Bell Labs Consulting

The big inversion

How 5G+ technologies will create new value for industries in a post-COVID world

NOKIA BELL LABS

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Executive summary

While the social and economic disruption caused by COVID-19 is evident to all, the larger-scale trends it has set in motion are less obvious and will continue long after the pandemic is gone. As industries and enterprises embrace the “new normal” and prepare for a post-COVID world, they must capitalize on the emerging digitalization opportunities and challenges that are set to accelerate the “inversion” of global value paradigms.

To begin with, the pandemic has served as an acute reminder that digitalization doesn’t merely enhance industrial growth and profitability, it also critically impacts society and the economy. For example, the sharp growth in video conferencing and telemedicine demand is a testament not only to the effectiveness of digital services in filling gaps in supply at short notice, but also to the sustainability and resilience of these services.

Second, the COVID-19 crisis has increased the gap between leaders and laggards, both within and across industries. While it is easy to chalk this up to pandemic-induced demand shifts, this argument masks the fact that COVID-19 has only accelerated digitalization trends that had begun much earlier. Businesses that had adopted digital automation strategies such as e-commerce were well positioned to meet these demands head on. Furthermore, the acceleration has been unprecedented in both speed and scale. A recent survey of over 2,500 companies across all industries worldwide found that COVID-19 has accelerated the implementation of digital communications by six years on average [1].

A solid digitalization foundation may have helped online retailers and web services companies address the big spike in demand for online goods and services during the pandemic, but many companies have only scratched the surface of digitalization’s potential to generate significant value in terms of increased safety, productivity and efficiency (SPE). The speed and scale with which they are able to respond makes them resilient in the face of changes in

supply and demand brought about by future shocks. Digital industries such as online retail, media and banking have already realized much of their digitalization potential, but physical industries like manufacturing, healthcare, transportation, logistics, mining and energy utilities have lagged significantly. Today, the ratio of information and communications technology (ICT) investment between digital and physical industries is 70:30—even though the proportion of their respective GDP contributions is 30:70. This disparity is the new opportunity for inversion.

Physical industries are poised to make investments in a broad ecosystem of technologies that Bell Labs Consulting collectively terms “5G+”. 5G+ comprises not only the underlying foundational 5G networks, but also key technologies that will work hand in hand with 5G to digitalize every aspect of a company’s operations. This includes edge cloud infrastructure, augmented intelligence/machine learning (AugI/ML), enterprise private networks, and advanced sensors and robotics. These technologies will act in concert and increasingly be accessible “as a service,” allowing instant access to the optimum tools and capabilities, from anywhere, at any time.

5G+ will establish the supply-side readiness required by these industries in the post-COVID era to create optimized SPE benefits that will enable a more purposeful, resilient future. These benefits to enterprises will translate into higher wages, increased profits and higher government revenues, resulting in sustained global GDP growth.

Bell Labs Consulting projects that ICT investment enabled by these 5G+ technologies will grow to $4.5 trillion globally in 2030, led primarily by physical industries undergoing a massive digital transformation. This huge spending infusion will mean the historical 30:70 ratio of ICT spending between physical and digital industries will invert, becoming 65:35 in favor of physical industry spend. What’s more, this investment in industries will cascade throughout the global economy; we estimate that increased wages, profits and tax revenues will induce an increase in global GDP of up to $8 trillion.

In summary, we predict that we are approaching a “big inversion” in ICT investment in physical and digital industries, driven by this emerging set of 5G+ technologies. This inversion will restore the parity in ICT investment between the amount these industries invest in ICT and their respective contributions to overall global GDP and workforce employment. When this inversion is complete, industries will be optimized to create and capture new value.

Digitalization leaders and laggards

Twelve months into the pandemic, it is now easier to discern its wide-ranging impact across all industries. It has severely impacted industries requiring high levels of physical contact—such as public transportation, hospitality and entertainment—but it has also boosted industries that deal heavily in digital content and services. For example, e-commerce demand has surged. Figure 1 (left) shows that the e-commerce share of total US retail spend, which had been gradually trending upwards over the past decade, shot up two-fold within three months of the onset of COVID-19. Figure 1 (right) shows e-commerce adoption as a share of the total infrastructure supply required to meet US retail demand. It is clear that e-commerce supply-side readiness was well ahead of the actual demand, thereby enabling e-tailers to fully meet the demand surge when it arrived.

This surge, however, has been by no means limited to digital industries and digital products. Physical industries have faced similar demand spikes for many of their products in the wake of COVID-19. For example, the demand for personal protection equipment (PPE) and ventilators shot up dramatically in the US as a result of the pandemic. However, PPE manufacturers were not initially able to meet the demand, as they lacked the ability to rapidly scale up their supply to a commensurate level, leading to massive shortages.

To some degree, PPE supply has ramped up since the start of the pandemic, using 3D printing and adaptive manufacturing to create a broad range of PPE products with customized and complex product designs. But bringing such capabilities to a level that would efficiently address today's PPE shortages would require large-scale deployment of intelligent systems connected to a distributed and flexible manufacturing infrastructure capable of rapidly disseminating custom product designs and process codes across both local and wide areas. It would also require access to real-time information on the specific demands in each location. Creating this level of supply readiness requires a close integration of operations technologies (OT), which control closed-loop automated

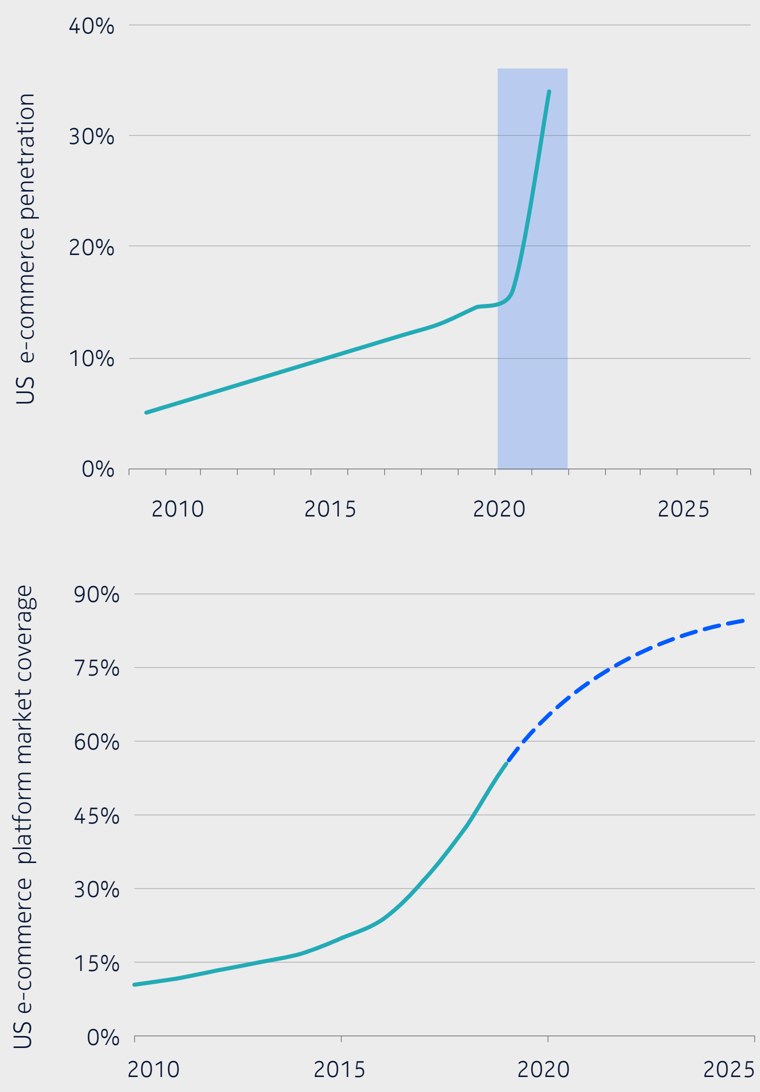
processes, and ICT, which controls and connects those processes. Without that digital infrastructure in place, PPE manufacturers were left largely powerless to act, facing down demand that they were simply unable to meet.

Digital infrastructure and ICT-OT integration will impact more than just the COVID-induced demand spike. What is far more consequential is that industries will be forced to rethink strategic resilience and productivity paradigms. To that end, the short-term growth driven by the pandemic serves as a catalyst to accelerate those long-term gains.

