The 5G Economy

How 5G will contribute to the global economy

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This report, which offers an independent assessment of the importance of the 5G technology to the global economy through 2035, was commissioned by Qualcomm Technologies, Inc. IHS Markit is exclusively responsible for this report and all the analysis and content contained herein. The analysis and metrics developed during this research represent the independent views of IHS Markit and are intended to contribute to the dialogue on the role of 5G in promoting global economic growth.

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Executive summary

The printing press. The internet. Electricity. The steam engine. The telegraph. Each of these discoveries or inventions is part of an elite class of socioeconomic mainsprings known as general purpose technologies (GPTs). Established through pervasive adoption across multiple industries, GPTs are often catalysts for transformative changes that redefine work processes and rewrite the rules of competitive economic advantage. The profound effects arising from these innovations range widely, from the positive impacts for human and machine productivity to ultimately elevating the living standards for people around the world.

IHS Markit views 5G as a catalyst that will thrust mobile technology into the exclusive realm of GPTs. In the 2017 edition of this landmark study and now for the 2019 update, IHS Markit evaluated the potential of 21 unique 5G use cases that will affect productivity and enhance economic activity across a broad range of industry sectors. IHS Markit further examined the central role the 5G value chain will play in continually strengthening and expanding the mobile technology platform. Finally, IHS Markit determined the net contribution of 5G to positive, sustainable global economic growth. While this study focuses on long-term economic contributions of 5G, it is important to recognize that the 5G economy is beginning to emerge, and since the 2017 study, numerous deployments of commercial 5G have launched, creating the potential for economic contributions starting in 2020.

Key findings

- Compared to the 2017 study, the 2035 forecast for **5G technology's impact on global economic output has increased by ~$1 trillion** due, in a large part, to the early completion of the first 5G standard and the resulting earlier-than-anticipated commercial 5G launches by major operators.
- In 2035, 5G will enable **$13.2 trillion of global economic output**. That is nearly equivalent in current dollars to US consumer spending ($13.9 trillion) and the combined spending by consumers in China, Japan, Germany, UK, and France ($13.4 trillion) in 2018.
- The global 5G value chain will generate **$3.6 trillion in economic output** and support **22.3 million jobs** in 2035. This is approximately the combined revenue of the top-10 companies on the 2019 Fortune Global 1000—a list that includes Walmart, Sinopec Group, Royal Dutch Shell, China National Petroleum, State Grid, Saudi Aramco, BP, ExxonMobil, Volkswagen, and Toyota. Fortune estimates these companies employ almost 6.5 million workers. Thus, for the same level of output, the 5G value chain will support 3.4 times as many jobs.
- The 5G value chain will **invest an average of $235 billion** annually to continually expand and strengthen the 5G technology base within network and business application infrastructure. This figure represents nearly 80% of total US federal, state, and local government spending on transportation infrastructure in 2017.
- The investment in and deployment of 5G will fuel sustainable long-term returns to global real GDP. For the study period of 2020 – 2035, **5G's stream of annual contributions to real global GDP yields a net present value of $2.1 trillion, equivalent to the present-day size of Italy's economy**, currently the eighth-largest in the world.

Note: Unless otherwise stated, monetary units are 2016 US dollars.

To date, mobile technology has progressed from a predominantly people-to-people platform (3G) toward people-to-information connectivity on a global scale (4G). 5G can leverage and extend the research and development (R&D) and capital investments made in prior mobile technologies to advance mobile to a platform that delivers the much-needed ubiquity, low latency, and adaptability required for future uses. 5G will make possible new classes of advanced applications, foster business innovation, and spur economic growth. The emergence of 5G is a fulcrum in the evolution of mobile technology from a technology that had transformative impact on personal communications to a true GPT that promises to transform entire industries and economies.

How will 5G be used?

Enhanced Mobile Broadband (eMBB)	Two key facets of eMBB will drive adoption and value creation in the 5G economy. The first is extending cellular coverage into a broader range of structures including office buildings, industrial parks, shopping malls, and large venues. The second is improved capacity to handle a significantly greater number of devices using high volumes of data, especially in localized areas. These improvements to the network will enable more efficient data transmission, resulting in lower cost-per-bit for data transmission, which will be an important driver for increased use of broadband applications on mobile networks.
Massive Internet of Things (MIoT)	5G will build upon earlier investments in traditional Machine-to-Machine (M2M) and IoT applications to enable significant increases in economies of scale that drive adoption and utilization across all sectors. 5G's improved low power requirements, the ability to operate in licensed and unlicensed spectrum, and its ability to provide deeper and more flexible coverage will drive significantly lower costs within MIoT settings. This will in turn enable the scale of massive IoT and will drive much greater uptake of mobile technologies to address MIoT applications.
Mission Critical Services (MCS)	MCS represents a new market opportunity for mobile technology. This significant growth area for 5G will support applications that require high reliability, ultra-low latency connectivity with strong security, and availability. This will allow wireless technology to provide an ultra-reliable connection that is indistinguishable from wireless to support applications such as autonomous vehicles and remote operation of complex automation equipment where failure is not an option.

5G will transform mobile into a GPT

Following an incubation period, a GPT hits an adoption tipping point that leads to transformational, and often disruptive, changes to industries and entire economies (see sidebar: GPTs have profoundly changed industries and economies).

GPTs share some common attributes, including pervasive use across many industries, continual improvement over time, and the ability to spawn new innovations. GPTs lead to deep and sustained impacts across a broad range of industries that often redefine economic competitiveness and transform societies. IHS Markit anticipates that as 5G technology advances and becomes embedded within devices, machines, and processes, wireless communication will be elevated to the pantheon of GPTs.

Digital mobile technology has steadily progressed from interconnecting people to serving up the data people depend on in both their personal and professional lives. For example, mobile technology is often cited as playing a basic yet essential role in connecting remote citizens in emerging economies to vital services, such as the rise of mobile banking in Nigeria. Accordingly, many of the advancements in mobile technology to date have delivered the increasingly higher bandwidth necessary to provide nearly ubiquitous voice and data coverage. While some M2M and early IoT applications have emerged, these typically employ older technologies for specific use cases. Driven by media and investor hype for companies at mobile vanguards such as Uber, mobile technologies are still primarily used to address consumer and enterprise use cases and have yet to make significant inroads in radically transforming the industrial or public sectors of economies. While these early mobile generations have been foundational for mobile technology's journey to ubiquity, 5G will be the technology platform that connects cars and cities, hospitals and homes, and people to everything around them in more meaningful ways. Legacy cellular technologies (2G, 3G and 4G) currently enable a range of connected car applications such as Wi-Fi internet, infotainment, usage-based insurance, engine monitoring and many others. With 5G, connected cars will also be able to communicate with other cars and roadside infrastructure, such as traffic lights.

The planned advancements for 5G are expected to explicitly address the incredibly diverse set of use cases present in IoT. Different aspects of the standard are being "purpose built" to address MIoT-type applications, as well as mission- critical use cases that include autonomous vehicles, industrial automation, and telehealth. This expansion of capabilities is being implemented as part of one unified design, which means that the same 5G infrastructure can be used to support a wide range of use cases. The widening diffusion across industries and processes where wireless currently has limited penetration will position mobile technologies for a deep and sustained impact across a broad range of sectors.

The 5G economy will introduce a new level of complexity to policymaking and regulation as new business models emerge and the old ways of delivering goods and services are either dramatically altered or abandoned completely. Areas where policy and regulatory modernization will be required for a 5G-ready world include public safety; cybersecurity; privacy; spectrum allocation; public infrastructure; healthcare; spectrum licensing and permitting; and education, training, and development. The challenge for policymakers in the 5G economy is that they must be prepared to address the ubiquity of 5G in everyday life without creating regimes that stunt the continued innovation that will be critical to the success of the 5G economy. Policies that safeguard the ability of firms to take risks, make investments, and continue the relentless pursuit of innovation—particularly rules governing intellectual property protection—are the optimal vehicle for leveraging and capturing the full value of the 5G economy.

By 2035, the ubiquity of 5G will result in impacts that advance beyond the capability of existing technologies, platforms, and industries, yet the proliferation of 3G and 4G mobile technology provide important analogs as the 5G economy blossoms. As large as 5G private-sector-led investment is expected to be, it is, nonetheless, additive to the infrastructure investment and R&D spending that was preceded by 3G and 4G. The prospect of 5G ubiquity is a continuum of 3G and 4G investments that emerge from technology and spectrum licensing dynamics that incentivized R&D and big economic wagers on the prospect of an increasingly wireless-reliant economy. Policies and incentives that encourage investments and the availability of risk capital, aided by strong intellectual property protections, will maintain the hospitable environment that will allow the 5G economy to flourish.

The IHS Markit analysis of the 5G economy assesses both a technology perspective—how 5G improves upon existing and enables new use cases—and how 5G technology will impact the global economy. Ultimately, the test of any investment is how much it improves the quality of life globally. The IHS Markit analysis documents how 5G technology will improve the ability for people and machines to interact with each other and more quickly share information to achieve greater return on their time and capital in pursuit of their personal and professional goals and outcomes. The economic effect of new investment, R&D, and technological innovation alone indicates 5G will have a profound and sustained impact on global growth. IHS Markit further asserts that the diffusion of 5G technologies across wide swaths of the global economy represents one of the fundamental contributors to expansion in the global economy over the next two decades.

GPTs have profoundly changed industries and economies

Gutenberg invented the printing press around 1440. Prior to this, books had to be laboriously hand copied one at a time. With the printing press, books could be mass produced, helping spread ideas throughout Europe as it entered the Renaissance in the early 16th century.

Before the steam engine, large factories needed to be located near rivers, which were not always reliable sources of power for equipment. The steam engine broke that dependency while also allowing factories to be located closer to raw inputs or transportation routes.

Electricity took it a step further. In steam-driven factories, equipment still needed to be organized around a system of belts that delivered power. Electricity allowed machinery to be designed with integrated power supplies. This allowed new, more efficient configurations of machines, including the assembly line, which redefined manufacturing practices and competitive dynamics on a global scale.

Prior to the widespread use of the telegraph in the 1860s, long-distance communications could travel only as fast as a physical asset could carry a message from point A to point B. The telegraph virtually eliminated the time constraints of long-distance communications, setting the world on the path that led to today’s sophisticated, instantaneous telecommunications infrastructure.

Other technologies that qualify as GPTs include rail systems, the automobile, and the internet.

Introduction: The 5G economy

5G mobile networks represent the next major phase of mobile telecommunications standards beyond the current 4G Long Term Evolution (LTE) standards. 5G technology will do far more than usher in new service opportunities for mobile network operators (MNOs). Indeed, IHS Markit expects 5G will act as a catalyst that turns mobile into a robust and pervasive platform that fosters the emergence of new business models and transforms industries and economies around the globe. 5G technology will advance mobile networks by heightening the mobile broadband experience while evolving to address the emergent requirements of MIoT and MCS applications.

Initially, 5G deployments are centering on eMBB applications that address human-centric needs for access to multi-media content, services, and data. eMBB use cases will include new application areas, requirements for improved performance, and an increasingly seamless user experience beyond what is possible using existing mobile broadband applications. For example, many future wide area coverage applications will require seamless coverage, medium-to-high mobility, and a much-improved user data rate compared with existing data rates. Further, eMBB applications may require hotspots, areas characterized by high user density, very high traffic capacity, low mobility, and user data rates higher than that of wide area coverage. These improvements to the network will enable more efficient data transmission, resulting in lower cost per bit for data transmission, which will be an important driver for increased use of broadband applications on mobile networks. As of writing, South Korea’s operators have already attracted 3 million 5G subscriptions since launch in April 2019. The country’s three operators have deployed 5G using both 3.5GHz spectrum and 28GHz (mmWave); in Seoul hotspots using mmWave have been deployed.

As integration of 5G progresses, industry and governments—as much as consumers—will be chief drivers of 5G deployments. MCS will include autonomous vehicles, many drone applications, and telemedicine. These applications will require ultra-reliable and low latency communications, with stringent requirements for capabilities such as throughput, latency, and availability. Many industries and municipalities will also deploy MIoT—applications characterized by large numbers of connected devices typically transmitting relatively low volumes of low-priority data. Enabled by low-cost, long-life modules with sensors and connectivity, MIoT applications will range from asset tracking to smart cities to the monitoring of utilities and vital infrastructure.

IHS Markit assessed three facets of potential economic contribution 5G could make to the global economy by 2035, assuming the regulatory environment is favorable to growth. The first is potential sales of products and services that will be enabled by the pervasive use of 5G across a broad spectrum of industries to both optimize their core processes and establish new business models. Second, a vibrant 5G value chain will continue to deepen the underlying 5G technology base through focused R&D efforts, infrastructure investments, and application development. Finally, mobile technology enhanced by 5G holds the potential to drive long-term, sustainable growth of global GDP—the ultimate gauge of healthy economic progress.

When at the cusp of an era that promises transformational technological change and a revamping of countless activities within everyday life, public policy is often strained to keep pace with technology advancements. The 5G economy will introduce a new level of complexity to policymaking and regulation as new business models emerge and the old ways of delivering goods and services are either dramatically altered or abandoned completely. In the 4G era, the policy challenges born of the “sharing economy” with disruptors such as Lyft and Airbnb are emblematic of the nascent tidal wave of policy challenges that will emerge in the 5G economy.

To realize the economic potential of the 5G economy, it will be necessary to continue the investment and R&D that are already driving innovation and advancing this new generation of technology. An understanding of the need for swift progress was evidenced by the initial 5G standard being completed ahead of scheduled. Hastening the ongoing journey to the 5G economy requires that policymaking bodies:

- Enable firms to make long-term investments and R&D
- Engender public-private cooperation on development of 5G standards
- Ensure regulation and permitting keep pace with the rate of innovation

The challenge for policymakers in the 5G economy is that they must be prepared to address the ubiquity of 5G in everyday life without creating regimes that stunt continued innovation. This was less the case in prior generations of wireless technology that addressed the requirements of voice, data, and digital content via mobile devices. As 5G diffuses across home and business, leisure and workplace activity, and public and private spaces, modernization of policy becomes essential.

Furthermore, policymaking will be affected at all levels of government—national, state/provincial, and local. The pervasiveness of 5G technology and pace of technology change evident in the use cases outlined in this study place an even greater burden on policymakers to try to keep up with the ways that 5G will transform lives and industries. Public safety; cybersecurity; privacy; public infrastructure; healthcare; spectrum licensing and permitting; and education, training, and development are merely a few of the areas where policy and regulatory modernization are required for a 5G-ready world.

