across an ecosystem may have to cooperate in order to implement a given use case.[13] Many have never collaborated before, but they will need to work together on issues such as agreeing on technical standards. In mobility, for instance, vehicle-to-infrastructure and vehicle-to-vehicle warning systems involve public infrastructure providers, rival automotive manufacturers, connectivity providers, technology players, and equipment manufacturers. All must align on technical standards in the hardware for the system to work—but standards are still evolving, even in the most developed markets.

— **Use case fragmentation:** The value at stake from enhanced connectivity is substantial when viewed cumulatively across the entire economy, but it requires aggregating many small pockets of potential across hundreds of use cases and domain participants. Connectivity use cases are not always core priorities for participants, especially those who are not as far along in their digital transformation journey. All of this can contribute to companies taking a "wait-and-see" approach or stalling in never-ending "pilot purgatory." Retailers and manufacturers, for example, could both benefit from advanced computer vision, but the value it could produce may not be significant enough for companies in these sectors to create strong demand for someone to deliver these services right away. In such cases aggregators may be needed to create enough viable scale in demand.

— **Misaligned incentives:** This is the familiar monetization question. The actor assuming the cost and risk of investment (and doing the heavy lifting of implementation) in a domain may not be the one who captures the ultimate financial gain. In healthcare, for instance, several connectivity-enabled use cases have the potential to increase efficiency and improve health outcomes. But while hospitals and health providers may be the ones to make such

[13] "Management's next frontier: Making the most of the ecosystem economy," McKinsey.com, October 2017.

investments, train workers, and change their day-to-day operations, the financial benefits may accrue to health insurers or consumers. Similarly, consumer internet, media, and advertising companies have long profited from offering "over-the-top" services that run on networks built and maintained by connectivity providers, but the providers themselves have struggled to monetize this activity in a proportional way.

— **Data complexity:** Many use cases require data sharing across firm and industry boundaries. But standards to ensure privacy, security, ownership, and interoperability are still evolving.[14] Protecting data is paramount for both companies and consumers to guard against ever-evolving risks. In addition, machine-to-machine transmissions (for example, between a hospital's health informatics system and a patient's home health monitor, or between equipment in a remote production plant and an operations hub) requires interoperability between IoT systems.

— **Deployment constraints:** Some of the issues holding back progress include physical barriers slowing network enhancement and use case adoption. Connectivity providers and domain users alike may have an extensive legacy asset base that will be expensive to upgrade. Regulatory uncertainty also needs to be resolved around broad issues as well as domain-specific questions in areas such as mobility and healthcare. For connectivity providers, practical constraints like spectrum availability, access rights to public infrastructure, and power density limits are persistent challenges that often have to be overcome at the local level. Even among commercial customers such as retailers, manufacturers, or wholesalers, adopting connectivity-enabled use cases can be delayed by long capital investment cycles. In the past decade, many firms have postponed asset upgrades due to weak growth and an uncertain investment outlook.[15]

These are thorny issues that cannot be solved by technological advances alone. But they are also not insurmountable challenges. Fragmentation presents an opportunity for an actor—whether government, connectivity providers, tech giants, or industry coalitions—to play a coordinating role. Likewise, current business models may have to evolve to allow for more cross-sector partnerships, realignment of incentives, and risk sharing. In most countries, governments can play a coordinating role or set standards, but the private sector will shoulder most of the weight of forming smoothly functioning ecosystems.

The development of connectivity and the geographic distribution of economic value will be uneven

Even if the market issues described above are resolved, connectivity will not be uniform across different regions. Deployment will be influenced by each market's revenue potential, its existing telecom infrastructure, its urban density, and local market dynamics including competition and regulation. Connectivity providers' own ability to undertake and monetize major capital investment is crucial. Another consideration is the evolution of demand and its distribution across users, applications, and geographies. As a result of all these factors, the business case for deploying advanced connectivity, and especially frontier connectivity, looks very different across markets.

The evolution of connectivity will vary across four country archetypes

We define four country archetypes based on differences in revenue dynamics, such as average revenue per user and level of data usage; cost dynamics, such as the quality and extent of existing telecom infrastructure as well as urban density; and market dynamics, including differences in regulation and competition. Based on these characteristics, we classify countries as being pioneers, leaders, followers, or trailing in connectivity today. We consider China and India as two unique cases in addition to these four archetypes.

[14] *Unlocking the potential of the Internet of Things*, McKinsey Global Institute, June 2015.
[15] "The road to 5G: The inevitable growth of infrastructure cost," McKinsey.com, February 2018.