The stark difference in how e-commerce and PPE manufacturing responded to the pandemic illustrates the different levels of digitalization of these two industries, but they are by no means outliers. All industries have executed digitalization strategies to a lesser or greater degree, leaving them either exposed when the next big demand spike hits or prepared to meet the demand surge and even generate new demand. In order to characterize these differences, we classify industries into three groups according to their current digitalization maturity level, as defined by the Brookings Institution [2], and their ICT spend. These industry groups are:

1. **Digital Mature:** This group comprises all digital industries; these sectors have the highest digitalization scores, reflecting a maturity built upon several years of strong ICT spend. Industries included in this group include communications and media, banking and securities, and insurance.
2. **Physical Leading:** These are physical industries that have achieved limited digitalization through moderate ICT spend. However, these industries have significant motivation to increase their spend as it leads to strong productivity gains. This group includes manufacturing, healthcare, transportation, retail, education, government and utilities.

Figure 1: The impact of COVID-19 on e-commerce demand



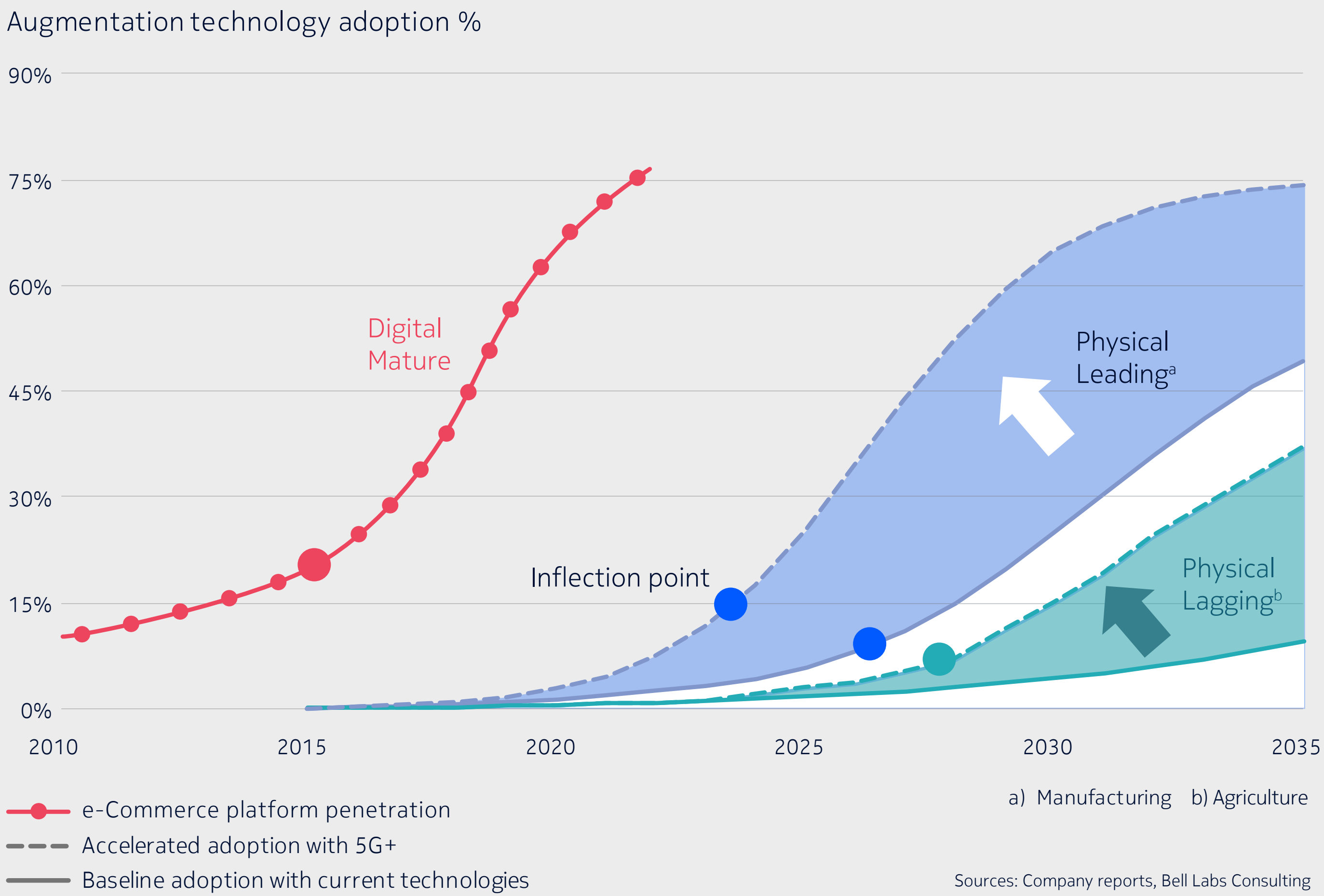
Sources: McKinsey, Company reports, Bell Labs Consulting

Top panel: Rapid growth in e-commerce penetration in US in the first three months of the pandemic; bottom panel: Readiness of e-commerce supply infrastructure to meet demand surges through early buildout of systems and platforms

3. **Physical Lagging:** These industries have low digitalization scores and low ICT spend. While some sub-sectors have benefited significantly from greater automation, the extent to which these industries can realize these benefits is strongly dependent on geography environment. Besides, there is significant variability in the productivity gains potential achievable by different sub-sectors within the same industry. This group includes construction, agriculture, mining, wholesale trade, live performance arts and entertainment, and accommodation and food services.

Digitalization of physical industries will happen through the adoption of augmentation technologies, bringing together ICT and OT. This enables an industrial platform for extreme robotic automation, massive-scale sensing, AugI/ML-enabled cognitive control, and local and wide area networking. These capabilities, when supplemented with required human augmentation skills, will collectively form the hyper-augmented environment required for

Figure 2. Digitalization adoption in physical industries



Estimated adoption of augmentation technology for Digital Mature industry represented by e-commerce platform penetration in US retail and projected proportion of jobs that will be augmented in representative Physical Leading and Physical Lagging industries.

the digitalization of Physical Leading and Physical Lagging sectors.

The confluence of ICT and OT will result in a new augmented industry. An environment that is highly adaptive and resilient can achieve significant improvements in productivity and enable physical industries to scale up and down easily to meet unforeseen demand spikes or supply disruptions in the future. Workers in these future augmented industries will themselves become hyper-augmented through physical and cognitive augmentation. In a previous study, Bell Labs Consulting had predicted that this class of augmented workers, called "new-collar" workers will account for as much as 70% of the workforce in the US by 2030 [3].

While the digitalization of physical industries has started, the scale of adoption so far has been well short of its overall potential, primarily because of the limited introduction of new enabling technologies to generate new economic benefits. While these technologies are well identified now, their widespread deployment will be contingent upon their maturity, the pace of global 5G adoption, the implementation of standards pertaining to high-performance services and the ability of industries to open up and overcome the challenges of successfully integrating ICT with OT. In general, we expect the pace of digitalization to be faster in Physical Leading industries than Physical Lagging industries and will depend on the maturity of the augmentation technologies, the associated cost of deployment, the dynamics and readiness of the labor market and the expected economic benefits, as well as regulatory and social factors.

In Figure 2 we compare the pace of digitalization of the industry groups. For Digital Mature industries, we plot the percentage of merchants in the US that have online presence (derived from company reports on e-commerce platform sales and Bell Labs Consulting estimates) to represent the penetration of augmentation technologies. For physical industries, we plot the penetration of jobs that will be augmented in the manufacturing sector, which is a Physical Leading industry and agriculture sector, which is a Physical Lagging industry.

E-commerce originated in the late 1990s, and for the most part its growth in the following decade was limited to established retailers and electronic-marketplace providers with the ability to invest in the necessary infrastructure and platforms. The emergence of e-commerce platform-as-a-service providers such as Shopify around 2010 made it easier for the smaller merchants to offer their products and services online as well, leading to a very rapid growth in e-commerce platform adoption in the US by 2015.