In summary, while consumers and industry have voted with their spending with respect to integrating more technology into day-to-day existence, policymakers will be under new challenges to adapt policies and regulations to the many innovations engendered by 5G technology. In the mid-20th century, government investment led the way in transforming the global economy through massive investments in public infrastructure. Early in the 21st century, private investment in technology infrastructure is shaping how goods and services are delivered, and private investment will likely continue to transform the global economy. Policy frameworks that safeguard the ability of firms to take risks, make investments, and continue the relentless pursuit of innovation are important vehicles for continuing on the path to the 5G economy and ensuring growth.

On the trek to the 5G economy, policymakers should ensure adequate intellectual property protections for standardized technology in order for growth to materialize over the investment cycle. Firms at the vanguard of 3G and 4G mobile technology invested heavily in R&D based on an investment risk calculus that factored in adequate intellectual property protections for innovations. To realize the investment and economic potential of the 5G economy, similar conditions that stimulate continued R&D and risk capital must endure.

5G technology and use cases

5G overview

5G mobile networks are the focus of mobile telecommunication standards now that LTE is inching toward a decade of deployment and the planned improvements have been released. Since the 2017 edition of this study, LTE Advanced (LTE-A) and LTE Advanced Pro (LTE-A Pro) standards were completed and are essential building blocks for 5G. Additionally, the first 5G standard, Release 15, was completed ahead of schedule, in 2018, and will be discussed further below.

Each successive generation of mobile network technology has improved to address the voice experience as well as the data throughput, efficiency, and capacity challenges presented by the current set of mobile broadband applications. The current technical roadmap for 5G is expected to take this a step further—not only improving the mobile broadband experience, but also evolving to address the particular requirements of MIoT deployments and MCS use cases.

Initially, 5G deployments are centering on enhanced Mobile Broadband (eMBB) and fixed wireless access applications. eMBB addresses the human-centric use cases for access to multi-media content, services, and data. In particular, video is expected to play an important role across a broad range of MBB devices. One of the key benefits of 5G is that it will also enable mobile networks to operate more efficiently, driving a lower cost per bit for data transmission. This will be critical for mobile network operators to address new use cases that are media and data intensive, such as AR and VR applications. The eMBB usage scenario will come with new application areas and requirements, in addition to existing mobile broadband applications for improved performance and an increasingly seamless user experience. This covers a range of cases, including wide area coverage and hotspots, which have different requirements.

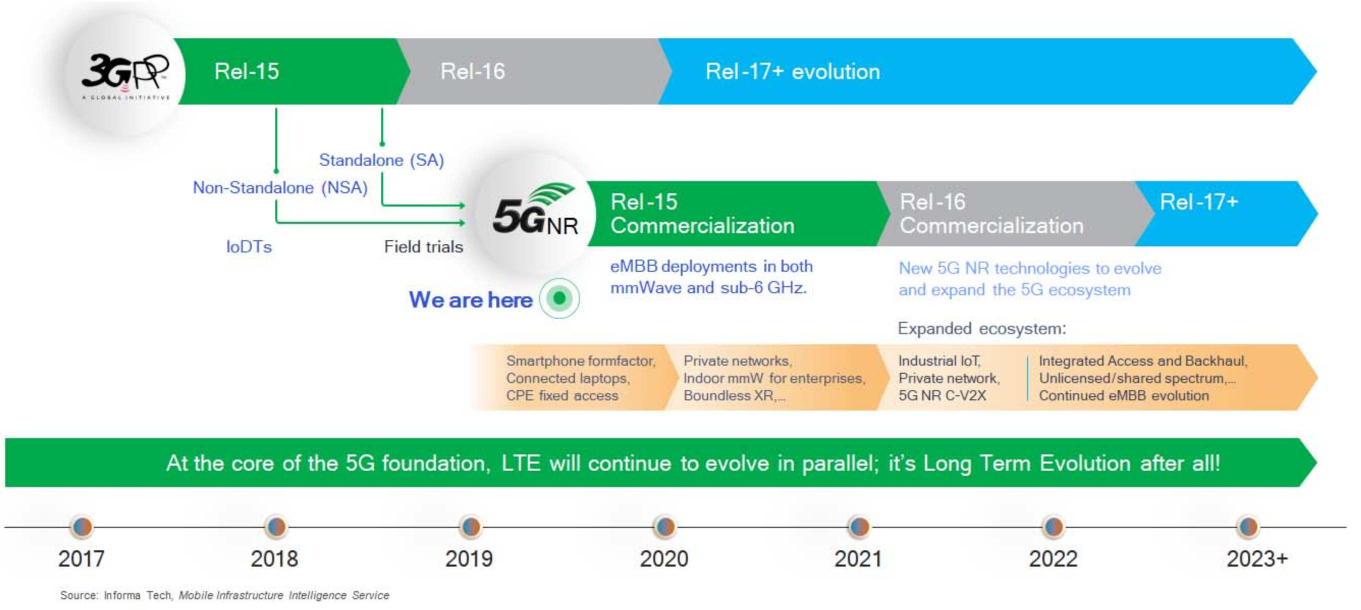
- Hotspots are areas with high user density. Very high traffic capacity is needed, the requirement for mobility is low, and the user data rate is higher than that of wide area coverage.
- Wide area coverages need seamless coverage. Medium to high mobility are desired, with a much-improved user data rate compared with existing data rates; however, the data rate requirement might be relaxed compared with hotspots.

Beyond the eMBB use cases, the proposed 5G specifications also include features that will significantly extend the capabilities of current mobile and fixed-line technologies. These will allow 5G to address a range of use cases, including MCS and MIoT applications.

MCS use cases require ultra-reliable and low latency communications, with stringent requirements for capabilities such as throughput, latency, and availability. Some examples include autonomous vehicles, wireless control of industrial manufacturing or production processes, telemedicine, and distribution automation in a smart grid.

While the MCS use cases require extremely high performance, the MIoT use cases are characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Consequently, these devices are required to be low cost and have a very long battery life.

There are several important standards efforts under way for 5G. The 3rd Generation Partnership Project (3GPP) completed Release 15, the first full set of 5G standards in 2018. This release primarily enables eMBB use cases. Future 5G standards based on Release 16 and 17 will be developed in the next few years and address MIoT and MCS requirements.



There is significant commercial work under way by the entire ICT ecosystem, from chipset and device suppliers to network infrastructure players. As of August 2019, the GSA reported 39 operators who had launched 3GPP 5G services.

For the purpose of this study, specifically the issue of looking at an assessment of the economic impact of 5G networks, the decision was made to use 2035 as the measurement point. This is based on the following assumptions:

- The 5G standard development milestones continue to be met
- The pre-standard development work will accelerate development of 5G capable chipsets and devices
- Standards-compliant 5G radio access network deployments continue in 2020 and are widely commercially available from 2022 onward
- Prices on 5G radios for end devices (all types—eMBB, MCS, and MIoT) are very competitive, driven in part by economies of scale

Based on these assumptions, IHS Markit expects that, by the year 2035, 5G will have had over 10 years of broad commercial availability. By this point, even the new use cases targeting markets like industrial, which has historically been slower to adopt new technologies, are expected to be in heavy use.

5G use cases

For this study, IHS Markit assessed the technological diffusion cycle, adoption, and potential long-term economic contribution of 21 foreseeable 5G use cases described below, which fall into the three broad classifications of eMBB, MIoT, and MCS. This is not intended to be an exhaustive list of likely 5G use cases, merely a representative sample that highlights what the technical innovations of 5G will make possible. The following sections provide a brief overview of each use case segment, with a detailed description for all 21 use cases located in Appendix A of this report.

Use case adoption timeline variance between this and the 2017 edition are highlighted at the end of each section.

Enhanced Mobile Broadband (eMBB)

Two key facets of eMBB will drive adoption and value creation in the 5G economy. The first is extending cellular coverage into a broader range of structures, including office buildings, industrial parks, shopping malls, and large venues. The second is improved capacity to handle a significantly greater number of devices using high volumes of data, especially in localized areas. The net result of these two improvements is that end users will have an improved, and more consistent, experience using mobile broadband applications regardless of location.

- Enhanced indoor wireless broadband coverage
- Enhanced outdoor wireless broadband
- Fixed wireless broadband deployments
- Enterprise teamwork/collaboration
- Training/education
- Augmented and virtual reality (AR and VR, respectively)
- Extending mobile computing
- Enhanced digital signage

The eMBB use cases are most likely to have a near-term impact. These are largely an extension of the existing 4G value proposition and should see relatively quick uptake in the market as 5G networks become commercially available. While there are going to be significant impacts to global economic activity as a result of the eMBB use cases (such as operators now being able to offer stadium coverage services, AR/VR capabilities and support extended mobile computing), because these are largely enhancements to existing services, the net economic impact of 5G will be less transformative than with the MIoT and MCS cases.

Variance between the January 2017 report and this report are limited in eMBB use cases. On the one hand, some operators have taken advantage of the early completion of 5G NSA NR by launching 5G commercial service in 2019. On the other hand, other operators and countries, such as Japan, have engaged in extensive field trials (using mid-band and mmWave spectrum) ahead of commercial 5G launches in 2020. Operators will benefit from a quickly growing range of 5G handsets coming on stream over the next few years. In its Design Forecast Tool (Mobile Handsets (August 2019), IHS Markit forecasts that 22 5G handset models will be introduced in 2019, rising to 119 in 2021 and over 200 in 2023.

With its enhanced capacity and available bandwidth, 5G is much better placed to address the requirements of households and businesses than 4G LTE, which failed to gain significant traction as a fixed wireless technology. Nevertheless, the short- and longer-term impact of 5G fixed wireless broadband has been slightly downgraded. Operators that have launched commercial 5G fixed wireless are typically rolling out coverage gradually as they focus on providing a consistent, reliable quality for this new type of service. They are also still working out how best to price 5G fixed wireless (both the service and hardware, customer premise equipment or CPE, elements) including differentiation based on speeds or data allowances. The fragmented nature of the spectrum bands used across the world for 5G fixed wireless access, from sub-6GHz (3.3-3.8GHz) to mmWave (28GHz and 39GHz), may require the development of region- or-country-specific CPE, inhibiting potential economies of scale.

In the longer-term, 5G is well placed to address geographical areas where fixed broadband (DSL, cable or FTTP) are either unavailable or supports limited bandwidth: typically, rural or suburban, rather than urban areas that are typically well served by DSL, cable or FTTP. Operators will need to weigh the cost and opportunity of deploying 5G fixed wireless against extending out or upgrading their current fixed broadband networks to uncovered or underserved areas.

Massive Internet of Things (MIoT)

5G builds upon earlier investments in M2M and traditional IoT applications to enable significant increases in economies of scale that drive adoption and utilization across all sectors. Improved low-power requirements, the ability to operate in licensed and unlicensed spectrum, and improved coverage will all drive significantly lower costs within the MIoT. This will, in turn, enable the scale of MIoT and will drive much greater uptake of mobile technologies to address MIoT applications:

- Asset tracking
- Smart agriculture
- Smart cities
- Energy/utility monitoring
- Physical infrastructure
- Smart homes
- Remote monitoring
- Beacons and connected shoppers

The MIoT use cases are where we start to see the transformative impact of 5G. Many of these applications are being serviced today by a mix of older generations of cellular technologies and low-power wireless technologies operating in unlicensed spectrum. The roadmap for LTE includes purpose-built cellular technologies such as Cat-M1 (eMTC) and Cat-NB1 (NB-IoT), which are starting to incorporate low-power improvements to address the growing cellular IoT market. These technologies are establishing the foundation for 5G MIoT, which will continue to improve upon the extended low-power operation capabilities, as well as the ability to utilize both licensed and unlicensed spectrum. IHS Markit believes 5G has the potential to address a much larger segment of the M2M and IoT markets, as well as reducing costs because of economies of scale. The use cases outlined above are expected to see uptake in the near to medium term, with faster growth once 5G MIoT modules are widely commercially available.

There is greater variance between the January 2017 report and this report for MIoT than eMBB. Overall, the "ramp-up" of 5G MIoT has been pushed back, reflecting the postponement of work items related to MIoT among other topics from Release 15 to Release 16 and 17 and the ability of deployed 4G-based NB-IoT and eMTC (also known as LTE-M) to address most use cases.

NB-IoT and eMTC were standardized in Release 13 in 2016. Subsequently, Releases 14 and 15 added new capabilities around positioning, power consumption and other elements. The number of commercial NB-IoT and eMTC networks now exceeds 140, although less than half of these provide full country coverage. To date, adoption of NB-IoT and eMTC has largely been restricted to use cases such as smart metering and asset management, that were historically served by 2G. Widescale adoption of the truly massive IoT, including new use cases, is several years off. Extensive field trials will be required to assess the commercial feasibility (return-on-investment) of the most promising new use cases.

Mission critical services (MCS)

MCS represents a potentially huge growth area for 5G to support applications that require high reliability, ultra-low latency connectivity with strong security, and availability, including:

- Autonomous vehicles
- Drones
- Industrial automation
- Remote patient monitoring/telehealth
- Smart grid

The use cases outlined in this section highlight many genuinely new applications for mobile technologies. The potential to support applications with high reliability, ultra-low latency, and widely available networks with strong security creates significant growth opportunities. Many of the use cases are still emerging markets (autonomous vehicles, commercial drones, and remote medical treatment), so growth will be dependent on market innovation and development of appropriate regulation, as well as the deployment of 5G networks. As a result, growth may take longer to accelerate, but given the broad implications of some of these use cases, the overall impact to society is expected to be tremendous.

As explained below, work items related to MCS (uRLLC) among other topics have been pushed back from Release 15 to Release 16 and 17. This may slightly delay the introduction of technical features that specific applications require, such as near-ubiquitous coverage availability and guaranteed levels of latency.