The countries that are out in front today can continue to expect superior performance and new capabilities that may remain out of reach for years for the countries that trail in connectivity today (Exhibit E4). The countries that stay in the forefront of connectivity could have a first mover's advantage and position themselves to be the innovators.

These four sets of countries are progressing along the connectivity continuum at varying speeds and are likely to continue to do so:

— **"Pioneers,"** including the United States, Japan, and South Korea, have consistently led the pack in connectivity. They are already beginning to deploy high-band 5G networks in cities, taking advantage of mature fixed infrastructure and the relatively strong capital positions of their providers. In these markets, competitive dynamics are forcing providers to race ahead.

— **"Leaders,"** typified by markets such France, Germany, and the United Kingdom, are consistently close behind the pioneers. But operator investment may be constrained in these markets since price competition has reduced margins.

— **"Followers,"** such as Brazil, Poland, and Turkey, are starting with less adept infrastructure, and their providers will find it hard to support the large capital investment needed to build more sophisticated networks. They are expected to lag a few years behind in deployment, especially for frontier connectivity, which will likely be limited to major urban cores only.

— **"Trailing"** markets, such as Pakistan, Bolivia, and many African nations, are unlikely to gain widespread advanced or frontier connectivity in the near term. Although LEO satellites may provide connectivity options in these markets (and in rural areas of follower markets), the cost of deployment and the affordability of user devices will be limiting factors.

In addition to the four archetypes above, China and India retain their unique status:

— **China** has poured huge investment into its fixed and cellular networks for the past several years. It is building out this backbone at a faster rate than any other country, with the aim of offering 5G in all major cities and switching a quarter of mobile subscriptions to 5G by 2025.

— **India** is digitizing faster than any trailing market. Although it is rapidly modernizing mobile networks, they are likely to have performance limitations outside of a few major cities. The country's connectivity providers have come under pressure from price wars, and it will likely take price increases or government action to spur buildout.

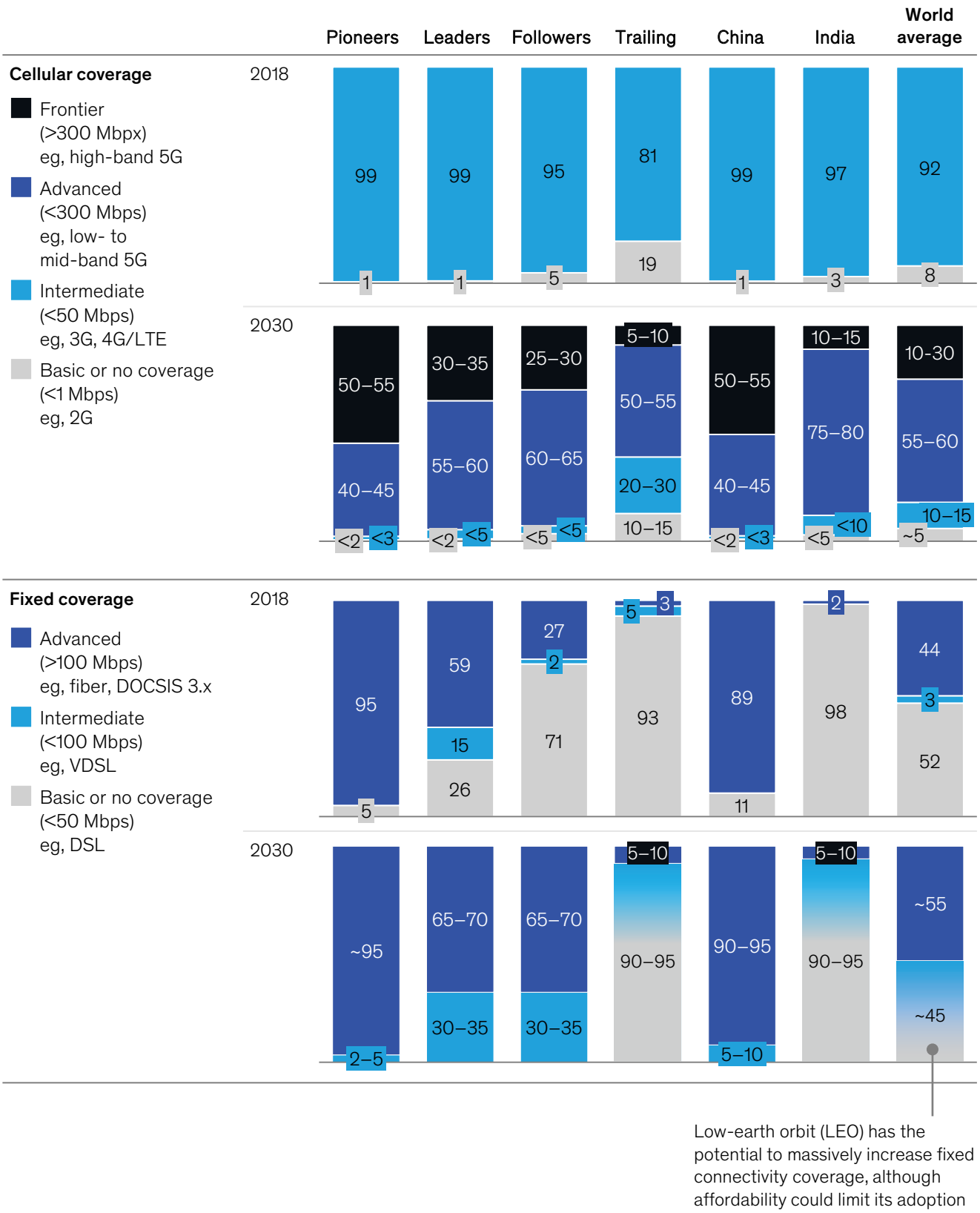
Over the next decade, connectivity providers will continue to build and upgrade networks, but the rate of progress will vary across these archetypes, with pioneers and China consistently leading the pack.