For physical industries, we use the year 2015 as the reference point to mark the beginning of the new generation of augmentation technologies emerging from the confluence of the Internet of Things, machine-to-machine communications, advanced wireless technologies, cloud computing and AugI/ML. In making these projections we consider two aspects: the extent of adoption and the pace of adoption. The solid line in Figure 2 represents the pace and extent of adoption using current technologies. The dashed line represents our projections for how these trends accelerate once enterprises realize the increased SPE benefits of integrating 5G and related enabling technologies with OT technologies. Extent of adoption is represented by the percentage of jobs that can be augmented in different industries and is based on the Bell Labs Consulting analysis of work activities across different job functions and industries [3]. The difference between the different sectors is a function of the proportion of job activities in the sector that benefit from these augmentation technologies.

The pace of adoption captures how quickly different players in the industry adopt augmentation technologies. Past studies have shown that there is a wide variation in the pace of adoption of different technologies, and it can take decades for a new technology to achieve maximum penetration, with enterprise technologies taking longer than consumer technologies because of the multiple criteria that go into business decision processes [4]. Moreover, the extent of technology diffusion will vary from country to country and within a country across different industry sectors [5]. The difference in the pace of adoption between the Physical Leading and Physical Lagging industries duration is due to the inherent difference in the nature of these industries. In the agriculture sector there is significant variation in the environment and type of crop planted across different parts of the world making it inherently more complex for augmenting technology solutions to be developed and deployed. Moreover, this industry in most parts of the world comprises small farms run by individual farmers or farm cooperatives. For example, 67% of the farmland in India is held by marginal farmers that own fewer than 2.5 acres [6]. The lack of wherewithal to make the type of investments needed to deploy these technologies will also inhibit the pace of advanced technology adoption. On the other hand, even though there is variation in the type of goods produced, manufacturing for the most part happens in more controlled environments, with more streamlined processes making it easier for companies to adopt these technologies.

While the specific diffusion timelines and inflection points for mass adoption may vary across industries, it is important to consider the relative advantages provided by 5G+ in terms of the industry resilience and proportional SPE gains that will be the primary drivers for adoption.

We discuss in more detail the key enablers and the benefits that physical industries can derive from these technologies in the following sections.

5G+: The new enabler for industry digitalization

The gap between physical industries and their digital counterparts may be wide, but we believe that it can be bridged with 5G+ technologies; the essential infrastructure that merges enterprise ICT and industrial OT, and, as the "plus" in 5G+ implies, extends well beyond 5G network infrastructure, as described below.

Pervasive 5G provides the essential high-capacity, low-latency, highly reliable, secure connectivity services, with guaranteed service levels across wide area mobile and fixed network services.

Edge infrastructure/cloud platforms comprise the underlying edge cloud infrastructure and platform services, as well as the cloud-native functions (CNFs), and the applications and services they support. The entire service is located within 100 kilometers of the end user in order to enable high-reliability, low-latency SPE applications that optimize productivity.

Augmented intelligence and ML systems comprise the data management, training toolset, deep learning models, analytics and mathematical and statistical tools, as well as their associated visualization and orchestration hardware and software. This suite of capabilities also needs to reside on the edge cloud infrastructure to support real-time automation and augmented reality services.

Private networks refer to so-called dedicated networks ranging from Standalone Non-public Networks (SNPNs) with minimal dependence on the external wide area network to Public Network Integrated NPNs (PNI-NPNs) that share many access and core functions with external networks. They can use licensed, unlicensed or shared-license spectrum and utilize network slicing to provide end-to-end service guarantees from the end device(s) to the edge cloud and between all the different application and service components.

5G+ suite of technology enablers

- End-to-end 5G networks
- Edge infrastructure/cloud platforms
- Augmented intelligence and machine learning
- Private networks
- Advanced sensor and machine technologies
- End-to-end security
- Network-as-a-service business models

Advanced sensor and machine technologies will be required to sense the physical world, both to allow navigation by humans and machines (and the co-sensing of human-machine interactions) and to accurately create digital twin representations that can be used to analyze different scenarios, both present and future.

End-to-end security will be essential to ensure the business and data integrity across the dynamic array of different sensors, devices, machines, systems and people that will define each industrial automation service and application. This represents a massively increasing and continuously varying threat surface that has to be validated with, for example, blockchain-based ledger and AugI/ML-based pattern recognition in real time.

Network-as-a-service business models will be an essential value accelerator, reducing upfront capital investment and mitigating business and technology risks by scaling operations elastically as demand shifts and as application needs change.

In addition to the above-mentioned enablers, 5G+ also includes the **enterprise applications, services and platforms** that are impacted by these technologies. These comprise enterprise computing platforms; general and vertical-specific applications, including application development and business intelligence solutions; and professional and managed services and projects that are impacted by 5G+ technologies. We believe that an inclusive view of ICT spend enabled by 5G+ is necessary to capture the pervasiveness of 5G+ technologies and the extensive impact they have on traditional enterprise applications and services.

The above constituent solutions will allow 5G+ to digitalize the operations technologies being used in different industries. Every industry will require an optimal combination of these 5G+ technologies to establish the ICT infrastructure foundation necessary to achieve supply-side readiness.

5G+ enables strategic resilience with safety, productivity and efficiency benefits

Both Physical Leading and Physical Lagging industries are now poised to make major ICT investments over the next decade. Each industry will optimize the use of 5G+ technologies to digitally augment themselves to realize new SPE benefits at faster speeds and scale.

We will now discuss how 5G+ deployment generates new SPE gains in four physical industries. We consider example sub-sectors within each industry: Factory automation in manufacturing, seaports in logistics, open-pit mines in mining and precision farming in agriculture. We determine the range of relative improvement in the composite SPE gain achievable with 5G+ over the currently available technologies. Our results are based on a number of case studies involving real deployments. We incorporate actual—but duly anonymized—data on the performance of current technologies.

The relative improvement expected from 5G+ deployment is based on trials, early deployments and expert judgment supported by reported performance results.

The metric used for computing safety improvement is the percent reduction in the number of safety-related incidents. Following the classification used by the Bureau of Labor Statistics (BLS), we define safety-related events as accidents involving contact with objects and equipment; worker falls, slips and trips; injuries related to worker overexertion; transportation-related incidents; human exposure to harmful elements; and fires and explosions.

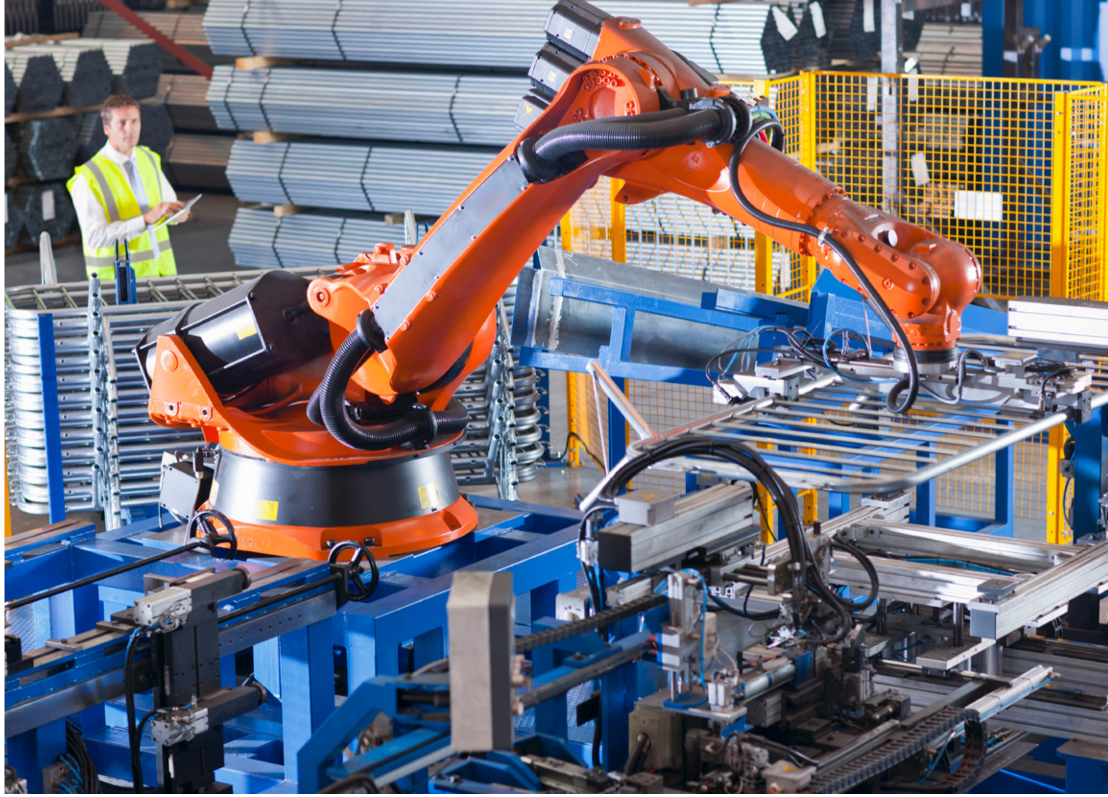
Productivity improvement, which is the major determinant of overall SPE gains, refers to the percent increase in the volume of goods or services produced from the same asset base. Essentially driven by process

or operational improvement such as automation, coordinated real-time scheduling, etc., productivity increases typically manifest through lower cycle times (for repetitive operations), reduced process idle times, and fewer work stoppages and maintenance events. Productivity growth usually results in higher asset utilization; it also leads to potential revenue growth. The metrics that we used to measure productivity improvement varied by industry, ranging from reductions in cycle times and lead times to increases in labor productivity, overall output and potential revenue.