In the MIoT space, 5G faces competition from several unlicensed connectivity technologies. This is less the case in MCS, where no other wireless technology can support 5G's characteristics of mobility, deep coverage, high speed, and low latency. Therefore, industry-specific factors, such as regulation on autonomous driving and line-of-sight operation of drones, will have the most impact on 5G MCS ramp-up. In this report, the forecasted impact of 5G on autonomous vehicles and drones has been delayed to reflect these regulatory factors; however, the outlook for industrial automation, medical, and energy/smart grid has remained unchanged. Several countries, such as US and Germany, are planning to provide dedicated spectrum for private networks. These have attracted some initial interests from industries such as manufacturing and mining that want to have control over network performance (availability, bandwidth and latency), costs and their data. Should the private model prove successful, more countries are likely to follow suit and create an upside case for faster MCS adoption.

5G ecosystem development and upstream dependencies

There are several factors that will contribute to the overall success and relative growth of the 5G ecosystem. These include issues related to the development of the standard, policy questions around spectrum allocation and use, market and application-specific drivers, and inhibitors. The following section looks at these factors in more detail.

5G standard development

In January 2017, when this study was last published, the first set of 5G standards, based on 3GPP Release 15, had not been completed. At that time, IHS Markit's expectation was that 3GPP Release 15 work items would be completed in mid-June 2018 and commercial 5G launches, based on 3GPP Release 15, would occur from mid-2019.

Subsequent to the publication of that report, there was a strong push from various stakeholders that wished to launch 5G as soon as possible and accelerate completion of Release 15. The specification of 5G non-standalone (NSA) NR in Stage 3 was completed in December 2017, six months ahead of schedule. 5G standalone (NSA) NR was completed by 14 June 2018 and enabled 5G deployments in a standalone (SA) mode. Please note that the acceleration of Release 15 meant that a range of items (such as vehicle to everything (V2X), URLLC enhancements through PDCCH and processing time enhancements, NR MTC for industrial sensors, among many other items) have been pushed back to 3GPP Release 16 and 17.

5G spectrum

One of the critical improvements that 5G offers over previous generations of cellular technologies is support for a much broader range of spectrum, extending from 400MHz to 100GHz. The increased range of spectrum that 5G can theoretically utilize is a potential benefit, but there are challenges. The different spectrum ranges each have physical properties that are best suited to enable different types of 5G implementations and use cases.

- Low band (below 1GHz): works well for large-area coverage
- Mid-band (1–6GHz): works well for urban deployment with increased capacity
- High band (6–100GHz): millimeter wave (mmWave) for multi-giga bit data rates, ultra-low latency, and much more capacity.

As a result, no single band can meet every 5G requirement and fulfill the promises of 5G.

In addition to the expanded range of licensed spectrum that 5G can utilize (if available), another unique feature of 5G is the ability to utilize both licensed and unlicensed spectrum, as well as shared spectrum. As with many other features in 5G, the foundational work for shared spectrum use actually began with LTE and work that was done for licensed-assist access (LAA), Wi-Fi link aggregation (LWA), and licensed shared access (LSA). While the more efficient and flexible use of existing spectrum utilizing these capabilities is important, making new spectrum available for 5G is also critical for future development.

To that end, there are a number of initiatives globally that are looking at opening up spectrum in a variety of bands for 5G use. This includes activities by the European Commission for the European Union (EU), the Asia Pacific Telecommunity for the Asia Pacific (APAC) region, and the Federal Communication Commission (FCC) in the United States.

5G network deployments

The accelerated completion of Release 15 enabled the first 5G launches in 2019, a year ahead of previous expectations. According to the GSA report, *Evolution from LTE to 5G: Global Market Status* (August 2019), as of 6 August, 39 operators had launched 3GPP 5G service.

Based on IHS Markit’s assessment during the first half of 2019 (*5G Technology and Market Development Report*, September 2019), there are three types of fundamentally different 5G launches:

- Large scale: massive numbers (over 10,000) of 5G NR/gNBs (China and South Korea);
- Small scale: tactical rollouts of pockets (100s) of 5G NR/gNBs (Australia, UK, Saudi Arabia, Switzerland, UAE, and the US);

- Laggards: places where 4G LTE is underdeveloped, such as Antel Uruguay, Claro Chile, Claro Colombia, and Personal Argentina, which are deploying 5G and may be leapfrogging full-blown 4G services.

As of September 2019, all commercial 5G networks were based on 5G NSA NR. IHS Markit's July 2019 published survey (*Evolution from 4G to 5G Service Provider Survey*), based on interviews in May and June 2019 found that 78% of 18 service providers, accounting for half of the world's telecom capex and revenue, had launched 5G NSA NR, and 83% were planning to by the end of 2019. Furthermore, based on the same survey, 33% of the 18 were planning to launch 5G SA NR in 2020.

An analysis of 37 commercial 5G launches (source: IHS Markit's *5G Technology Market Development Report*, September 2019) found that 11 of these were fixed eireless access (FWA) only, 18 eMBB only, and 8 both FWA and eMBB. The GSA's *5G Devices Ecosystem* report from September 2019 report cited 129 announced 5G devices across 15 form factors, including 41 smartphones (of which 16 were commercially available), 9 hotspots (of which at least 5 were commercially available), and 28 indoor and outdoor CPE (of which at least 8 were commercially available). The rapid development of a broad ecosystem of smartphones and other devices contrasts with the early experience with 4G LTE, when the first commercial devices available were USB dongles.

IHS Markit's Evolution from 4G to 5G Service Provider Survey – 2019 found that most existing 5G NR commercial deployments and service launches and those planned for the rest of 2019 will use mid-band spectrum (3–6GHz), particularly 3.5GHz and 4.5GHz. This is the most widely used spectrum in Asia Pacific and EMEA. 6–39GHz spectrum, which includes the mmWave bands of 28GHz and 39GHz, is the next widely used spectrum (e.g., deployments from AT&T and Verizon in the US). Sub-1GHz and 1–3GHz represent the least commonly utilized spectrum. As of writing, China's telecoms operators are deploying extensive 5G networks using mid-band spectrum; however, they have yet to launch commercial 5G services.

5G applications, content, and services

The increased bandwidth and latency capabilities of eMBB 5G will enable the development of new applications and services, such as for multi-player gaming and augmented reality (AR) applications that could not be supported by previous cellular technologies. Interoperability between operating systems and app stores will help propel the introduction of hosting access to compelling applications, content, and services.

5G industry-specific factors impacting adoption

In addition to the key dependencies above that impact all industries, there are also certain factors that will have industry-specific impacts on adoption of 5G. These include:

- **Certification:** In industries such as medical (human health & social work) and energy (utilities), device vendors must adhere to rigorous safety and environmental rules. Devices may require to be tested and certified to meet these rules. Increasingly, security issues are being considered and factored into certification processes, as breaches of devices could have serious implications such as taking remote control of a medical device or disrupting power supply to critical infrastructure.

- **Integration with other protocols and standards:** The industrial automation space (manufacturing) represents a fragmented landscape of legacy and new technology protocols and standards. Some leading industry bodies such as PI and OPC UA have included or are considering the inclusion of 5G into the roadmaps for their technologies. The pace of this development work will shape the readiness of manufacturing to adopt 5G.

- **Skillsets and business-model fit:** Wireless (cellular in particular) plays a limited role in the manufacturing space. Concerns over coverage/reliability and questions over the security of public cellular networks are two common inhibitors. Because most industrial automation connectivity is based on private wired technologies, manufacturers often lack the in-house skillsets to manage cellular-enabled machines and devices. The preference for private wired over public cellular connectivity also means that manufacturers are not accustomed to an opex (i.e., monthly fees for connectivity) business model. Shifting from a capex-centric to an opex-centric business model would require a fundamental change in how companies in the manufacturing space operate.

5G adoption by industry

5G technology will allow mobile to move beyond consumer and enterprise use into industry, thereby allowing humans to interact with the physical world like never before. As previously discussed, the technical specifications and capabilities of 5G are significantly different from the generations that came before. There are multiple classes of radios that can be used in a wide range of end devices to accomplish diverse set of tasks. The standard has the potential to utilize not only licensed and unlicensed spectrum, but also shared spectrum, as well as operating on private and public networks. This incredible flexibility means that 5G will be able to address an unprecedented number of industrial use cases. For mobile ecosystem players to penetrate these markets successfully, it will be critical to develop a deep understanding of the different industries and use cases they are trying to address. Many of these markets will have device lifecycles that will span 10 years or more. Others may have network requirements that necessitate either a private network, or a guaranteed slice of the network, and service assurance.

This diversity of use cases and device types is one of the key factors in the economic impact assessment and why there is more rapid uptake in some markets than others. Mobile ecosystem players that understand the full potential of 5G and all the different enhancements, and that develop a strong understanding of the target vertical applications they are going after, are more likely to succeed and establish an important foothold in the market.

Implications of 5G technology for key industries

Transportation & logistics, manufacturing, utilities and agriculture are among the industries most likely to be impacted by 5G technology adoption. In the future, these industries will benefit from some or all of the capabilities of eMBB, MIoT, and MCS, including very high levels of availability, deep coverage, very high bandwidth and very low latency, reduced network energy usage, 10-year battery life for low power IoT devices, and increased cell density–the ability to connect 1 million nodes per square kilometer. These capabilities will gradually become available as new standards (3GPP Release 16, 17 and beyond) are released, networks deployed, and devices become available.

Among the leading benefits enabled by 5G (alongside other capabilities and technologies, such as analytics and AI), will be increased operational efficiencies, more flexible production techniques, improved customer experience, and new revenue opportunities.

Transportation & storage is a broad industry, ranging from commercial freight carriage, public transport and the rental of transport equipment. Among the top priorities for both commercial freight carriers and retailers with their own fleets are the management of costs and maximizing levels of reliability: getting goods from A to B on time and in the right condition. These users have already embedded cellular and other forms of connectivity in their vehicles to comply with regulation (e.g. on driver hours), provide infotainment services to drivers, monitor driver behavior, engine performance and the condition of goods in transit.

5G enhancements are able to address these requirements and further drive cost benefits and higher levels of reliability through the transition to autonomous. Both leading freight carriers and large online and physical retailers are engaged in extensive autonomous (electric) vehicle pilots which if successful and allowed by regulation could lead to large-scale deployments in the longer term and the transformation of the transportation industry.

Reliable, resilient 5G connectivity could also transform the public transportation industry by enhancing the online experience for passengers and providing improved monitoring of on-board electrical and mechanical systems and visibility into external risks (such as obstacles on a train line) that could result in disruption or damage.

For transport equipment rental companies, 5G will enable a shift to autonomous and a transition to “as-a-service” business models based on usage or consumption rather than traditional day-/week-based charging.

Manufacturing will be affected by 5G in several ways. First, it will benefit from the need to mass produce 5G components, infrastructure, and devices. Second, 5G connectivity for inherently mobile or moving devices such as automated guided vehicles (AGV), handheld devices, and robotic arms can improve monitoring and operation, including collaboration between devices. 5G can also enable more flexible production techniques, more rapid time to market with new products, and greater product customization. Although there will be potential for 5G wireless retrofitting to enable applications such as real-time closed-loop communications and hands-free remote monitoring and control, the dominance of wired technologies on the factory floor and lengthy fixed equipment replacement cycles means this benefit will evolve over the long term, utilizing the eMBB and MCS capabilities of 5G. Third, the integration of 5G connectivity into manufactured products, such as white goods, will enable OEMs to directly offer customers (and monetize) after-sale services such as remote monitoring and maintenance.

As of writing, there is increased interest among factories for private LTE and 5G: networks that facilities can build and operate themselves. Mainly originating in Germany, thanks to the country's Industry 4.0 initiatives, the concept is gaining attention in other markets with spectrum regulations offering deterministic spectrum allocations for campus area networks.

In contrast to Wi-Fi, private LTE and 5G demand spectrum certainty for maximum performance and high tool density, an assurance provided by licensed spectrum. The United States' initial commercial deployment (ICD) of the CBRS spectrum paves the way for factories in the US to embrace the concept while France's ARCEP agency has allocated a band of 2.6 GHz LTE spectrum for industrial deployments. IHS Markit believes more countries will move to offer a licensed industrial spectrum option. For those countries that do not, we expect local mobile network operators (MNO) to create focused service offers aimed at providing virtualized private network environments over a dedicated spectrum band supplied by the local MNO. For 5G, this concept will be a realization of the Network Slicing concept promised in advanced versions of the 5G network technology.

Support for private LTE and 5G allows factories to limit opex spend (i.e., connectivity fees payable to operators), geofence sensitive data, and scale up their networks based on their requirements. Initial LTE and 5G private deployments in factories emerged in proof-of-concept factories operated by mobile telecom equipment suppliers such as Nokia, Ericsson, and Samsung. In June 2019, German automaker Daimler announced its plan for the world's first 5G mobile network for automobile production. Deployed in partnership with Telefónica Deutschland and Ericsson, the Mercedes-Benz "Factory 56" is intended to provide direct experience with emerging private LTE and 5G capabilities. Daimler plans to leverage the learnings gained by the project into plans for future plant evolution.

Utilities can benefit from the MIoT and MCS capabilities of 5G for smart metering and smart grid automation. Currently, smart metering deployments are enabled by a range of different cellular, mesh, and wired technologies. 5G’s ability to support private networks, use licensed and unlicensed spectrum, and radio hopping/mesh renders it a flexible, multi-purpose technology for both greenfield and replacement deployments. Alongside the general economies of scale, the deep coverage and low power characteristics of 5G will enable utilities to benefit from automated meter reading (reducing the need for manual readings or inspector visits), more accurate customer billing, and fraud prevention.

There is an ongoing trend for renewable energy, such as solar or wind, to be integrated onto the grid; however, the fragmented and irregular nature of this supply makes integration complex. 5G, alongside analytics that can identify the optimal time for different sources of energy to come on to the grid (i.e., managing supply and demand), can enable automated real-time grid switching.

Agriculture will benefit from 5G in several ways. 5G sensors equipped with long battery life and the ability to connect remote locations can monitor many types of equipment and conditions such as tank levels, soil moisture, and chemical content. This can then reduce truck roll expense related to replenishment and can optimize schedules for watering and the application of fertilizer. Similarly, tracking devices attached to livestock can geofence their location (reducing the likelihood of loss) and monitor their movement and vital signs, which can help in the early identification of illness that if unrecognized would otherwise have a negative impact on farm output. The eMBB and MCS capabilities of 5G can also be leveraged by agriculture, notably through the remote operation of drones (with embedded cameras and sensors) to monitor crops and herds in real time and the monitoring and control of driver-operated and autonomous agricultural vehicles.