Advanced connectivity—in particular, advanced connectivity that relies on mobile networks, in the form of low- to mid-band 5G coverage—could reach as much as 80 percent of the global population by decade's end. This would come at a cost of some $400 billion to $500 billion. Yet significant gaps will remain. While coverage rates might exceed 90 percent in most of the world, they will likely reach only around 60 percent on average in trailing countries.

Exhibit E4

Connectivity divides between country archetypes are likely to widen.

% of population



Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; United Nations; World Bank; WCIS; National Census Bureaus; corporate annual reports and press releases

Advanced connectivity that relies on fixed networks is a different story. Today, pioneer countries and China enjoy very high fiber coverage rates relative to the rest of the world, due in large part to various private- and public-sector investments. In the years ahead, connectivity providers may not have a strong business case to expand fiber coverage further in many markets without subsidies from governments or other third parties. Without additional investment, fiber coverage is not likely to grow substantially in many parts of the world, although it could more than double in follower markets as they pursue catch-up growth. Overall, we estimate that fiber coverage rates could reach 90 percent or higher in pioneer markets and China, 65 to 70 percent in leader and follower countries, and 5 to 10 percent in trailing markets and India by 2030.

Frontier connectivity (that is, high-band 5G) drives the required investment much higher, creating a tougher business case to do so on a comprehensive scale. Yet in certain dense urban areas with very high per capita data consumption, providers may find that the network efficiency benefits alone justify deployment. Covering roughly a quarter of the world's population by the decade's end would require some $700 billion to $900 billion. While China and pioneer markets are projected to cover up to 55 percent of their populations, the corresponding share is projected to reach 35 percent in leader markets, 30 percent in follower countries, and 10 to 15 percent in trailing markets and India.

Despite the fact that huge populations stand to gain coverage for the first time, the digital divide that separates urban and rural populations and trailing countries from the rest of the world appears likely to persist in the decade ahead. If LEO satellites are successfully deployed, they have the potential to change the game and almost erase the gap. Yet they remain a wild card—and other barriers such as readiness and the affordability of devices and data plans would need to be addressed in addition to coverage.

Where will the value associated with these use cases flow?

Some $1.2 trillion to $2 trillion is at stake in mobility, healthcare, manufacturing, and retail alone. But the pie will not be divided evenly across country archetypes (Exhibit E5).[16] These differing outcomes stem from the expected availability of advanced and frontier connectivity—and the coverage gap will be especially pronounced for frontier connectivity.

In terms of advanced connectivity use cases, we estimate that 60 to 65 percent of the value could go to pioneer markets and China, 20 to 25 percent to leader markets, 10 to 15 percent to followers, and 5 percent to India and trailing countries.[17] The share going to China and pioneers would slightly exceed their expected weight in the global economy in 2030, while the share going to India and trailing markets would fall below. Leader and follower markets stand to make gains that are largely in line with the share of global GDP they are expected to generate.