While productivity focuses on increasing output, efficiency measures the ability to reduce the amount of resources consumed for the same level of output. Efficiency improvement invariably results in cost reduction be it on account of lower material cost through better quality and waste reduction, or lower labor costs through reduction in labor content, or lower overhead cost through lower inventories. Better asset utilization due to productivity increases also leads to efficiency improvements as it reduces capital costs. We measured efficiency improvement through the reduction of operating costs, the decrease in inventory levels, the increase in overall equipment effectiveness (OEE), and higher energy efficiency.

Consider the **manufacturing** industry. 5G+ will enhance the SPE benefits realized in a factory as follows: intelligent video sensing coupled with AugI/ML will detect an accident before it happens, thus enhancing worker and equipment safety. AugI/ML systems will forecast demand for specific products to enable anticipatory production [7], shorten order response time and allow companies to maximize their production capacity. AugI will also play a critical role in optimizing product design to facilitate mass customization and streamline the manufacturing process [8]. Factory productivity is enhanced further through intelligent reconfigurable robots that augment shop floor workers.

Similarly, 5G+ improves factory efficiency in a number of ways: New sensory technologies supported by AugI/ML systems detect a machine failure before it occurs thereby



minimizing unexpected disruptions, video analytics forewarn a possible quality issue to prevent material wastage, and real-time control of factory-wide operations ensures minimal inventories. Increased operational flexibility, enabled by network-as-a-service business models and improved network redundancy, together with enhanced business intelligence driven by digital acceleration tools, allows industries to achieve SPE benefits at speed and scale.

For example, Nokia's Conscious Factory in Oulu Finland, a part of the World Economic Forum's Global Lighthouse Network project [9], is a fully digitalized factory that incorporates all 5G+ technologies to drive machining and assembly using collaborative robots, autonomous transportation through mobile robots, quality control through massive-scale sensing and video analytics, and maintenance schedules driven by AugI/ML recommendations based on real-time asset condition data. All these systems are connected by a private 5G network and are overseen by an augmented workforce. This site has seen a 30% year-over-year improvement in productivity; it has experienced efficiency gains through the reduction of robot lead time by

80%, and it has reduced staff floor time by 20% leading to greater worker safety.

As shown in Figure 3, we expect 5G+ to yield a 4x to 11x increase in the overall SPE metric of a typical medium to large factory relative to current technologies. Productivity increases, ranging between 4.0x and 12.1x, are the largest contributor to this growth. 5G+ also boosts the efficiency (5.7x to 9.8x) and safety (4.4x to 6.6x) dimensions substantively.

A seaport represents a typical enterprise in the Physical Leading **logistics** sector. Facing serious congestion, container management and sustainability issues due to increasing vessel sizes and growing container exchanges, seaports can realize SPE gains through 5G+ in multiple ways. AugI/ML-enabled video surveillance working in conjunction with low-latency automated motion control and geofencing prevent collision events even at high levels of container transfer. Remote and autonomous operation of key assets, such as quay and gantry cranes and automated guided vehicles, ensures high levels of operation continuity. Port productivity is also enhanced through synchronized real-time berth scheduling, yard planning and gate traffic management driven

Figure 3. 5G+ driven SPE gains in physical industries

Source: Bell Labs Consulting

Range of SPE benefits achieved in example sub-sectors within two Physical Leading (Manufacturing, Logistics) and two Physical Lagging Industries (Agriculture, Mining) by AugI/ML-based analytics [10]. End-to-end coordination of vessel and yard operations with demand planning at the gate ensures high equipment utilization to drive down operating cost and improve energy efficiency of ports. 5G+ also enhances climate resilience through AugI/ML-enabled advanced alert systems that are linked to their demand and operations planning.

A Bell Labs Consulting study of a major port showed that deploying autonomous/remote-controlled equipment, vehicles, drones, smart sensors, video analytics and AR/VR along with 5G could result in an additional 24% increase in operations cost savings and a 35% increase in available operational capacity compared with using 4G.

As shown in Figure 3, 5G+ is expected to provide a 4x to 9x increase in the overall SPE metric of a typical medium port relative to today's technologies. Productivity increases, ranging between 5.2x and 15.0x, are the largest contributors to this growth. Higher efficiency in the order of 3.5x to 5.8x, is the next major contributor. 5G+ also boosts the safety dimension (4.2x to 6.3x) significantly.

Precision farming (PF) refers to the use of new technologies to increase crop yield and minimize cost through targeted deployment of seeds, fertilizer and water to match the soil, crop and environment needs. Faced with the challenge of growing 70% more food in the next 30 years to keep up with the population growth [11], the **agriculture** industry has identified PF as a key enabling strategy. Even though the overall agriculture industry has lagged in digitalization, PF exemplifies an area that can reap strong SPE gains from 5G+. The major contributor to these gains is the use of AugI/ML and video analytics systems—supported by reliable connectivity to a large number of sensors and high-power local computing—to improve PF productivity significantly. Farms can finely separate crops from weeds using reliable video sensing. They can precisely spray seeds, fertilizers, herbicides and water using teleoperation and AugI/ML-based real-time soil condition monitoring. These techniques not only help optimize farm yield, they also result in efficient operations by tightly controlling the costs of resources and maximizing farm equipment utilization.

A field study conducted by KPN and Wageningen University and Research in the Netherlands showed that deploying a PF approach using 5G+

technologies in a sugar beet field resulted in 6.7x productivity increase [12]. This study used an autonomous mobile robot armed with cameras to stream images of the plants on the ground to a cloud-based edge computing server over a 5G connection. The server applied a deep learning algorithm to identify good crops from the weeds and remotely trigger the spraying mechanism on the robot to remove the weeds.

As shown in Figure 3, 5G+ should result in a 2x to 6x increase in the overall SPE metric relative to today's technologies for a typical precision farm. Productivity increases, ranging between 1.7x and 8.1x, are the largest contributor to this growth. Higher efficiency (2.2x to 5.3x) and improved safety (3.5x to 4.8x) also add to the superior SPE growth achieved with 5G+.

The digitalization of open-pit mines exemplifies how 5G+ technologies can help the **mining** industry meet its SPE challenges after enduring several years of declining productivity followed by modest growth [13]. Fine-grained 360˚ situational awareness and geofencing capabilities, built upon thousands of sensors deployed over a wide area with 5G connectivity and supported by AugI/ML systems, prevent accidents arising from factors such as operator fatigue, contamination and slope stability issues [14]. Autonomous operation of high-power drills, driverless trucks and other equipment through low-latency video sensing and AugI/ML-based control has significantly reduced the frequency and duration of work stoppages. This autonomous equipment usage improves mine productivity and efficiency further through the ability to safely and predictably run 24 hours a day, 7 days a week. Similarly, digital twins can be used to detect and resolve a variety of operational problems in mines. AugI/ML systems, supported by hyperscale sensing, enables real-time planning and control of entire pit-to-port operations to ensure high asset utilization and on-time performance.

A Bell Labs Consulting preliminary analysis of an iron ore mine in Australia showed wide-ranging benefits achieved by a private 5G+ enabled network over the Wi-Fi-based automation currently deployed. It resulted in 20x reduction in Wi-Fi sites, 4x reduction in personnel required to maintain sites, and a 15-hour-per-week reduction in downtime due to work stoppages, which in turn produced annual savings of €70 million for each mine. In addition, 5G+ provides ultra-reliable coverage with seamless mobility and built-in support for a wide range of services to handle dynamic application demands.