The economic contribution of 5G

As discussed in the "5G technology and use cases" section, the early years of the 5G economy will be characterized by efforts to constantly strengthen the infrastructure and technology base followed by an ever-deepening global deployment of the 5G use cases. Increasingly, businesses around the world will leverage 5G technologies to grow sales through increased efficiency, engage existing and new customers, and continually evolve their business models. Early deployments will be skewed toward eMBB applications; MIoT and MCS applications will gain traction in the medium-to-long term as 5G drives mobile technology deeper into industrial and municipal applications.

By 2035, the entire range of 5G use cases will be fully ramped up and organizations will have evolved their business models to take full advantage of 5G. Experts at IHS Markit projected forward to 2035 and looked at the economic contributions of 5G through three lenses. The first lens viewed the level of sales enabled by 5G, above and beyond what would be possible with the current trajectory of 4G. IHS Markit considered how 5G would enhance sales activity in 16 major industry sectors, based on the International Standard Industrial Classification of All Economic Activities, Revision 4 system (ISIC). Developed by the United Nations, ISIC provides standardized reporting of economic indicators regardless of country (definitions of the ISIC industries are provided in Appendix B). The Comparative Industry Service, a proprietary product of IHS Markit, which is consistent with ISIC, was leveraged to integrate additional economic information, as needed, to enhance the analysis.

The second lens focused on how the combination of investment in 5G infrastructure plus R&D will foster the emergence of a value chain that continually deepens the 5G technology base. IHS Markit used industry-standard input-output economic modeling techniques to conduct this assessment. These models were built using data from the European Commission-funded World Input-Output Database (WIOD) program. The 5G infrastructure and R&D investment could generate economic value beyond the 5G value chain. Therefore, the third lens used IHS Markit's proprietary Global Link Model (GLM) to assess the macroeconomic impact of these investments on global GDP.

The methodologies used for the three assessments build upon those used in the original 2017 study, which IHS Markit developed in partnership with Dr. David Teece, Chairman and Principal Executive Officer of the Berkeley Research Group and the Thomas W. Tusher Professor in Global Business at the Haas Business School at the University of California at Berkeley, and Kalyan Dasgupta, Principal at the Berkeley Research Group. The reader is referred to Appendix C for a discussion of the modeling methodologies.

IHS Markit's outlook for the global economy has changed since the 2017 study was published, which leads to subtle changes to our projected impacts of 5G. Perhaps most notable is a lower growth rate for the global economy due, in large part, to a slowdown in China's growth rate. Paradoxically, the country is also expected to increase its share of global manufacturing output, a sector where 5G will have a significant impact. A brief discussion of the drivers behind the differences in economic contributions from the 2017 study is presented in Appendix D.

Global output: The $13.2 trillion global opportunity

5G deployments will positively affect virtually every industry sector. Indeed, adoption and integration across many industry sectors will solidify the role of 5G in transforming mobile technology into a GPT. Industries have differing economic and regulatory structures that will affect the timing and adoption of the new business models that 5G will enable, which is why IHS Markit focused on a longer time horizon and chose 2035 as the analysis year. Assuming the standards process, regulatory environment, and industry adoption proceed as discussed earlier in this report, IHS Markit estimates that potential global sales activity across multiple industry sectors enabled by 5G could reach $13.2 trillion in 2035. This represents about 5.0% of all global real output in 2035.

A word of caution is warranted concerning the sales enablement metric. Specifically, the sales enablement metric is **not** a direct measure of contribution to global GDP and should not be interpreted as such. Rather, sales enablement is a measure of global sales activity that 5G will enable across the 16 ISIC industry sectors. This includes both intermediate purchases required to make and deliver goods and services plus sales to end users (i.e., final demand). Intermediate purchases include, for example, when a car manufacturer buys components (tires, batteries, etc.) needed to build a vehicle from suppliers. The car is assembled, sold to a dealership (another intermediate purchase), and eventually sold to a consumer (final demand). The sales enablement metric captures the sales transactions that occur at every point of the journey from initial assembly to the consumer driving the car off the showroom floor. GDP, on the other hand, measures the value of final demand for goods and services within an economy. In our example, only the final purchase by the consumer would be included in a GDP calculation. Thus, relative to GDP, the sales enablement metric will be significantly larger.

The following infographic presents the consolidated sales enablement findings by industry, ranked from highest impact (manufacturing) to lowest impact (arts and entertainment). Manufacturing will garner almost $4.7 trillion, or 36%, of the $13.2 trillion in sales enablement. This might appear high until one considers that implementing any of the 5G use cases will stimulate, at a minimum, complementary spending on equipment, all of which will be produced by the manufacturing sector. For example, drones will enable sales within the transportation sector; however, this will require the transportation sector to buy additional drones from the manufacturing sector. Medical use cases will require complementary spending on 5G-ready equipment from the manufacturing sector. The same line of reasoning applies to the information and communications sector, which will see the second largest share of 5G-enabled economic activity, at almost $1.6 trillion. Implementing any of the 5G use cases will require spending on communication and content services. A detailed look at specific use cases driving industry adoption of 5G is provided in the next section.

While 5G could enable about 5.0% of global real output in 2035, the 5G-enabled sales percentage by industry will vary from a high of 10.7% in the information and communications sector to a low of 2.2% in the hospitality sector. The sheer size of the manufacturing sector, which will account for over 31% of global real output in 2035, along with the fact that much of the 5G-enabled manufacturing sales will be secondary (i.e., equipment sales in support of use case) will lead to a percentage (5.4%) that is slightly below the overall average. Perhaps more notable is the fact that 5G could enable 6.3% of public service (government) and 5.3% of agricultural output in 2035, driven by smart city and smart agriculture deployments, respectively.

To put these findings in a broader context, one must also consider the secondary linkages across multiple industries for a given use case. For example, the availability of autonomous vehicles and drones will do more than stimulate sales of driverless cars and unmanned aerial vehicles (UAVs) to consumers. They will also be deployed in agricultural and mining applications ranging from surveillance of remote natural resources to autonomous transport of ores to self-driving tractors. They will be widely used in the transportation sector for driverless transport and delivery of commercial and consumer goods. Municipalities will integrate autonomous vehicles into their transit systems while using drones for monitoring functions. In manufacturing, autonomous vehicles will also be used in intra-plant stocking and retrieval systems. Finally, autonomous vehicles will also positively affect the insurance industry as vehicle accident rates decrease.

Use cases driving 5G adoption and industry output

Each industry will identify different use cases and benefits of 5G technology. The most near-term use cases for each industry are discussed below, presented in order of those industries that will have the greatest sales enabled by 5G.

- Manufacturing: Adoption will benefit in the short-to-medium term from enhanced indoor wireless broadband coverage. Other early use cases include asset tracking (visibility over incoming and outgoing components and goods in the supply chain) and industrial automation, such as connectivity for moving assets such as AGVs.

- Information and communication: This industry includes telecommunications, broadcasting, and video. The provision of enhanced outdoor wireless broadband (particularly smartphone) connectivity is the main early use case.

- Wholesale and retail: Enhanced indoor wireless broadband coverage (enabling consumers to access product information, offers, and store maps) via their smartphones is a key early use case. Out-of-store tracking of vehicles and condition monitoring of perishables in transmit will also leverage eMBB/MIoT capabilities.

- Public service: This segment includes government activity, including smart cities development and defense. Energy/utilities (e.g., smart metering) is a key early use case for smart cities, enabling not only more accurate customer billing but also more insight into consumption at different times of the day and year. This can be a useful tool for governments and suppliers to predict future demand and manage supply, including the integration of non-traditional forms of energy on the grid.

- Construction: The remote monitoring and control of both driver-operated and autonomous construction vehicles will be an early use case.

- Transportation and storage: This includes land, water and air transport, transport via pipelines, and warehousing and support activities for transportation. In the short-to-medium term, asset tracking (including fleet management) and drones will drive 5G adoption in this industry.

- Financial and insurance: Early use cases will include enterprise teamwork/collaboration and training/education. 5G's role in monitoring remote patient conditions will be among the earliest use cases investigated by health insurance companies.

- Professional services: Enterprise teamwork/collaboration and extending mobile computing (remote access to cloud-based information and applications) will be among the earliest 5G use cases.

- Health and social work: The dispersed, mobile nature of the healthcare and social work workforce will drive enterprise teamwork/collaboration as an early use case. Medical applications such as remote patient monitoring and treatment guidance from hospital-based clinicians to field workers (nurses, paramedics) will be early use cases.

- Agriculture, forestry, and fishing: In the short-to-medium term, asset tracking (including fleet management) and drones will drive 5G adoption in this industry. Livestock and soil monitoring (MIoT) will be an early use case. The increasing integration of 4G LTE into agricultural vehicles provides an upgrade opportunity for eMBB-based 5G.

- Real estate activities: Hosting 5G cell infrastructure represents a near-term use case for real estate.

- Mining and quarrying: The remote monitoring of high-value mining equipment to drive efficient usage and prevent outage will be the key early use case.

- Utilities: Early use cases will include smart metering (electricity, gas, and water) and monitoring of power and sewer infrastructure.

- Education: Key early use cases will include enterprise teamwork/collaboration and training/education as well as AR, particularly in research-intensive scientific disciplines.

- Hospitality: As with arts and entertainment, enhancing the customer experience (through enhanced indoor wireless broadband coverage) will be a short-term driver.

- Arts and entertainment: Enabling a better audience experience through reliable connectivity and the ability to share live video is driving stadium owners' interest in eMBB 5G.

The 5G value chain in 2035: $3.6 trillion in output and 22.3 million jobs

Achieving the sales enablement potential of 5G will require ongoing investments by firms in the 5G value chain to continually improve and strengthen the foundational technology base. The 5G value chain will encompass a broad spectrum of technology firms, including but not limited to:

- Network operators

- Providers of core technologies and components

- OEM device manufacturers

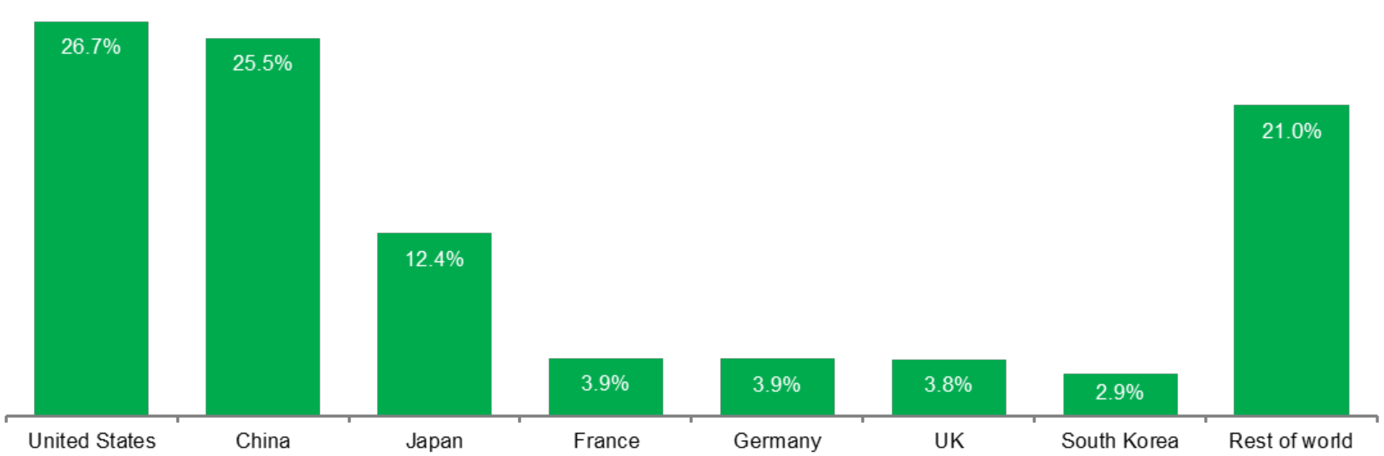
- Infrastructure equipment manufacturers

- Content and application developers

IHS Markit modeled the economic activity of the 5G value chain for seven countries that are expected to be at the forefront of 5G development: the United States, China, Japan, Germany, South Korea, the United Kingdom, and France. From 2020 to 2035, IHS Markit anticipates the collective investment in R&D and capex by firms that are part of the 5G value chain within these countries will average over $235 billion annually. In the early years, foundational R&D and network infrastructure deployments will dominate 5G investment activities. Subsequently, IHS Markit expects the overall investment in R&D and capex to slowly taper. During this period, the focus of investments will shift from primarily infrastructure towards development of applications and services that exploit the unique capabilities of 5G. The sustained investment cycle is another indicator that 5G is a “long game” that will see investment priorities shift as infrastructure is deployed, the underlying technology base is continually strengthened, new business models come online, and replacement cycles for many of the use cases are lengthened.

The United States and China are expected to dominate 5G R&D and capex, investing a total of $1.3 trillion and $1.2 trillion, respectively, over the 16-year time horizon of this study. IHS Markit estimates that the United States will account for about 26.7% of global 5G investment, closely followed by China at 25.5%. While not a primary focus of this study, spending beyond the seven core countries will make up about 21% of the global 5G investments. Additional details on the methodology are provided in Appendix C.