For use cases running on frontier connectivity, the dispersion of value is more striking. We estimate that 70 to 75 percent would go to China and pioneer markets, 15 to 20 percent to leaders, 5 to 10 percent to followers, and only 2 to 5 percent to India and trailing countries. China stands to capture an outsized share that could be 40 to 50 percent higher than its share of global GDP, while the share going to pioneer markets could be 20–30 percent higher. The story is not as positive for the rest of the world. Leaders might capture a share that is 20 to 30 percent lower than what the expected size of their economies would indicate. Followers might punch 30 to 40 percent below their weight, while trailing countries and India could capture a share of the anticipated value that is 70 to 80 percent below their share of global GDP.

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16 We estimate this distribution based on each archetype's GDP share, its current and expected evolution of fixed and wireless connectivity, its urban density, and the demand for use cases and their economic viability in the region.

17 It should be noted that significant value and GDP gains are possible in India and trailing markets from a range of use cases enabled by the expansion of intermediate connectivity, along with foundational digital identification infrastructure and digital payment systems. See *Digital India: Technology to transform a connected nation*, McKinsey Global Institute, March 2019; and *Digital identification: A key to inclusive growth*, McKinsey Global Institute, April 2019.

Exhibit E5

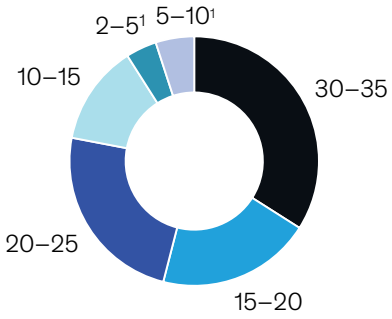
The value produced by use cases running on advanced and frontier connectivity could be distributed unevenly.

2030

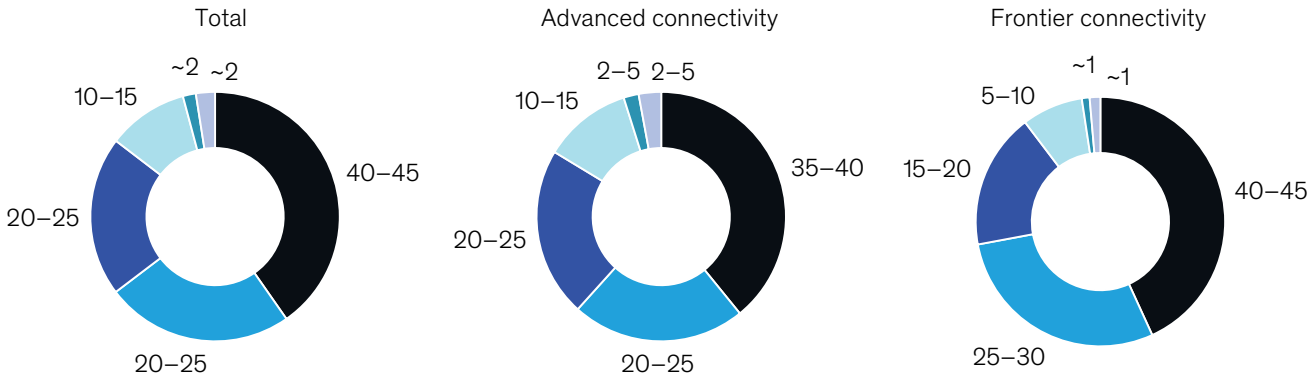
%

Pioneer | China | Leader | Follower | Trailing | India

Projected global GDP contribution by country archetype



Distribution of GDP impact of connectivity-enabled use cases



Note: Figures may not sum to 100% because of rounding.

1. The relatively low shares in India and trailing markets could be offset by a range of use cases enabled by the expansion of intermediate connectivity, as well as foundational digital identification infrastructure and digital payment systems.

Source: McKinsey Global Institute analysis of data from GSMA Intelligence; iDate; Analysys Mason; Ovum; *The Economist*; UN data; World Bank; World Cellular Information Service; IHS Markit Global Industry Service; national census bureaus

Unlike the value produced within commercial domains, approximately half of the $1.5 trillion to $2 trillion associated with bringing a larger share of the population online could be concentrated in India, trailing countries, and follower countries. This is because the affordability and network availability gaps that can be closed over the next decade are most prevalent in these types of countries. An additional one-third would stem from China.

Providing connectivity is a tough business that could get tougher

The question of how to monetize usage has dogged connectivity providers (notably telecom operators) in previous technology cycles, and now the same issue threatens to carry over into the next. It will not be resolved solely through investing in new networks. Those networks will create major opportunities, but it will take new strategies to capture them.