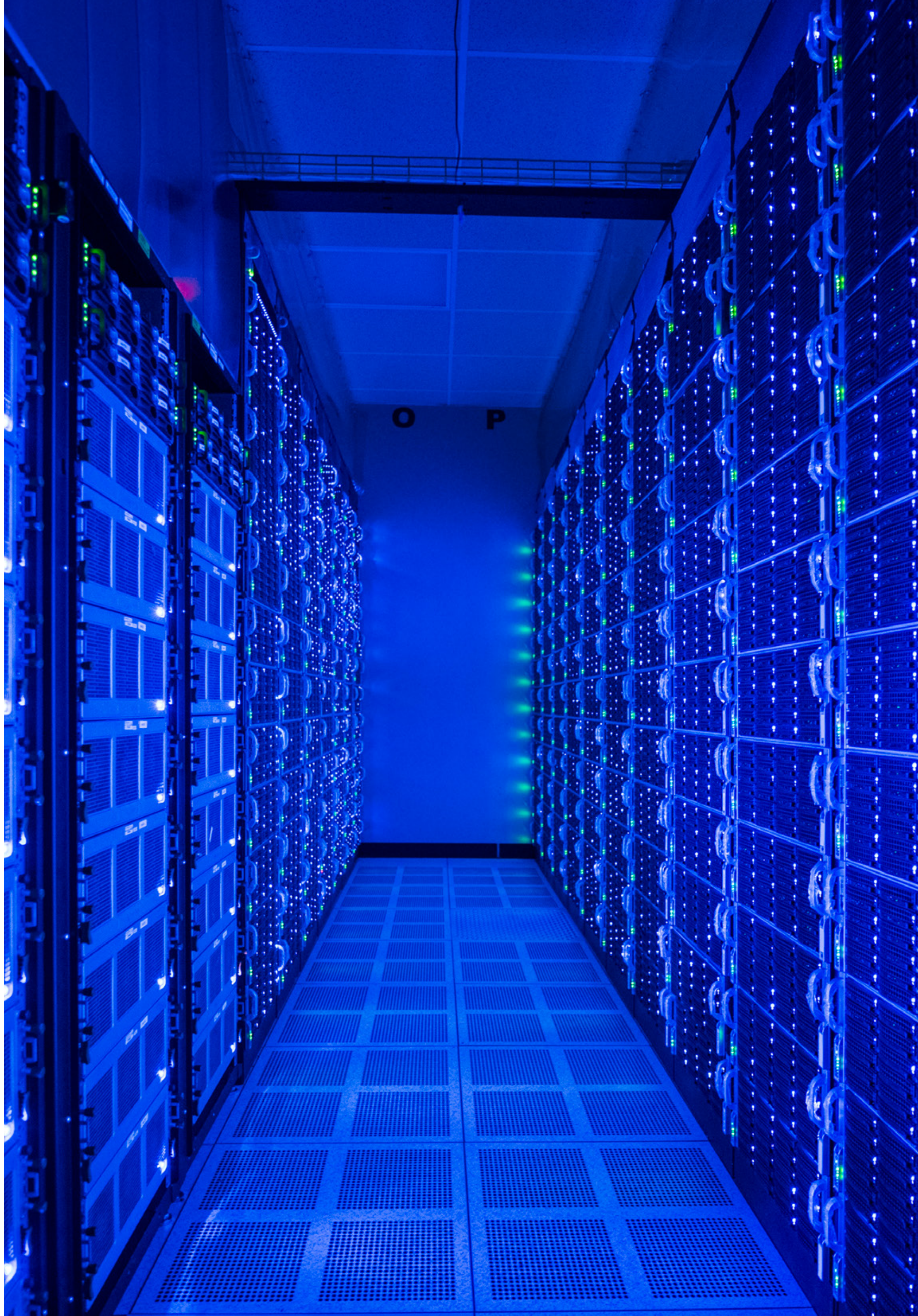
As shown in Figure 3, we expect 5G+ to yield a 3x to 5x growth in the overall SPE value of a typical open-pit mine compared with current technologies. Productivity increases, ranging between 2.8x and 4.7x, are the major determinants of this growth. Higher efficiency (3.0x to 4.5x) and increased safety (4.6x to 7.0x) also contribute to the increase in SPE value.

5G+ technologies enable all four of the sub-sectors discussed above to adapt their operations with speed and at scale to sudden changes in supply, demand, and business and operating environment. This adaptability will allow these sub-sectors to exhibit high resilience—extracting maximum SPE value in response to positive shocks and minimizing loss of SPE value in the face of negative ones. A resilient enterprise will have a lasting competitive advantage over those that are not. A resilient 5G+ factory will have a global view of the current and expected future states of orders, production status, inventories and the supply chain, with the ability to rapidly and cost-effectively reconfigure operations. A resilient seaport would be able to scale network capacity at short notice without bearing the full costs (and delay) associated with new network infrastructure. A resilient precision farm with AugI/ML-based mapping could optimize crop and soil treatment according to real-time climate variations. And a resilient mining facility would have the ability to foresee geological events and quickly develop the optimum, SPE-maximizing responses. Our analysis showed that 5G+ leads to a significant increase in the resilience of all four sub-sectors—factories (3.2x to 7.0x), seaports (2.7x to 5.4x), precision farming (2.3x to 6.3x) and open-pit mining (2.4x to 4.3x)—relative to current technologies.

Digital infrastructure investment is shaping the next decade

After overcoming a COVID-induced dip in 2020, we expect enterprise ICT spend to grow significantly in the next decade to realize the SPE benefits. As depicted in Figure 4, annual global ICT spend is forecasted to increase from $2.8 trillion in 2020 to $6 trillion by 2030 [15]. We build upon market analyst projections [16] [17] for developing these forecasts. The actual ICT expenditure incurred by enterprises will be strongly influenced by the magnitude of the COVID-induced dip and the actual timing and shape of the post-COVID recovery that will be experienced by economies across all regions. We note that economists differ in terms of their global GDP recovery projections. While this variability carries over to ICT spend as well, we do expect ICT investment to recover earlier than the overall economy as it is a driver of that growth.

Figure 4 shows that overall ICT spend through the next decade comprises two streams: fast-growing 5G+ expenditures as these technologies are increasingly adopted by industries, and gradually declining expenditures in traditional applications and services (labelled “other ICT”) that ride on legacy technologies in regions lagging in 5G adoption. As shown in the figure, 5G+ ICT spend starts growing only from 2021; however, we project that by 2030 it will account for 75%, or $4.5 trillion, of ICT spend. Edge infrastructure/cloud platform and services will have the largest share (49%) of this spend. While private networks and associated applications (18%) will be virtually on par with AugI/ML services (20%) in their share of 2030 spend, they will end that year with a higher growth rate indicating a stronger future share of enterprise ICT outlay. Basic connectivity (13%), which includes wide area mobile- and fixed network services, and unified communications, will form a smaller and diminishing share of total spend. ICT spend on end-to-end security is built into each of these four 5G+ components.