Average annual share of value chain R&D and capex by country, 2020–35



Source: IHS Markit

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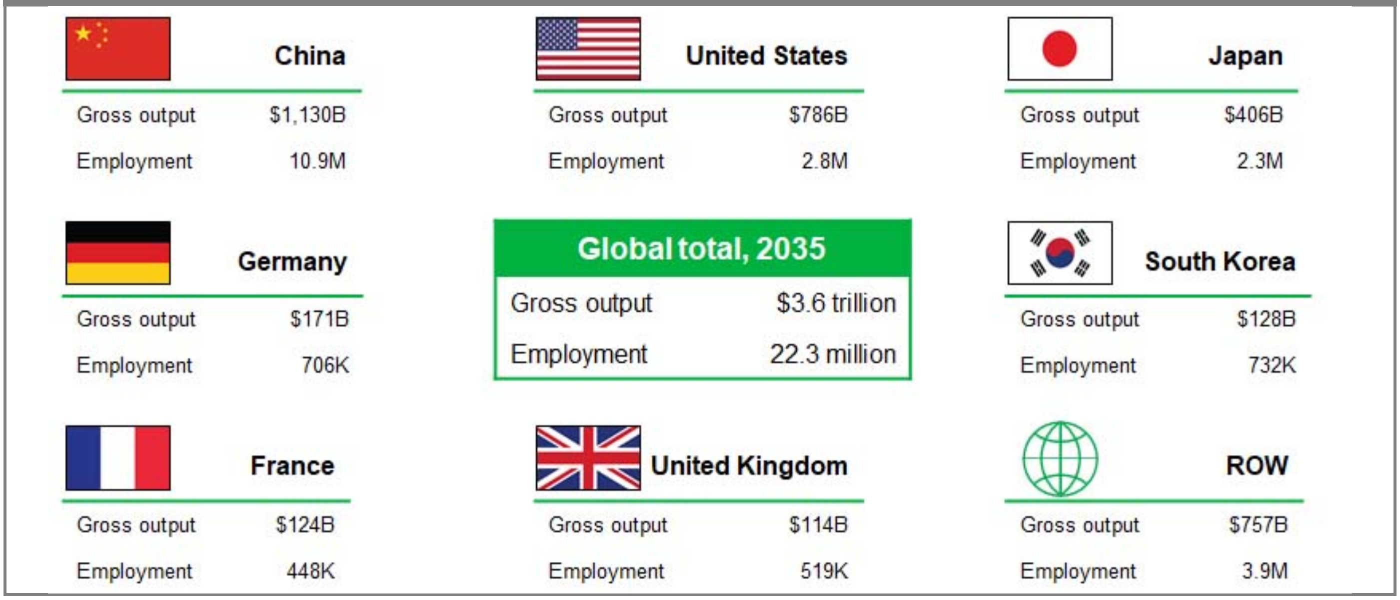
Ultimately, the investments in R&D and capex will facilitate bringing the 5G use cases online. This will enable sales across virtually all industry sectors while also driving sales throughout the 5G value chain and its associated supply networks. IHS Markit estimates that, by 2035, the 5G value chain alone will drive $3.6 trillion of economic output and support 22.3 million jobs. Not surprisingly, given the relative size of the population and the investments made, 5G will support the highest number of jobs in China. The analysis also indicates how investments made by these seven countries will affect the rest of the world. Many developing and emerging economies are already leapfrogging older technology and becoming more mobile oriented, and 5G will have significant economic impact on these mobile-enabled economies. Value chain economic activity stimulated in the rest of the world is slightly less than that of the United States (the biggest investor in 5G).

The economic contributions of the 5G value chain in 2035



Source: IHS Markit

Sustainable global economic growth

Another measure of the economic contribution 5G will make to the global economy is an assessment of its net effect on global GDP. The sales enablement and value chain activity, while extremely large and positive, may have offsetting effects because of investments and spending that otherwise might have occurred in other sectors of the global economy that could have stimulated growth and positive productivity effects. If a net positive contribution is made to global GDP, then 5G can be considered a source of global expansion and growth.

IHS Markit used its proprietary Global Link Model (GLM), a system that captures the inter-connected nature of the global economy, with two primary sets of inputs. The first was the annual investments (capex and R&D) made by the 5G value chain within each of the seven countries that were the primary focus of the IHS Markit research for the 2020–35 period. This captures the effects of strengthening the country-level economy by making investments that deepen each country's respective capital stock. The second set was the use case productivity improvements (determined as part of the sales enablement analysis). This captures the economic knock-on effects attributable to companies increasing their efficiency and launching new business models enabled by 5G technology.

For the 2020–35 period, IHS Markit forecasts global real GDP will grow at an average annual rate of 2.5%, of which 5G will contribute almost 0.2% of that growth. From 2020 to 2035, the annual GDP contributions of 5G will total almost $2.7 trillion. While this figure is in real (inflation-adjusted) dollars, a simple sum does not factor in potential global risk. Therefore, IHS Markit took the net present value of the GDP contributions, discounted at a modest 3% rate, to derive a risk-adjusted value of $2.1 trillion. To put that in perspective, from 2020 to 2035, the total contribution of 5G to real global GDP growth will be equivalent to the current GDP of Italy—the eighth largest economy in the world. Based on this assessment, IHS Markit concludes 5G will be a source of positive global economic expansion and growth.

Conclusion

Based on the analysis of the expected technical contributions, IHS Markit translated the development and deployment of 5G technology into economic inputs. IHS Markit used these inputs to assess the economic impact through three different lenses (at the micro and macro levels). The models revealed that 5G technology would contribute very large and sustainable economic benefits across all sectors of the global economy. Like prior generations of mobile technologies, 5G will have a profound effect on how people live, work, and interact, but 5G will transcend the communications field and help fundamentally alter how a vast and diverse group of industries operate. IHS Markit, therefore, views 5G as a catalyst that will thrust mobile technology into the exclusive realm of GPTs. By 2035, mobile applications will experience pervasive adoption across multiple industries, initiating transformative changes that will redefine work processes and spur innovations that rewrite the rules of competitive economic advantage. These innovations will have extraordinary effects on human and machine productivity, and ultimately may help elevate living standards for people around the world.

IHS Markit evaluated the potential of 21 unique 5G use cases that will drive productivity improvements and enhance economic activity across a broad range of industry sectors. Further, IHS Markit assessed the central role the 5G value chain will play in continually strengthening and expanding the current mobile technology platform. Finally, IHS Markit determined that, in large part because of 5G, use of mobile technology will lead to sustainable economic growth on a global basis.

The 5G economy will introduce a new level of complexity to policymaking and regulation as new business models emerge and the old ways of delivering goods and services are either dramatically altered or abandoned completely. Areas where policy and regulatory modernization will be required for a 5G-ready world include public safety; cybersecurity; privacy; public infrastructure; healthcare; spectrum licensing and permitting; and education, training and development. The challenge for policymakers in the 5G economy is that they must be prepared to address the ubiquity of 5G in everyday life without creating regimes that stunt continued innovation. The policy frameworks that safeguard the ability of firms to take risks, make investments, and continue the relentless pursuit of innovation are the important vehicles for continuing on the path to the 5G economy.

In conclusion, the emergence of 5G signals a tipping point in the evolution of mobile from a mostly personal-technology dominated phenomenon to a platform that enables new classes of advanced applications, fosters business innovation, and spurs economic growth. IHS Markit concludes that, by 2035, 5G has the potential to stimulate $13.2 trillion in global sales activity across a broad spectrum of industries and use cases. This is an increase of $900 billion as compared to the 2017 edition of this same report, due in a large part to the early completion of the first 5G standard and the resulting earlier-than-anticipated commercial 5G network launches by major operators. The 2019 edition of this study further identified that 5G technology will support a global value chain ecosystem that generates $3.6 trillion in output and supports 22.3 million jobs in 2035, leading to long-term sustainable contributions to the growth of global GDP.

Appendix A: 5G use case descriptions

Enhanced Mobile Broadband (eMBB)

Enhanced indoor wireless broadband coverage: 5G will address the challenges many buildings face to provide consistent coverage, even with complex and sometimes expensive small cell and commercial WLAN deployments

Benefits include improved cellular coverage in structures of any size, allowing for wireless broadband coverage for a range of devices and applications. In terms of industry impact, this is expected to be far reaching since the benefits are neither industry nor application specific. For the purposes of this study, this use case was analyzed separately from fixed wireless broadband, which is discussed in more detail below.

Enhanced outdoor wireless broadband: Includes applications like streaming high-definition (HD) infotainment to cars, improved capacity for outdoor events, and highly populated urban centers. This includes improving internet access on mass transit systems, which would allow more users to work online during transit time.

Benefits include improved coverage and capacity for densely populated urban areas. This has the potential to reduce traffic congestion by encouraging citizens to use mass transit, and it will improve coverage and capacity for live events. As with the indoor wireless broadband coverage, the benefits are neither industry nor application specific, and are expected to positively impact a wide range of industries.

Fixed wireless broadband deployments: Going beyond what is already being done today with LTE networks with variable results, 5G will offer a better consumer experience. The main benefit for this use case is allowing carriers to offer more services without costly capex investments.

Some specific use cases include underserved rural areas and emerging markets with little or no fixed infrastructure but high wireless penetration. In developed markets, this is expected to be used to address last-mile deployments (as a lower cost alternative to fiber, for example), as well as in dense urban areas where it is costly and/or impractical to use a wired solution.

Enterprise teamwork/collaboration: As companies become increasingly global and rely more on virtual and remote teams, the ability to collaborate using a broader range of enterprise communications tools becomes more essential.

Benefits for this use case will be realized because of the combination of streaming ultra-high definition (UHD), AR/VR, video telepresence, and tactile internet. These will enhance existing enterprise communications solutions and encourage more dynamic interactions between team members and clients/end-users. This could affect a broad range of professional service industries and the overall ICT industry.

Training/education: Applies to both enterprise users (training) and traditional education (both K-12 and higher education), including remote and/or underserved areas.

While the overall benefits are similar to the previous use case, the specific benefit to society is the ability to expand the number of students significantly that can get access to general and specialized education and training.

Augmented and virtual reality (AR/VR): The ability to support dynamic AR content at scale will require a 5G interface. The reduced latency and multiple Gb per second speeds will enable computationally heavy AR/VR user interactions. Specific use cases include field support and telehealth.

There are two clear benefits to this use case. First, mobilized AR/VR (otherwise referred to as smart glasses) will benefit users by providing a virtual display in any environment or surface, negating the need for additional hardware or a display.

Second, this will mean reduced costs for field support workers, creating the ability to have a core team of highly trained and experienced workers that are centrally located to support a much larger field support team.

There are any number of industries that could benefit from this, ranging from industrial and manufacturing to construction and service firms and even social services.

Extending mobile computing: Combined with significantly larger wireless data pipes and easily accessible cloud computing, 5G smartphones will be able to take on productivity tasks that have been the province of laptop/desktop computers. This is really an extension of a trend that has been in existence since the beginning of digital mobile technologies. The benefits of 5G specifically are being able to deliver a robust mobile computing experience regardless of device form factor.

Enhanced digital signage: Using a combination of UHD and AR, 5G will support a variety of applications ranging from improving the retail experience to smart cities applications. Digital signage has become increasingly common, and improvements in UHD and AR support, as well as 5G, could significantly increase the number of use cases that are supported. This could serve as a key differentiator in retail environments, which continue to struggle to compete with online shopping. Other applications that could benefit from this use case include real estate and home improvement, hospitality and service industries, transportation, and smart cities, all of which have come to rely on digital signage.

Massive internet of things (MIoT)

Asset tracking: Monitoring the distribution of assets (and people) over large areas. This would include applications such as people tracking and high value goods in transit, which are well-established M2M markets today; however the (relatively) high cost of connectivity has limited the growth of the market. It is expected that 5G will offer additional benefits in terms of deep coverage, low power, and low cost (economies of scale), as well as being a 3GPP standard technology.

These improvements offered by 5G would include optimization of logistics in a wide range of industries, as well as improved worker safety and increased efficiency in locating and tracking assets, thereby minimizing losses. It would also expand the ability to track a wider range of goods in transit dynamically. As more shopping shifts to online retailers, asset tracking will become increasingly important.

Smart agriculture: 5G will lead to increased use of connected sensor technologies in farming/agriculture for applications ranging from basic tank monitoring to specialized sensors that can monitor the moisture levels and chemical composition of the soil. The use of connected sensor technologies in farming/agriculture has increased significantly over the past few years, driven in part by the increased availability and attractive price point of low-power wide-area networks (LPWAN) networks.

Benefits include optimization of watering and feeding schedules, as well as growing and harvesting scheduling. This leads to increases in farm operational efficiency, leading to less need for manual labor. Additionally, there can be improved reporting and accountability for “farm to market,” allowing greater transparency for consumers.

As with many other use cases, smart agriculture is not strictly a MIoT use case. Given the broad range of applications within agriculture, there are several ways IHS Markit expects to see 5G used. This will include autonomous agricultural equipment that leverages the MCS features of 5G, as well as drones with sophisticated camera and sensor packages monitoring crops and herds in real time, leveraging the EMBB capabilities of 5G. These are just a few of the many ways that 5G is expected to provide tangible benefits in efficiency and productivity for agricultural activities.

Smart cities: An area of growing interest for cellular operators, smart cities will offer opportunities for many different types of applications and potential new business models. Smart cities is a very broad term; some of the key technology applications include lighting, security, energy/utilities, physical infrastructure environmental monitoring, and transportation/mobility.

The main benefit of introducing 5G is to lower costs, improve quality of service (QoS) and reliability, and establish a standard for the market. One of the key reasons for this is the expectation that smart cities applications will be able to leverage existing carrier infrastructure, as opposed to heavier capex investment to deploy a dedicated proprietary network. By utilizing network slicing techniques, a guaranteed QoS could be provided for applications that are more essential (street lighting).

There are two important points to note with the smart cities use case. First, although it has been included in the MIoT segment for the purposes of this study, the reality is that the wide range of use cases that could be included in the overall smart cities category includes applications that would rely on the EMBB and MCS capabilities of 5G. For example, dynamic traffic management and control is a smart cities application (closely related to transportation) that would leverage many of the MCS features of 5G. Similarly, utilizing both security drones and fixed cameras as part of a safe cities solution would require the capabilities offered by the EMBB features of 5G.

The second key point is that even in 2035, smart cities will still be in a relatively early stage of development. Consequently, IHS Markit has based its economic impact assessment on the fact that smart cities applications will be widely deployed, but not pervasive. As this market matures beyond 2035, mobile technologies and 5G are expected to play an even more important role.

Energy/utility monitoring: Historically, utility markets are heavily regulated and fragmented, so 5G has the potential to enable a more unified connectivity platform that address a wide range of use cases, which could provide economies of scale.

Smart meter deployments currently utilize a wide range of technologies, including cellular (2G/3G), LPWAN, Zigbee, and proprietary radio technologies. Consolidating on a single technology platform would allow for significant cost savings because of economies of scale. The ability for 5G to allow for private networks, use licensed and unlicensed spectrum, and radio hopping/mesh mean it will be incorporating all of the strengths of the competitive technologies. This will potentially make smart metering (all utilities types) more accessible to more types of utilities worldwide.

Physical infrastructure: The features of MIOT can be combined with connected sensors to significantly improve the monitoring of physical structures such as bridges and overpasses to smaller structures such as elevators. Beyond this, geotagging can allow AR to be used for visitors to large cities to improve the tourism experience.