The road for many connectivity providers has been rocky in recent years, and it does not look much smoother in the decade ahead. Build-outs and upgrades will demand major investment at a time when mature markets are saturated, and competition is leading to price wars. Many providers will struggle to find the required capital and make investments pay off with conventional revenue models. In some countries, competitive pressures or regulation are forcing connectivity providers to plunge ahead with buildouts and upgrades even before the economics have become clear.

Connectivity providers that have already invested heavily in laying digital infrastructure foundations will likely be able to maintain stable ratios of capital investment to earnings even as they continue with their rollouts. But the pressure will be acute for those that have not yet invested heavily and now find themselves facing a game of catch-up with new technologies. Those outside of pioneer markets and China will collectively need to find significant additional annual revenue growth to deliver adequate returns to their shareholders while continuing to cover the costs of advanced connectivity upgrades—let alone frontier networks.

Our research raises more questions about the future of connectivity

Our research to date has surfaced a number of questions and uncertainties that require further investigation.

First, as connectivity providers face the need to sustain major capital investment, what kind of new business models might emerge? Can providers form partnerships to share the costs of deployment? Network sharing has proven successful with previous generations of cellular connectivity, and it could reduce the cost of 5G deployment.[18] Further, can providers partner with businesses in other domains to create viable long-term strategies, potentially taking a bigger role in developing innovations such as connected vehicles, remote healthcare, or the Internet of Things?

A second set of questions revolves around what types of new players might become connectivity providers, from tower and infrastructure companies to tech giants. To what extent will companies across industries opt to build their own private networks, and who will own that space? How likely is it that today's traditional telecom operators will continue to provide the backbone of connectivity architecture for years to come? What about in the "last mile" of connectivity services? LEO satellites in particular remain a wild card; it is still unclear if their offerings will gain traction and become profitable. If so, they could dramatically expand capacity and intensify pricing pressure throughout the industry.

Beyond infrastructure implications for connectivity providers, the broader technical architecture is changing within specific domains. Enhanced connectivity may open opportunities to rethink where and how computing happens, especially when combined with advances in computing (such as cloud, edge, and quantum computing), device and sensor efficiency, storage, and software design. Connectivity providers and technology companies alike are already hurrying to identify potential new offerings, as evidenced by Amazon and Verizon's recent 5G Edge computing partnership.[19] These changes could have meaningful implications for the full technical stack of companies and across entire domains.

Another set of questions relates to consumers. Consumer media and entertainment accounts for most of the capacity usage—yet the demand is skewed by a small share of consumers, and providers have had a hard time monetizing this usage. Will this trend continue, or will new applications change this dynamic? The research suggests that 2 billion new consumers will come online over the next decade. Will they follow the same pattern?

[18] "Network sharing and 5G: A turning point for lone riders," McKinsey.com, February 2018.
[19] Brian Heater, "Verizon and AWS announce 5G Edge computing partnership," TechCrunch, December 2019.

A related area, which we will explore in future research, centers around use cases in other commercial domains. How much more economic value can they generate? How different are their use cases from the ones considered in this research, and can most of them similarly be executed using currently available technologies? Beyond the barriers to adoption identified in this research, do other domains have additional, specific issues due to their market dynamics, incentives, or regulations?

Lastly, the role policy makers will take in shaping the connected world of the future remains unclear. To date, governments around the world have taken markedly different approaches in facilitating the expansion and evolution of connectivity. In some markets, governments have played a very hands-on role through direct investment and subsidies for connectivity providers. Some are investing heavily in R&D. Others are taking a more hands-off role, simply facilitating the broader connectivity market through actions like spectrum auctions. In addition to these levers, regulations on topics such as spectrum sharing and power density will have major implications for where, when, and how the value of enhanced connectivity will be realized.

Advanced and frontier connectivity will give companies in every domain a powerful new platform for innovation and productivity. The full range of new use cases that can be developed on top of this digital backbone will become apparent in the decade ahead, including some that we cannot imagine today. Turning all of this potential into reality depends on whether connectivity providers, end users in multiple domains, and public officials can forge new models and clear away some of the barriers. The world could soon be more connected—setting the stage for both innovation and disruption along the way.

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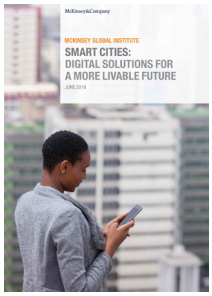

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