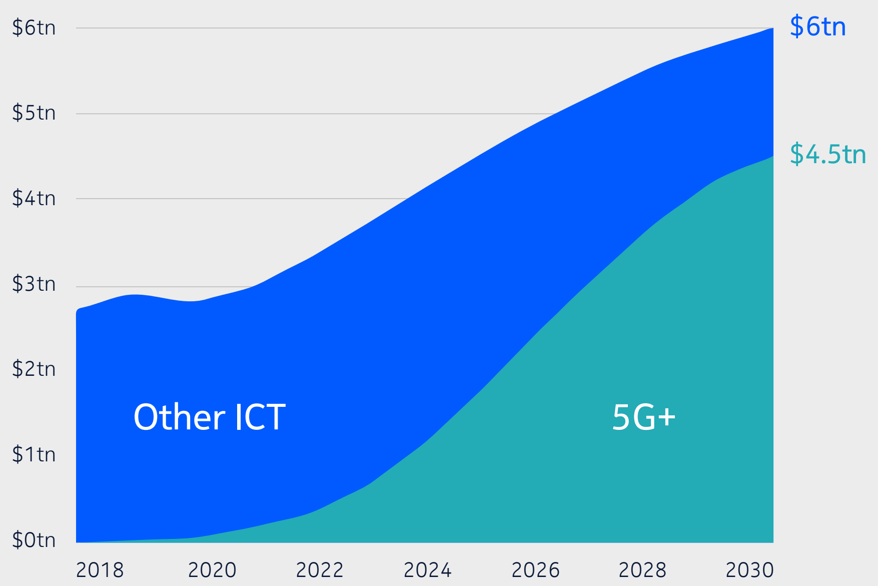
While 5G+ will impact all industries, the associated ICT spend will vary because of the different adoption timelines that different industry groups will follow as we discussed earlier. To examine these differences, we aggregated ICT spend forecasts by industry group and tracked them through 2030. We expect each industry group will follow a three-phased trajectory over this period:

- The **fall** due to the pandemic, characterized by the throttling back of all but the most critical ICT spending to address the economic fallout. However, this phase will be an opportune period for industries to deeply analyze themselves, plan for the technology enablers that will address near-term business resilience, and understand how SPE gains can be realized by augmenting specific activities in the broader business operations.
- The **rise**, or the rebound in their ICT spending. As industries bounce back, they will not only regain their pre-COVID growth trajectory in line with the economic recovery but will also accelerate their investment further to reach their optimum SPE potential. We expect the early part of this phase will act as the inflection point in their investment cycles, with the mass adoption of augmentation technologies.
- The **new normal**, or the steady state reached when industry ICT spending responds to a fully stabilized economy, having completely recovered from the impact of the pandemic. With pervasive availability and wide-scale deployments of 5G+ technologies, ICT investments in this phase are expected to reach a steady state.

The big inversion created by the end of the next decade due to higher relative growth in ICT spend of Physical Leading and Physical Lagging industries

Figure 5 captures the year-on-year growth rate in the ICT spend of the three industry groups through 2030. As shown in the figure, the magnitude and timing of the impact of each phase will differ significantly for individual groups. These differences are driven primarily by two factors: the unequal impact of COVID-19 on

Figure 4: 5G+ enablement drives growth in total ICT spend



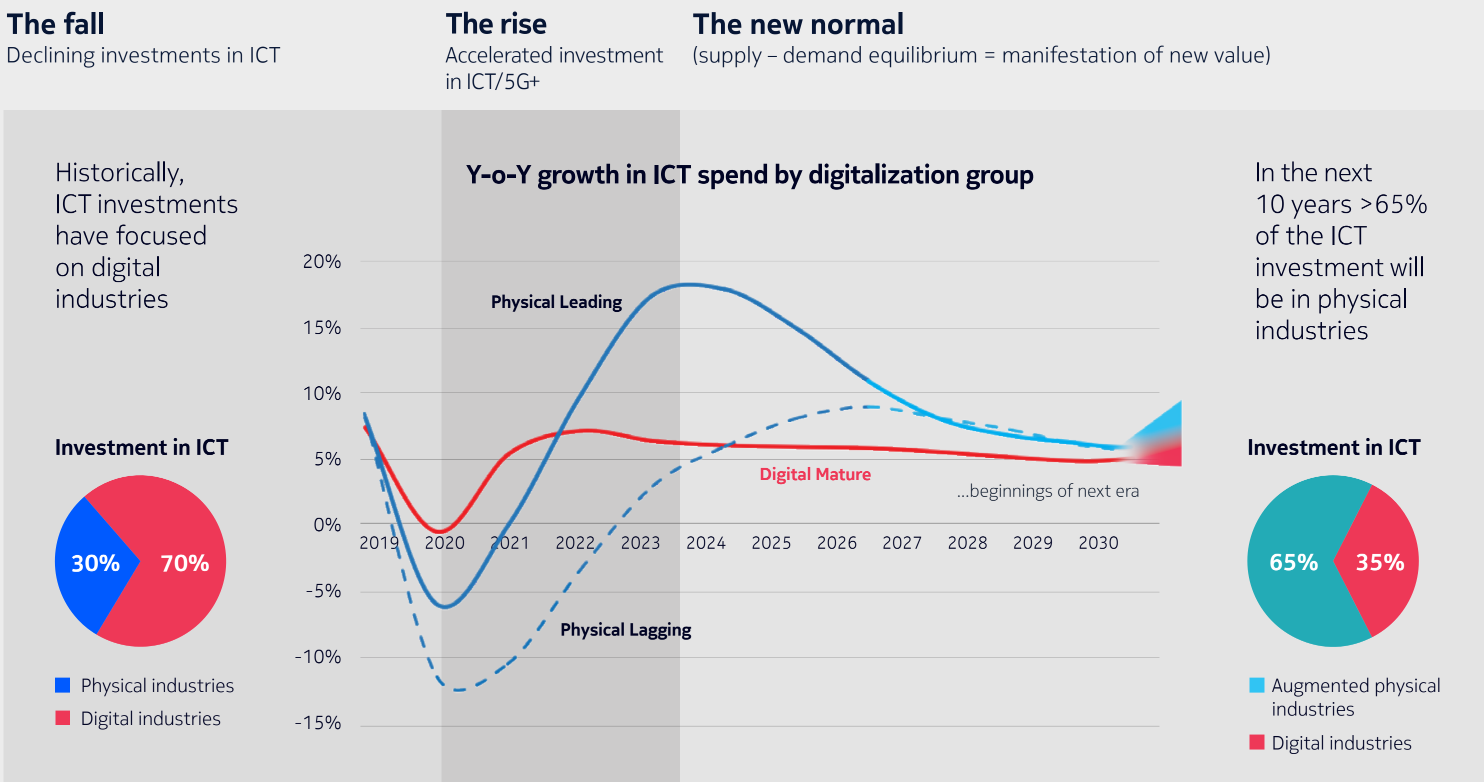
Source: Bell Labs Consulting

5G+ projected to account for 75% of total ICT spend in 2030 these groups, and the variation in their digital maturity levels.

Digital Mature industries will see the least variation in annual ICT spend among all three industry groups. A reduction of 0.5% in 2020 during the fall phase is followed by a 5.5% increase in 2021 during the rise phase. Digital Mature ICT spending eventually levels out into a steady-state annual growth of about 5% through the rest of the decade. While this industry group has been impacted the least by the negative consequences of COVID, it has also achieved a high level of digitalization because of its strong ICT spend in the past. This capability not only enables Digital Mature industries to meet the pandemic challenges aggressively, it also positions them well to address the ICT requirements arising during the new normal.

For example, the banking industry has been impacted by a COVID-induced revenue slump due to business failures and declining customer deposits; consequently, we expect the 2020 ICT spend in this industry to decline by 2% relative to 2019. However, as financial institutions

Figure 5: Journey to a new normal



Source: Bell Labs Consulting

The big inversion created by the end of the next decade due to higher relative growth in ICT spend of physical industries.

are likely to have a pivotal role in any recovery measure, they can mitigate the financial damage caused by the pandemic. They are further accelerating their recovery by implementing digital technologies such as software robots for repetitive processes, AugI/ML for creating new products and fraud prevention, face and image recognition for improved self-service, and digital assistants that automate transactions [18]. Consequently, we expect that the annual ICT spend in the banking industry will bounce back to the 2019 level in mid-2021 and will grow by 8% that year over 2020 levels; it will settle down into a steady-state annual growth of about 5% through 2030.

In contrast, Physical Leading and Physical Lagging industries will see larger variations in their ICT spend during the fall and rise phases. These industries have also been impacted more severely by COVID-19, and they have low digital maturity. In particular, Physical Lagging industries that require close human interaction, such as construction and hospitality, have seen significantly larger revenue decreases. We expect the 2020 ICT spend to decrease 6% for Physical Leading industries and 12% for Physical Lagging industries during the fall phase.

However, ICT spend in both the Physical Leading and Physical Lagging industry groups will see much stronger gains relative to Digital Mature industries during the rise phase, reaching peak annual growth rates of 18% and 10%, respectively. This is partly because both physical industry groups have more ground to make up in their recovery from the fall phase. The significant jump in ICT spending for Physical Leading industries primarily reflects the need to invest in 5G+ digital infrastructure to address the pent-up demand and the need to realize higher SPE gains. Physical Lagging industries will see a lower peak ICT spend growth rate because of the comparatively smaller SPE benefits that they realize.