Many countries are dealing with challenges around aging infrastructure, and benefits of utilizing 5G would include the ability to deploy wireless sensors to monitor structures such as bridges, roadways, train tracks, and overpasses in real time and prioritize repairs/improvements.

Smart homes: 5G could revolutionize how smart home devices are deployed and serviced, as it will address core consumer complaints, including difficulties with device set up, device unreliability, and high latency.

As the smart home market moves more to a do-it-yourself (DIY) model, it will become even more important for consumers to have a very easy set-up and configuration experience right out of the box. Leveraging cellular connectivity via 5G instead of relying on consumer knowledge of how to correctly configure their home WLAN and firewall correctly will allow for a more streamlined user experience and more secure devices.

Remote monitoring: Largely an industrial automation application spanning a wide range of industries, the focus is using pervasive sensing for incremental performance improvements and predictive maintenance of equipment. Current solutions rely heavily on wired technologies, which are difficult to retrofit. The potential for 5G is to provide a robust alternative that can be used to provide solutions for both new and existing equipment.

There are numerous benefits to pervasive sensing, which can be used to help prevent safety risks such as explosions, leaks, physical monitoring, and maintenance in sometimes inhospitable environments. Pervasive sensing is also a key component of predictive maintenance solutions, which help to decrease down time and increase efficiency and output.

Beacons and connected shoppers: Enhancing current retail technology trends to use beacons and smartphones to enhance the brick-and-mortar shopping experience, 5G would create the potential for not only retailers, but also products/brands, to interact with consumers in a more dynamic fashion. In addition, beacons are starting to gain traction in industrial applications, and a more robust wireless connectivity solution will be key to the growth of this market. Beacons today are largely using Bluetooth, but the potential is there to leverage a low-power variant of 5G.

Mission critical services (MCS)

Autonomous vehicles: A broad category that includes both consumer and commercial applications. The fundamental assumption is that 5G will be used to enable all forms of extra-vehicle communication (V2X), initially to provide more sophisticated advanced driver assistance systems (ADAS), and eventually leading to fully autonomous self-driving vehicles.

It should be noted that while the overall autonomous vehicles use case has been included in the MCS segment for the purpose of this study, the reality is that the EMBB features of 5G will also play an important role. While the 5G MCS features of ultra-low latency, high reliability, and high availability are vitally important for the autonomous vehicle market to succeed, the EMBB features will also be important for many data-intensive, but less mission-critical, activities. This would include the ability to receive and offload large amounts of mapping, sensor, and delay-tolerant or less-time-critical data. In addition, by 2035, Stage 5 fully autonomous vehicles should be in wide use in developed countries. Since these vehicles will not rely on a human operator at all, the ability to provide media-rich content for passengers will be essential.

There are significant benefits related to autonomous vehicles, ranging from safer roadways to reduced impact on the environment from more-efficient vehicle operation. Autonomous vehicles will also reduce costs associated with collisions such as down time, injuries/rehabilitation, repair, and insurance. Using 5G technology to enable this will also help reduce costs and investment into infrastructure, which would be required by alternative technologies "dedicated" to just automotive applications (as for the 802.11p).

Looking specifically at the commercial and industrial applications, there are even more benefits, with additional cost savings for reduced operating expenditures (opex) resulting from fewer drivers, as well as anticipated benefits from more efficient routes and longer hours of operation with fewer breaks.

From an economic impact assessment standpoint, this is one of the use cases that should have broad overall impact, especially when considering commercial vehicles and off-road equipment (farming, mining, construction, etc.). The ability to safely operate equipment for extended periods at a lower operational cost is significant and will have a transformative impact on some industries.

Drones: The widespread use of commercial drones has the potential to benefit multiple industries, including commercial transport, agriculture, construction, manufacturing, and public safety among others. As drone technology improves, demand for UAVs will increase from corporations and governments.

There are numerous benefits to using drones for commercial and industrial applications. These include minimized time and risk, enhanced functionality and effectiveness, and reduced costs compared to the fees being paid to vehicle operators. Potential uses of drones by governments could include police reconnaissance, anti-terrorism, riot control, patrolling, search and rescue, tracking, public safety, traffic regulation, exploration surveys, and weather monitoring.

There are examples of commercial drones in use today, although most of these are still in the trial phase. As the use of drones increases in commercial and industrial applications, it will be necessary to leverage several features of 5G to address the breath-of-use cases fully. As with autonomous vehicles, IHS Markit has included drones in the MCS segment of use cases because the low latency, high reliability, and high availability will be essential for reliably and safely operating commercial fleets of drones. Nevertheless, as the use of HD cameras and sensors packages on drone's increases, enhanced mobile broadband capabilities of 5G will also be critical for handling the large volumes of data being generated.

Industrial automation: While the vast majority of infrastructure on the factory floor will continue to rely on wired connectivity, creating smarter factories, augmenting workers, and supporting mobility of assets on the factory floor creates opportunities for a high bandwidth, secure wireless solution, which could be addressed through 5G.

There are two specific areas where the benefits of mission-critical 5G could offer specific benefits: real-time close loop communication and hands-free machine monitoring and control. Real-time close loop communication supports remote control of equipment and manufacturing processes. This can include connectivity of machines, robots, and mobile equipment in order to maximize overall equipment effectiveness (OEE).

Using 5G to enable hands-free machine monitoring and control would allow workers to monitor machine and production line performance while keeping their hands free for safety and/or sterility purposes. Assuming sufficient improvements in latency, workers could also use wearables and gesture control for remote operation.

Remote patient monitoring/telehealth: 5G will help eliminate the current reliance on disparate connection strategies between patients, care providers, and monitoring equipment. HD image quality should lead to increased use of many applications, including dermatology and wound care.

There are a broad range of applications that fall within this use case. This includes ubiquitous access to imaging and medical records, advanced telemedicine (including remote surgery and treatment using robotics and AR/VR), and remote clinical care. 5G would also enable health care workers to perform controlled substance management using wearables, which has the potential to dramatically improve pain management and provide a tool to help minimize the risks of abuse.

There are several benefits using 5G for these applications, including standardized connectivity platforms that will lead to greater ease of use, higher implementation, and lower costs. In addition, medical professionals will have faster, more secure access to records for patients on their devices, easier file management, and access for providers in any location. Finally, the increased use of outpatient monitoring and the ability to reduce in-hospital stays will offer both reduced costs and greater patient comfort.

Smart grid: The low latency of 5G should be attractive in this environment, where uptime is heavily regulated and, in more developed economies, downtime is penalized.

If 5G enables a push to bring cheaper, more ubiquitous low-latency radios to the market, this would have the potential to unlock an enormous use case for automated real-time grid switching. The economic impact could be significant, as this would essentially create a more reliable grid.

Appendix B: ISIC industries

(A) Agriculture, forestry, and fishing

This sector includes the activities of growing crops, raising and breeding animals, harvesting timber and other plants and animals or animal products from a farm or their natural habitats.

(B) Mining and quarrying

This sector includes the extraction of minerals occurring naturally as solids (coal and ores), liquids (petroleum), or gases (natural gas). Extraction can be achieved by different methods, such as underground or surface mining, well operation, seabed mining, etc. This sector also includes supplementary activities aimed at preparing the crude materials for marketing, for example, crushing, grinding, cleaning, drying, sorting, concentrating ores, liquefaction of natural gas, and agglomeration of solid fuels.

(C) Manufacturing

Manufacturing includes the physical or chemical transformation of raw materials, substances, or components into new products. Substantial alteration, renovation, or reconstruction of goods is also considered to be manufacturing. Assembly of the component parts of manufactured products is considered manufacturing.

(D) Electricity, gas, steam, and air conditioning supply

Electricity, gas, steam, and air conditioning supply includes the operation of electric and gas utilities, which generate, control, and distribute electric power or gas, as well as the provision of steam and air conditioning supply. This includes the provision of electric power, natural gas, steam, hot water, and the like through a permanent infrastructure (network) of lines, mains, and pipes, as well as the distribution of electricity, gas, steam, hot water, and the like in industrial parks or residential buildings.

(E) Water supply, sewerage, waste management, and remediation activities

Water supply, sewerage, waste management, and remediation activities include activities related to the management (including collection, treatment, and disposal) of various forms of waste, such as solid or non-solid industrial or household waste, and contaminated sites. Activities of water supply are also grouped in this section, since they are often carried out in connection with, or by units also engaged in, the treatment of sewage.

(F) Construction

Construction includes general construction and specialized construction activities for buildings and civil engineering works. It includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site, and construction of a temporary nature. General construction is the construction of entire dwellings, office buildings, stores, other public and utility buildings, farm buildings, or the construction of civil engineering works such as motorways, streets, bridges, tunnels, railways, airfields, harbors and other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, sports facilities, etc. Also included are the repair of buildings and engineering works, specialized construction activities, the erection of steel structure, building finishing, and building completion activities.

(G) Wholesale and retail trade, repair of motor vehicles and motorcycles

This sector includes wholesale and retail sales (i.e., sales without transformation) of any type of goods and the rendering of services incidental to the sales of these goods. Also included in this section are the repair of motor vehicles and motorcycles. A sale without transformation is considered to include the usual operations associated with trade, for example sorting, grading, and assembling of goods, mixing (blending) of goods, bottling, packing, breaking bulk, and repacking for distribution in smaller lots, storage, cleaning and drying of agricultural products, and cutting out of wood fiber boards or metal sheets as secondary activities.

(H) Transportation and storage

Transportation and storage includes the provision of passenger or freight transport, whether scheduled or not, by rail, pipeline, road, water, or air and associated activities such as terminal and parking facilities, cargo handling, storage, etc. Included in this section is the renting of transport equipment with a driver or an operator. Also included are postal and courier activities.

(I) Accommodation and food service activities

Accommodation and food service activities include the provision of short-stay accommodation for visitors and other travelers and the provision of complete meals and drinks fit for immediate consumption.

(J) Information and communications

Information and communications includes the production and distribution of information and cultural products, the provision of the means to transmit or distribute these products, as well as data or communications, information technology activities, and the processing of data and other information service activities.

(K) Financial and insurance activities

Financial and insurance activities include financial service activities, including insurance, reinsurance, pension funding activities and activities that support financial services. This sector also includes the activities of holding assets, such as activities of holding companies and the activities of trusts, funds, and similar financial entities.

(L) Real estate activities

Real estate activities include acting as lessors, agents, and/or brokers in one or more of the following: selling or buying real estate, renting real estate, and providing other real estate services such as appraising real estate or acting as real estate escrow agents. Also included is the building of structures, combined with maintaining ownership or leasing of such structures. This sector includes real estate property managers.

(M) Professional, scientific, and technical activities

Professional, scientific, and technical activities require a high degree of training, making specialized knowledge and skills available to users.

(N) Administrative and support service activities

Administrative and support services activities include a variety of activities that support general business operations. These activities differ from those in professional, scientific, and technical since their primary purpose is not the transfer of specialized knowledge.

(OSTU) Public administration and defense, other services (O,S,T,U)

Public administration and defense, other services includes activities of a governmental nature, normally carried out by the public administration. This includes the enactment and judicial interpretation of laws and their pursuant regulation, as well as the administration of programs based on them, legislative activities, taxation, national defense, public order and safety, immigration services, and foreign affairs and the administration of government programs. This section also includes compulsory social security activities.

Note, the legal or institutional status is not, in itself, the determining factor for an activity to belong in this section, rather that the activity is of a nature specified in the previous paragraph. This means that activities classified elsewhere in ISIC do not fall under this section, even if carried out by public entities. Similarly, non-government units may carry out some activities described in this section.

ISIC segment S (as a residual category) includes the activities of membership organizations, the repair of computers and personal and household goods and a variety of personal service activities not covered elsewhere in the classification. Notably, it includes personal services such as washing and (dry-) cleaning of textiles and fur products, hairdressing and other beauty treatments, and funeral and related activities.

ISIC segment T includes the activities of households as employers of domestic personnel such as maids, cooks, waiters, valets, butlers, laundresses, gardeners, gatekeepers, stable-lads, chauffeurs, caretakers, governesses, babysitters, tutors, secretaries, etc. Also included is the undifferentiated subsistence goods-producing and services-producing activities of households. Households should be classified here only if it is impossible to identify a primary activity for the subsistence activities of the household.

ISIC segment U includes the activities of international organizations such as the United Nations and the specialized agencies of the United Nations system, regional bodies, etc., the International Monetary Fund, the World Bank, the World Customs Organization, the Organisation for Economic Co-operation and Development, the Organization of Petroleum Exporting Countries, the European Communities, the European Free Trade Association, etc. Also included are activities of diplomatic and consular missions when being determined by the country of their location rather than by the country they represent.

(P) Education

Education includes training at any level or for any profession, oral or written, as well as by radio and television or other means of communication. It includes education by the different institutions in the regular school system at its different levels, as well as adult education, literacy programs, etc. Also included are military schools and academies, prison schools, etc. at their respective levels. The section includes public as well as private education.

(Q) Human health and social work activities

Human health and social work activities include the provision of health and social work activities. Activities include healthcare provided by trained medical professionals in hospitals and other facilities, residential care activities that still involve a degree of healthcare activities, to social work activities without any involvement of healthcare professionals.

(R) Arts, entertainment, and recreation

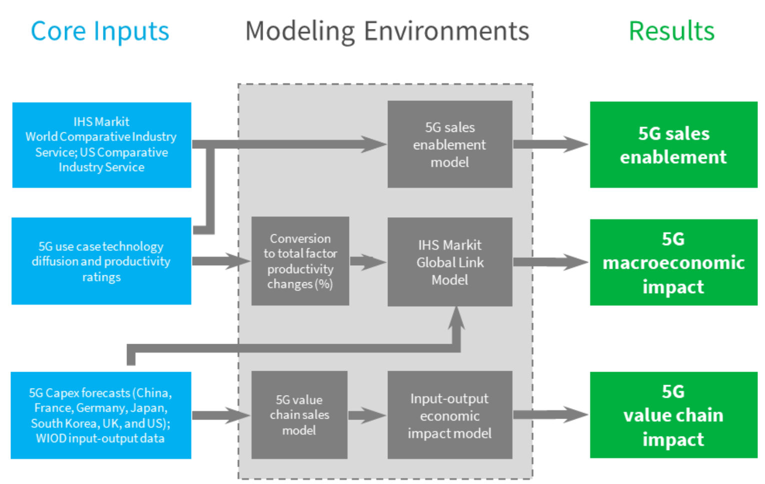
Arts, entertainment, and culture include a wide range of activities to meet varied cultural, entertainment, and recreational interests of the general public, including live performances, operation of museum sites, gambling, and sports and recreation activities.