The rise phase will also be longer for Physical Leading industries relative to Digital Mature industries because of the longer timespan required for the widespread deployment of 5G+ and integration of ICT and OT as discussed earlier. The Physical Lagging group will have an even more protracted recovery interval as their adoption of 5G+ ICT services will be even slower because of the limited immediate impact of these services on their operations.

The manufacturing industry provides a good example of how ICT spend will vary across the three phases for the Physical Leading industry group. Although the manufacturing industry comprises a diverse set of sub-verticals that have been affected by COVID-19 to varying degrees, overall the pandemic has triggered a decrease in demand and operational disruption across the board. This has led to many ICT projects being reprioritized to reduce costs and to free up resources for more urgent matters [19]; consequently, we project manufacturing's 2020 ICT spend to decline by 10%. The rise phase of this ICT spend will start in 2021 in line with the overall economy, and its growth rate will regain its 2019 level in 2022. However, manufacturing will see a strong rebound in its ICT spend to support digital technologies required to generate the potential SPE gains discussed earlier. Spurred by these needs, we expect the ICT spend to grow vigorously through this phase, achieving the peak growth rate of 18% in 2024 before converging on a steady-state growth of 8%.

The mining industry illustrates how ICT spend will vary in the Physical Lagging group. COVID-19 has forced many mining companies to completely shut down or cut back operations because of reduced demand for raw materials and safety concerns due to the virus's spread. The global impact of lost production is estimated to be $8.8 billion [20]. We expect that there will be a 13% decline in 2020 ICT spend of the mining industry worldwide. The rise phase will start in 2021 as demand recovers but annual ICT spend will get back to its 2019 level only in 2023. However, it will continue to increase investment further to support growing digitalization needs. We project that this recovery will reach a peak annual growth rate of 10% during 2024-2025 and will settle down to a steady-state growth rate of 6%.

As 5G+ is fully implemented across all industry groups, the annual growth in ICT spend will gradually slow down and converge on a stable rate of

4% to 6% in the new normal phase. As depicted in Figure 5, this steady state signifies the transformation of traditional physical industries into what we call augmented physical industries. These transformed industries will be equipped with a digital infrastructure that is not only optimized for maximum SPE gains but is also ready for 6G and the next human-technological revolution.

Through the next decade overall global ICT spend is projected to grow at 6.5% CAGR, but investment will be 40% larger in physical industries at a higher growth rate (7.5% CAGR) relative to digital industries (5.2%). As shown in Figure 5, 2030 will mark the “big inversion” of the traditional 70:30 ratio of ICT spend between digital and physical industries to a 35:65 ratio, restoring its parity with the GDP contribution of these two sectors.

As companies emerge from the COVID-induced dip, Physical Leading and Physical Lagging industries should start planning their investments in these digitalization and augmentation technologies as early as 2021. This will ensure these industries are able to ride the wave of initial adopters and gain competitive advantage by realizing SPE benefits. As the mass adoption of these technologies prevail across the globe, compounding SPE gains across Physical Leading, Physical Lagging and Digital Mature industries is expected to have a much broader impact on the economy and GDP. We discuss this in the next section.

New value creation and contribution to global GDP

Over the next decade, we expect 5G to become a general-purpose technology (GPT) [21] because of its wide-ranging impact on the entire global economy. The 5G+ suite of technology and services will build on 5G's pervasiveness to produce maximized SPE gains for enterprises and industries. 5G+ will also generate indirect benefits to the entire industrial ecosystem through cross-industry transfer of goods and services and produce a larger economic impact felt worldwide.

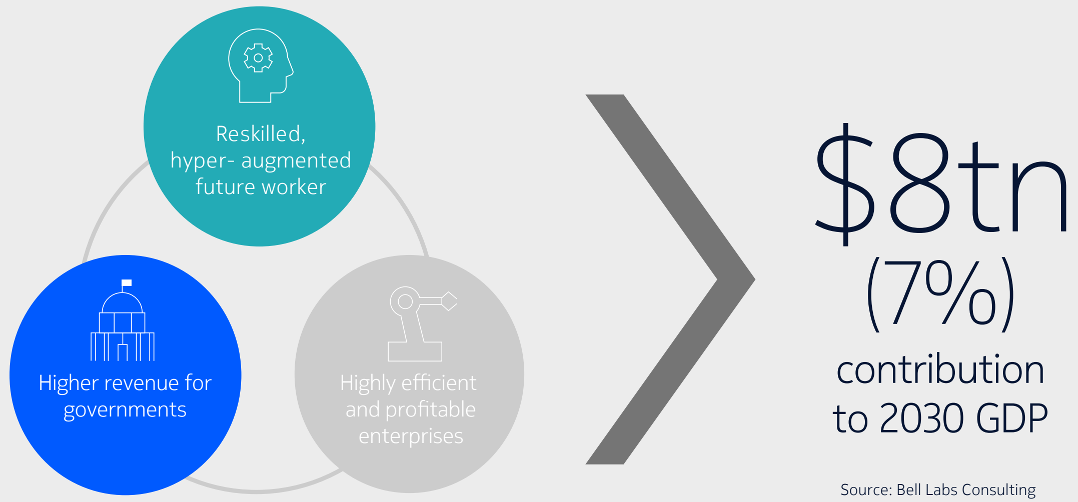
Figure 6 captures the broader economic impact of 5G+. We measure the macroeconomic value and contribution to global GDP along three dimensions: 1) employment and wage growth, 2) enterprise profitability growth resulting from SPE gains and 3) government revenue growth. Increased supply-side readiness will translate into higher enterprise output, and higher employment and income growth for the workforce throughout the ecosystem. Greater digitalization leads to the creation of re-skilled, hyper-augmented jobs and a workforce that commands premium wages. Increased economic activity will generate higher profits not only for the enterprises deploying 5G+, but for the entire economy. Higher production and consumption of goods and services, as well as growth in wages and profits, will lead to increased government tax revenues.

We use national input-output tables to analyze the compounding impact of 5G+ spend on global GDP. This analysis generates GDP multipliers that translate this spend in individual industries to overall GDP increases by including the direct and indirect benefits mentioned above. In addition, these multipliers account for induced benefits that are generated due to the increased household consumption of goods and services because of higher disposable income. For instance, the projected $214 billion ICT spend in 2030 in the healthcare industry will lead to a $412 billion contribution

to the overall global economy due to the cascading benefits of this spend. Aggregating these values across all industries and all regions will result in projected contributions of up to $8 trillion in global GDP, representing a 7% share.

Figure 7 shows the contribution of individual industries. While this list is led by individual industries in the Digital Mature group—because of the higher ICT investment and the higher GDP multipliers of individual industries in this group—Physical Leading industries taken collectively emerge as the overall largest contributing group.

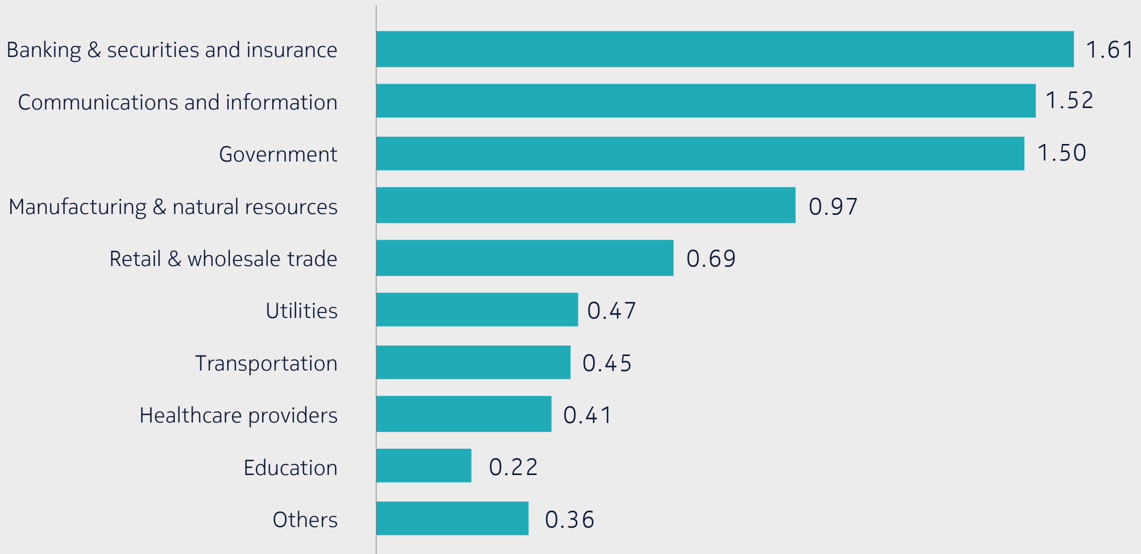
Figure 6: New economic value equation



Source: Bell Labs Consulting

GDP growth through higher wages, greater profits and increased tax revenues triggered by 5G+ ICT spend.