Appendix C: Economic modeling

The economics team of IHS Markit analyzed the micro and macroeconomic impacts expected for 5G technologies. Through multiple conversations with the internal technology experts of IHS Markit and external experts, it was determined that, from an economic perspective, the two main drivers of impact would come through the investments made in 5G technology and the productivity improvements enabled by the technology. Productivity improvements are expected to be both direct—technological advances in speed, latency, and capacity—and indirect—enabling new, more efficient business models and higher valued services.

The IHS Markit microeconomic impact analysis considered two questions: How much economic activity is generated by the 5G value chain, and what will be the impact of the use of 5G technology on all other industries. The IHS Markit macroeconomic impact assessment also asked the broader question of how much will 5G technology contribute to the overall growth of the global economy. The following provides an overview of the methodology for the three assessments.

Economic modeling: an overview



Source: IHS Markit

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Economic impact analysis: Value chain

The mobile value chain will develop and deploy 5G technology. Companies within the value chain provide the direct economic impact of 5G technology through the investments they make. The economics team of IHS Markit quantified the economic contribution of the global 5G value chain using standard input-output (IO) analysis[1] techniques. IHS Markit built an international IO model using data from the 2016 World Input-Output Database (WIOD) Project, which was funded by the European Commission as part of the 7th Framework Programme, Theme 8: Socio- Economic Sciences and Humanities. The WIOD Project developed a set of harmonized country-level supply and use tables, which were then integrated with data on international trade to create intercountry (world) input-output tables. The WIOD data was supplemented with employment and wage data from the IHS Markit Comparative Industry Service (CIS).

[1] IO analysis traces back to the seminal work of Harvard economist Wassily Leontief in 1941, when he calculated an IO table of US economy. Leontief ultimately earned the Nobel Prize in Economics in 1973.

At its core, an input-output table is a two-dimensional matrix that traces the extent to which a given industry both relies on other industries for supplies and serves as a supplier to downstream industries and final consumers. This structure captures the inter-industry relationships within an economic region. The WIOD World IO tables expand this concept to encompass the economic inter-relationships of 56 industries across 43 countries. This was of particular importance to this study, as IHS Markit examined a core set of seven countries: China, France, Germany, Japan, South Korea, the United Kingdom, and the United States. Building the model using the WIOD data allows, for example, IHS Markit to trace how sales in the United Kingdom stimulate downstream economic activity in China.

IO analysis is particularly well-suited for assessing how sales transactions initiate ripples of economic activity throughout an economic region and, thus, answer the question of "How much economic activity is generated by the 5G value chain?"

IHS Markit estimated the direct sales activity within the 5G value chain based on a structure initially put forth by Boston Consulting Group.[2] First, the technology team of IHS Markit generated country-level forecasts for 5G-related capex by the mobile operators through 2040. The complementary capex for the other links in the value chain were then estimated to be consistent with the BCG analysis. Finally, historical ratios of capex to sales were applied to estimate the expected country-level sales for each link in the 5G value chain. These estimated sales figures served as the direct inputs to the IO model.

The IO model calculates the downstream economic output resulting from the 5G value chain sales. The employment and wage data from CIS were then applied to estimate employment and wage effects across each of the seven core countries plus the aggregate rest of the world.

Economic impact analysis: Global sales enablement in 2035

The next piece of the analysis was to better understand qualitatively and then quantify how 5G technology will affect all other industries as it gets adopted and used in industries to produce goods and services more efficiently and create new goods and services. Thus, the approach was twofold. First, IHS Markit used a structured approach, detailed next, to gather the collective input from experts at IHS Markit on what the foreseeable use cases for 5G technology would be within three broad categories that 5G is expected to improve and enable: EMBB, MIoT, and MCS applications. IHS Markit then took the qualitative data provided by the technology team and translated this to economic quantities using data from the CIS and historical patterns.

As detailed in the "5G technology and use cases" section, the technology team conducted an extensive analysis of 21 5G use cases, including the development of technology diffusion cycles for use case that account for both application ramp-up times and the potential impact on productivity levels across 16 core industry sectors. The technology team used a semi-quantitative assessment using a 1 to 5 scale (no impact to full deployment and high impact). The uses cases for each of the three broad categories were then averaged to calculate an overall rating for the category. The three categories were then aggregated to determine an overall rating for the potential impact of 5G on each of the 16 industries. Furthermore, recognizing that some use cases could potentially be implemented in existing technology, a similar assessment was done for 4G. The net impact of 5G on each industry was calculated as the difference between these assessments; the ratings for the 16 industries ranged from 0 to 10 (in the aggregate the rating could be higher than 5). Based on guidance from the technology experts of IHS Markit and historical patterns, this translated to a rating of 10 being equivalent to enabling about 1.0% of an industry's sales.

[2] Boston Consulting Group, *The Mobile Revolution*, January 2015

Next, using industry-level output data from the IHS Markit CIS, a weighted average rating was calculated. The weights were the ratio of industry's projected sales in 2035 to overall global sales. IHS Markit used the methodology from the 2017 study (developed in consultation with the Berkeley Research Group) to ensure the diffusion cycle estimates, and final results were reasonable based on its knowledge of the academic literature concerning the impact of information technology on economic output.

Economic impact analysis: Global macroeconomic growth

IHS Markit Global Link Model

Source: IHS Markit

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The first two analyses are partial equilibrium in that they estimate the impact on a particular sector or group of sectors without accounting for where else in the economy the resources for developing, deploying, and adopting 5G could have been used. Thus, the first two analyses do not answer the question of whether and to what extent 5G technology will contribute to sustainable economic growth and development for the global economy. The last piece of the analysis answers this question.

The economics team of IHS Markit used its proprietary Global Link Model (GLM) to assess how the investments in and productivity improvements enabled by 5G technology would affect the trajectory of global economic growth.

The GLM is the most comprehensive global macroeconomic model commercially available. It includes 250–500 time series per country and 68 countries, covering every region of the world. It is in the class of dynamic general equilibrium models and, therefore, accounts for how investments in one area require re-allocation from other areas. Thus, the impact on the global economy is a net effect. Positive improvements show that the investments produced a higher value than their next best opportunity (from where they were re-allocated).

In order to perform the analysis, the economics team of IHS Markit took as inputs the yearly capital investments made by the mobile value chain in each of the seven countries analyzed. These inputs were used to adjust the overall fixed private investment in equipment variables in the GLM. Since investments in 5G are already beginning, the investment variables were adjusted each year beginning in 2017. The second adjustment was to each of the seven countries' Total Factor Productivity (TFP) variable. This was done to assess the contribution 5G technology will have on global economic growth via its expected improvements in productivity. The technology team of IHS Markit again provided assumptions on the improvement; they analyzed how the use cases would evolve over time using a 1 to 5 rating to assess how the diffusion would impact productivity. The economics team of IHS Markit then translated the 1 to 5 rating into a percent improvement in labor productivity number. The translation relied on a literature review of how GPTs affect labor productivity over time. The most relevant study used for the translation was Jorgensen and Vu (2016)[3] and on guidance received during the 2017 study from Dr. David Teece and Kalyan Dasgupta from the Berkley Research Group who are experts in the field to ensure that the labor productivity assumptions were in line with proper expectations. The percentage improvements in labor productivity were then converted to overall improvements in TFP using the GLM's country-specific relationship between labor productivity and TFP.

By using the model's assumption, the global labor productivity improvement was varied by country based on the country's structure and relative efficiencies. Analysis of the model results show that the productivity improvements start contributing to global economic growth around 2025.

[3] Jorgensen, Dale W. and Vu, Khuong M. (2016) "The ICT revolution, world economic growth, and policy issues." Telecommunications Policy 40, p. 383–3

Appendix D: Comparison of current economic contribution results to the 2017 study

The original 5G economy study that IHS Markit conducted for Qualcomm was published in January 2017. As such, the forecasts and data that formed the underpinnings of the three economic contribution assessments in the original study reflected IHS Markit's informed estimates as of the fourth quarter of 2016. Three years on, much has changed in the world. A divisive US election in 2016, Brexit, trade wars, and a cooling Chinese economy to name just a few. These factors (and many others) are incorporated into the current IHS Markit forecasts and data that were used to update the economic contribution assessments presented in the current study. This section addresses the reasons for differences between the current the economic contribution results and those reported in the prior study.

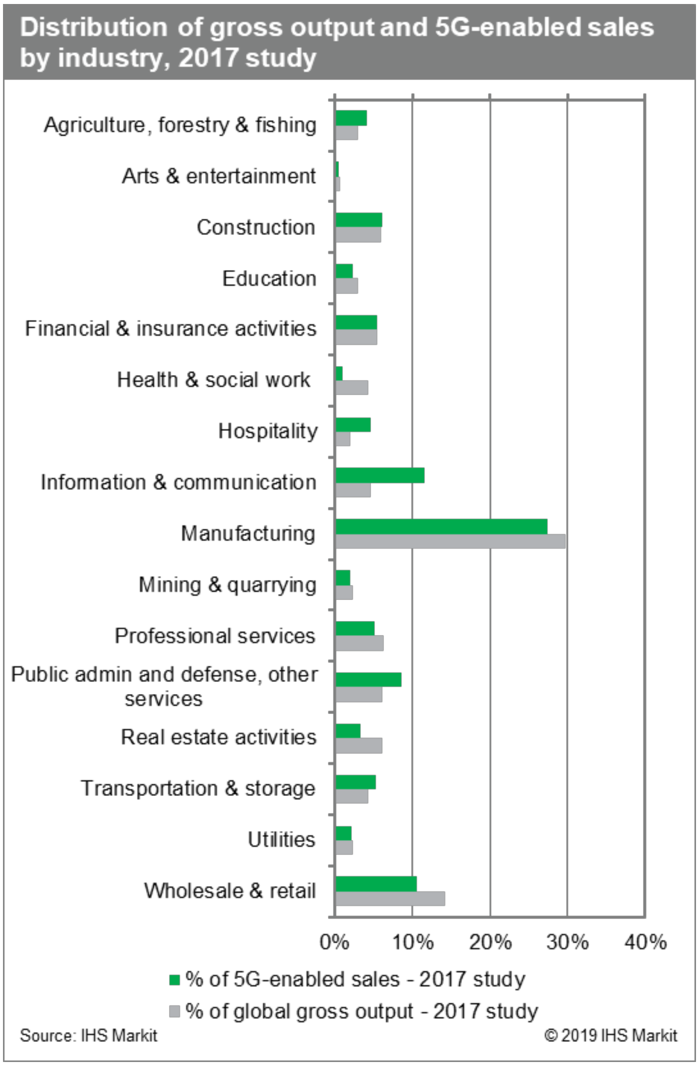
Sales enablement assessment

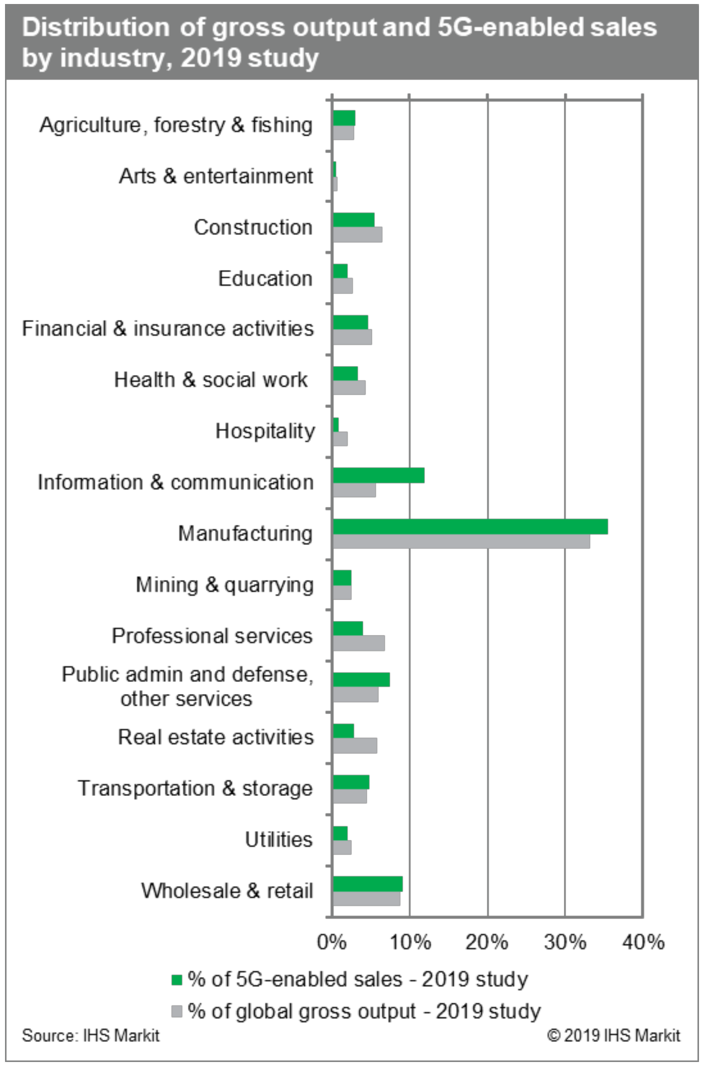
The sales enablement assessment blended together the use-case-by-industry ratings with the global forecast gross output trends by industry to derive estimates for the sales enabled by 5G technology in 2035. For the current study, IHS Markit did not modify the use-case-by-industry ratings used in the original study. In other words, IHS Markit's position on the relative impact of the 21 use cases on each of the 16 ISIC industries remains unchanged. However, as discussed in the main report narrative, the early completion of the first 5G standard, coupled with earlier-than-anticipated commercial 5G launches by major operators, points to a potential acceleration of MIoT and MCS use case deployments relative to IHS Markit's assumptions in the 2017 study. That said, the primary source of any differences in the sales enablement assessments are the underlying economic forecasts and data.

There are two primary drivers that dominate the shifts in the sales enablement results. The first is that IHS Markit's forecast for global gross output (sales) in 2035 is lower than our forecast from three years ago. The current forecast calls for global sales of $263.0 trillion versus the prior forecast of $270.2 trillion, a decrease of 2.7%. This is due, in large part, to lower growth for the Chinese economy. If all other factors held constant, this would put downward pressure on the revised sales enablement result and lower it to just under $12.0 trillion.

This downward pressure is more than offset by an increase in manufacturing's relative share of global gross output. Specifically, manufacturing's share in the current forecast is 33.2%, up from 29.7% in the prior forecast. This surge in manufacturing—which is significantly impacted by 5G—is accompanied by an increase in the sector's sales enablement of $1.3 trillion ($4.7 trillion in the current study versus $3.4 trillion in the 2017 study). This brings the overall sales enablement estimate up to $13.3 trillion. Finally, the share shift towards manufacturing pulls a little bit more out of the other sectors (as their relative shares of global gross output are lower). In the end, the sales enablement balances out to the reported $13.2 trillion.

The following charts show the distribution of global gross output and 5G-enablend sales across the 16 ISIC industries from both the 2017 and 2019 studies. While the patterns are quite comparable, the surge in manufacturing is readily apparent.





5G value chain

Investment in the continual development and deployment of the 5G technology base lies the heart of the 5G value chain analysis. Spending on both capital investment and R&D will spawn a global ecosystem (the 5G value chain) that provides the tools equipment, network infrastructure, software tools, and content needed to help ensure 5G becomes a general purpose technology.

To assess the differences between the 5G value chain results reported in the current study and those reported in the 2017 study, it is helpful to segment the 5G value chain into two levels. The first level is the direct or core level where 5G technologies are developed and brought to market. The growth of the core level will track closely to 5G investment. Second is the supply chain level that provides inputs (components, supplies, etc.) to the core level. The models IHS Markit developed to assess the 5G value chain include trade flows between the seven countries. Thus, examining shifts in the supply chain activity can provide insights on the sourcing of inputs by the core level.

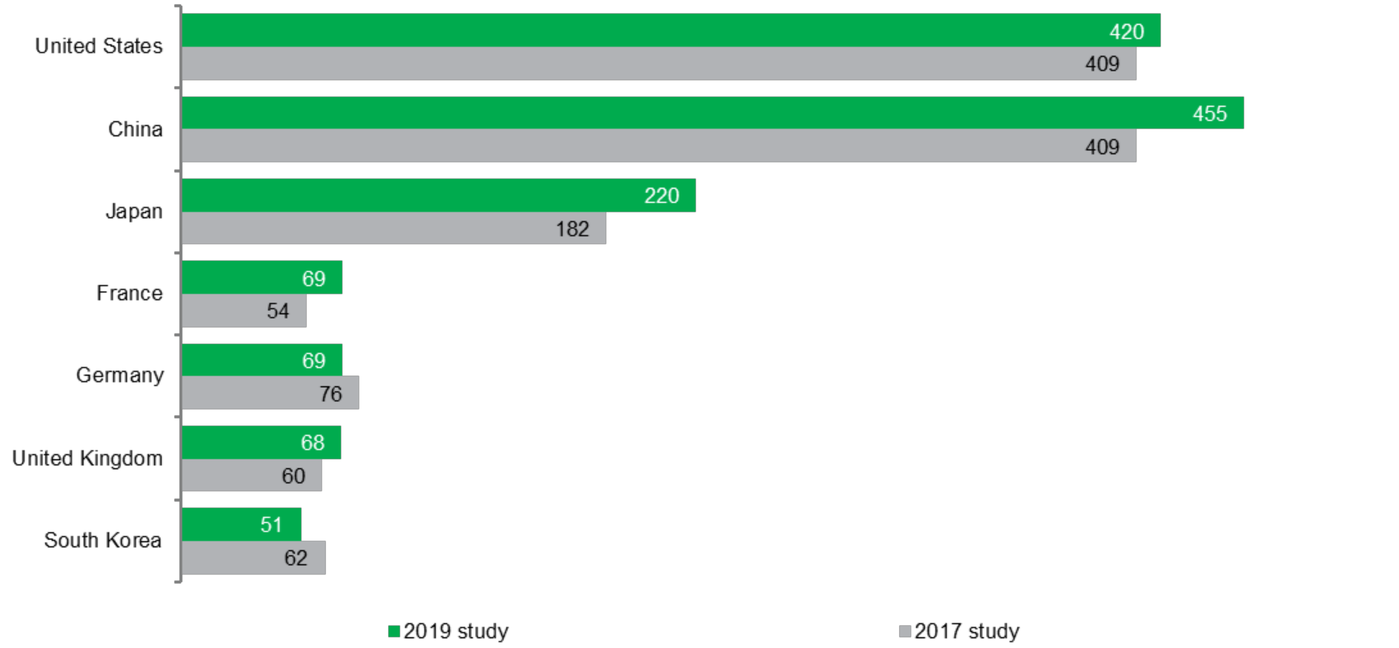
Updates to the WIOD data that IHS Markit used to develop the models used for the 5G value chain analysis likely contributed to differences between the 2017 and 2019 results. The original study used the WIOD 2014 data release, which provided input-output and socioeconomic data for 35 industry sectors across the seven countries. The current study used the WIOD 2016 release, which provided similar data for 56 industry sectors. The updated

WIOD data and new industry structure resulted in changes to inter- and intra-industry linkages (i.e., sales transactions within and between industries) that shifted the supply chain response characteristics. In addition, changes to the productivity statistics in the socioeconomic datasets affected the employment results (discussed later in this appendix).

Shifts in capex and R&D investment

The overall average annual 5G-related investment across the seven countries during the 2020–35 time period is expected to be 7.8% higher than IHS Markit expected during the 2017 study. The gross output of the core layer of the 5G value chain will also be 7.8% higher in 2035; however, as the distribution of investment shifts, so will the evolution of the core layer within the seven countries. The most notable upward shifts will occur in China and Japan, while the projected size of the value layer will notch downward in South Korea and Germany.

5G value chain core layer by country, 2035 (billions of 2016 $)

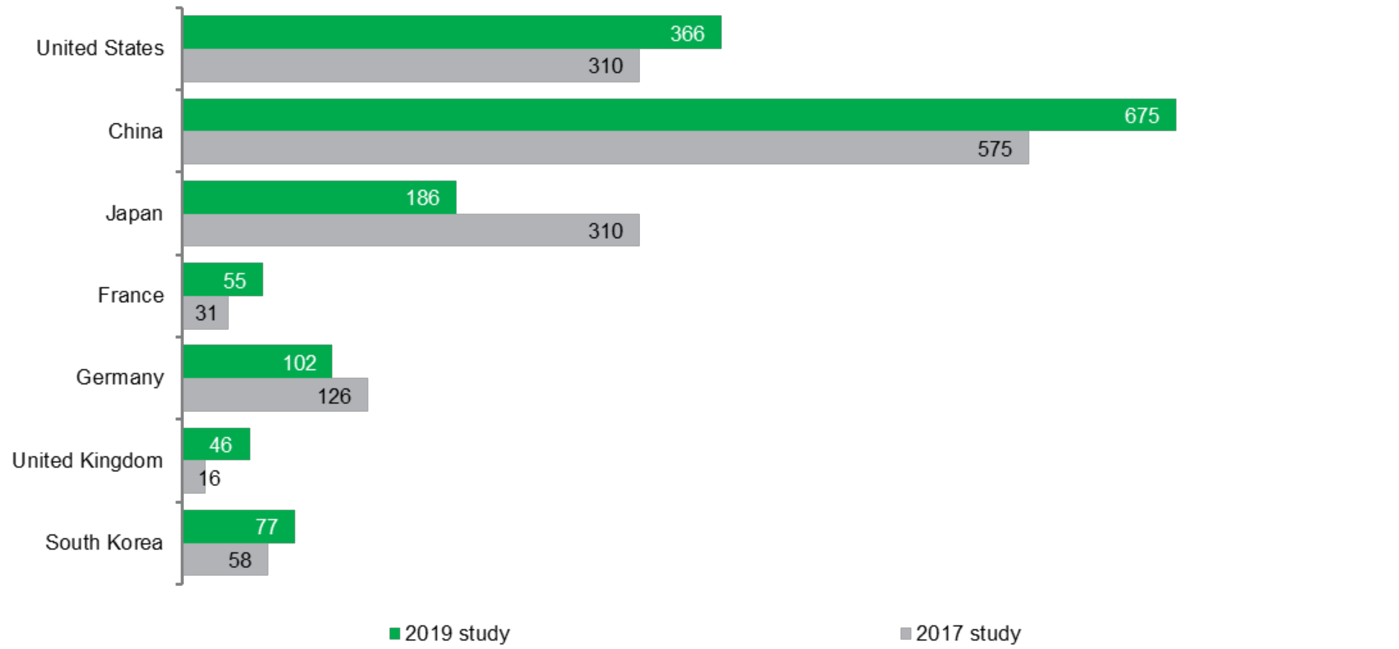


Source: IHS Markit

Shifts in supply chain dynamics

IHS Markit estimates the supporting or supply chain layer in 2035 will be 5.8% higher than originally forecast in the 2017 study. However, changes in the distribution of supply chain activity indicate shifts in sourcing towards the United States and China. On the flip side, the 2019 study projects relatively smaller shares of supply chain activity for Japan and Germany.

5G value chain supporting layer by country, 2035
(billions of 2016 $)



Source: IHS Markit

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Combining the core layer and supporting layer assessments provides insight regarding sources of the shifts in country-level 5G-related gross output results from the original study to the current study. For example, the US value chain was revised upward from $719 billion in the original study to $786 billion in the current study. Of this $67-billion increase, the core layer accounts for $11 billion while the supporting layer accounts for $56 billion. This indicates the United States' 5G-related supply chain activity is expected to be much stronger in the new study. Conversely, Japan's 5G-related gross output of $492 billion in the original study is marked down to $406 billion in the new study. Of this, core activity increases $38 billion while supply chain activity declines $124 billion, for a net shift of $86 billion. Looking at just Japan's overall 5G-related output (the $86 billion) would partially obscure a more pronounced negative shift in supply chain activity (the $124 billion).

Shifts in productivity statistics

The revision of the WIOD input-output socioeconomic data resulted in shifts in supply chain linkages (discussed above) and productivity statistics. Particularly noteworthy are changes to output-per-worker statistics. Increased output per worker indicates higher productivity levels. While increased productivity rates are desirable, they also tend to drive down employment levels per unit of output. Simply put, less people are required to produce a given level of output as productivity rates increase.

The productivity statistics have shifted quite a bit across both the country level and the industry level. China shows a drop of almost 20% in output per worker for the information and communications sector, which would tend to increase employment in the 5G value chain core level. This is offset to some degree by an increase of 21% in the manufacturing sector, which will tend to drive down employment in the 5G value chain supporting layer. The output per worker for these industries in the United States, on the other hand, have both increased. Thus, the employment response in the US for the current report is dampened compared to the prior study.

Percentage change in output per worker							
Industry	**China**	**Germany**	**France**	**Japan**	**South Korea**	**United Kingdom**	**United States**
Overall	9.3%	6.1%	-4.6%	-8.6%	12.1%	16.5%	0.7%
Agriculture, forestry & fishing	1.8%	7.0%	-9.5%	-8.0%	0.1%	35.0%	1.5%
Mining & quarrying	-11.5%	-5.3%	2.1%	1.6%	-9.6%	32.1%	17.8%
Manufacturing	21.2%	1.1%	-15.6%	-14.7%	28.6%	27.8%	7.4%
Utilities	-48.7%	-10.5%	2.4%	3.9%	-57.6%	-34.1%	-17.3%
Construction	24.5%	-4.5%	5.0%	0.8%	28.9%	18.8%	-7.1%
Wholesale & retail trade	20.7%	11.3%	-6.6%	-11.7%	33.6%	3.4%	3.7%
Transportation & storage	14.5%	7.8%	-7.3%	-18.6%	18.1%	64.6%	0.7%
Hospitality & food service	6.2%	26.5%	-3.5%	2.3%	13.6%	-37.5%	-12.7%
Information & communication	-19.7%	35.1%	44.3%	-13.0%	-25.2%	115.4%	6.1%
Financial & insurance	-13.0%	1.4%	17.0%	-27.9%	21.3%	69.7%	-24.4%
Real estate activities	-25.5%	10.7%	-26.9%	-3.0%	36.4%	406.6%	-10.9%
Professional, scientific & admin services	-50.2%	10.2%	-4.9%	-30.4%	-1.6%	-34.8%	-16.4%
Public service & defense	-44.5%	5.1%	9.0%	22.1%	-41.3%	77.4%	4.2%
Education	2.7%	9.6%	6.0%	-1.9%	17.3%	51.3%	14.8%
Human health & social work	-33.7%	2.8%	-0.3%	-9.1%	-19.6%	-17.9%	8.9%
Arts & entertainment	25.1%	-21.6%	-29.2%	-22.0%	22.1%	-23.7%	-14.4%

Source: IHS Markit

Stable economic growth

IHS Markit also examined the contribution to net global GDP stimulated by 5G-related capital investment and R&D investment. To do so, annual 5G-related investment was used as an input dataset to simulations run on IHS Markit's Global Link Model (GLM). The GLM is the most comprehensive global macroeconomic model commercially available. It includes 250–500 time series per country and 68 countries, covering every region of the world. It is in the class of dynamic general equilibrium models and, therefore, accounts for how investments in one area require re-allocation from other areas. Positive improvements show that the investments produced a higher value than their next best opportunity (from where they were re-allocated). Thus, the impact on the global economy is a net effect.

The annual net contributions to global GDP reported in the current study are lower than those in the original study. For the most part, this is likely attributable to the expected lower growth regime for the world economy in IHS Markit's current forecasts. Thus, even with slightly higher 5G-related investment, the response of the global economy is slightly muted in the current study; however, the key takeaway is that annual investment in 5G, coupled with productivity improvements from the 5G use cases, still yielded a risk-adjusted NPV GDP contribution of $2.1 trillion over the 2020–35 period. This indicates a positive contribution to global expansion and growth.

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About IHS Markit

IHS Markit (Nasdaq: INFO) is a world leader in critical information, analytics and solutions for the major industries and markets that drive economies worldwide. The company delivers next-generation information, analytics and solutions to customers in business, finance and government, improving their operational efficiency and providing deep insights that lead to well-informed, confident decisions. IHS Markit has more than 50,000 key business and government customers, including 85 percent of the Fortune Global 500 and the world's leading financial institutions. Headquartered in London, IHS Markit is committed to sustainable, profitable growth.

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