Figure 7. Contribution of 2030 ICT spend to global GDP by individual industries



Source: Bell Labs Consulting

Physical industries will collectively provide the larger share of ICT contribution to 2030 global GDP.

Summary

While the COVID-19 crisis has been massively disruptive across all regions, it has also ushered in an era of accelerated digitalization that will benefit both consumers and businesses for a decade to come. Although industrial digitalization had been on the upswing for some time, the pandemic placed a glaring spotlight on physical industries' lack of digital infrastructure. While mature digital industries' early investment in digital infrastructure has made them the immediate beneficiaries of COVID-induced demand shifts, physical industries have found that their lack of similar investment has left them unable to respond to the inherent demand for services and products following in the wake of the pandemic.

We expect physical industries to increase their ICT investment and aggressively adopt 5G+ technologies in the next decade, in the process transforming themselves into augmented physical industries. This transformation will result in what Bell Labs Consulting calls the **Big Inversion**. This new value shift will be realized through safety, productivity and efficiency gains in enterprises and industrials, the creation of new jobs, more employment, higher wages, increased profits and additional tax revenues. We expect the formulation of this economic equation driven by 5G+ will contribute up to $8 trillion in global GDP in 2030. The "new normal" won't just be an era where we no longer struggle with the COVID-19 crisis. It will be an era where industry and enterprises become far more resilient, driven by a new ecosystem of technologies linked closely to 5G.

Appendix

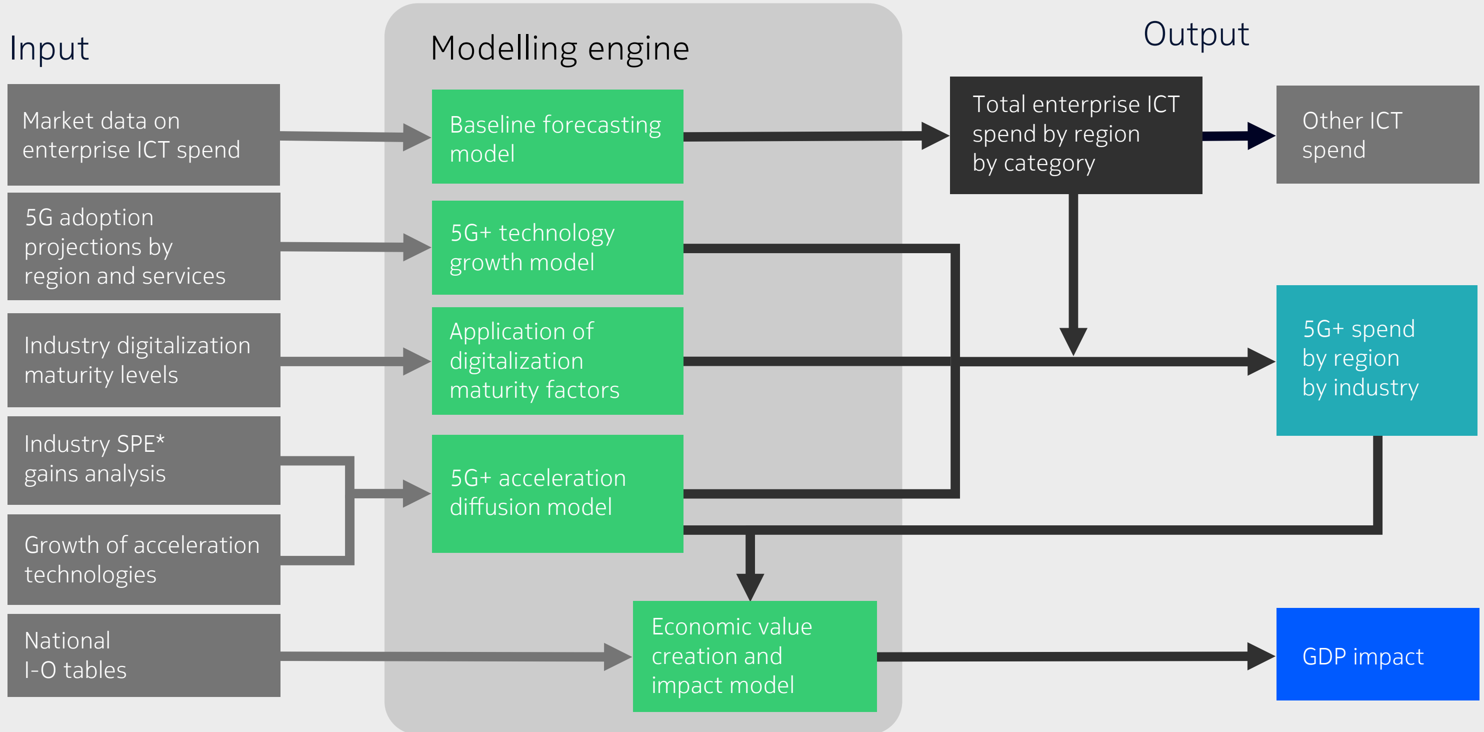
Methodology

Figure 8 shows the methodology for computing total ICT spend, 5G+ enabled ICT spend and the impact of their combined spend on global GDP. The "input" section shows the steps required to analyze the raw data from analysts and market reports, prior Bell Labs Consulting analyses and insights from interviews with subject matter experts. The "modelling engine" section includes the steps required to transform the input information into intermediate variables. The "output" section presents the steps required to generate the key metrics by individual regions and industries. These steps are described below.

Market data on enterprise ICT spend

Analyze current enterprise ICT spend along traditional categories, baseline market trends including the impact of COVID-19, and key assumptions underlying forecasts of future spend. Review of the impact of macroeconomic trends.

Figure 8: Framework for generating 5G+ ICT spend and determining global GDP impact.



*SPE: Safety, productivity, efficiency

Source: Bell Labs Consulting

Interworking of technology growth and diffusion models with macroeconomic flows to determine accelerated ICT spend and GDP growth

5G adoption projection by region and services

Analyze 5G adoption pattern across eight global regions and across services.

Industry digitalization maturity levels

Categorize 15 industries into three groups based on their digitalization maturity.

Industry SPE gains analysis

Analyze SPE gains achieved by enterprises in various industries and their primary technology drivers considering use cases today. Project expected industry-wide SPE gains for likely future use cases in both physical and digital industries.

Growth of acceleration technologies

Analyze maturity and adoption of enabling technologies and new business models included in 5G+ suite.

National Input-Output tables

Analyze national aggregate cross-sectoral monetary flows of countries representing each of the eight regions across the globe.

Baseline forecasting model

Extend baseline ICT spend through 2030 taking into account the likely macroeconomic impact on individual industries.

5G+ technology growth model

Project the adoption of 5G+ technologies across industry groups and regions.

5G+ enabled acceleration diffusion model

Project acceleration in ICT spend by technology, by industry, by region and by application category based on industry-wide SPE gains achieved by individual industries, the digitalization maturity of industry groups, and the adoption of 5G+ technologies.

Economic value creation and impact model

Determine the set of GDP multipliers applicable to capture GDP gains for each of eight regions.

Total enterprise ICT spend by region by category

Total resulting enterprise ICT spend by region and by industry.

5G+ enabled ICT spend

Aggregate ICT spend enabled through the adoption of 5G+ by region and by industry.

Other ICT spend

Aggregate ICT spend not impacted by 5G+ adoption. This is the difference between total enterprise ICT spend and 5G+ enabled ICT spend.

GDP impact

Analyze input-output tables of representative countries for each region to determine regional GDP multipliers. Apply these multipliers to the 2030 5G+ enabled ICT spend forecasted for the individual regions to determine regional GDP contributions. Aggregate regional GDP values to determine the global GDP impact.

Input-output analysis has been used widely [22][23][24][25] to determine the macroeconomic impact of new technology implementation such as broadband, mobile networking, etc.

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