

Long-term U.S. Productivity Growth and Mobile Broadband: The Road Ahead

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INTRODUCTION

The next generation of wireless is on the horizon.¹ While the standards for 5G are not yet finalized, it's clear that when 5G does arrive, it will mean faster streaming video, lower latency, and higher capacity. Companies such as AT&T, Verizon, T-Mobile, Ericsson and Nokia are in test mode, with widespread consumer rollout of 5G expected by 2020, or perhaps earlier.

At the same time, the attention of the mobile providers is focused on the spectrum auctions scheduled to start later in 2016. These auctions could make a significant contribution to freeing up spectrum for mobile data, and perhaps help reduce the short-term spectrum deficit.² Meanwhile, the Federal Communications Commission (FCC) has started exploring the use of "millimeter wave" frequencies (mmW) for mobile services, a move that could potentially open up much more spectrum in the medium- and long-run.³

But nothing is assured. In the short-term, network engineers and others are already indicating that the upcoming auctions are not going to be a complete answer to forestalling capacity crunches in the years ahead. In the medium and long-term, mmW could be the next great swath of spectrum beachfront but the promise of that technology is in its early stages. Policy actions, especially around the availability of spectrum and around business models, can have long lag times. Understanding the broad contours of the long-term relationship between wireless and economic growth may help influence today's policy decisions.

This paper focuses on 2030 and the potential of future wireless networks to support economic growth in the United States.⁴ We consider the economic implications of next generation wireless networks for long-term productivity growth and living standards, and relate those to current public policy questions. The result could be an acceleration of productivity growth in the physical industries

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that adds roughly \$2.7 trillion (in 2015 dollars) to U.S. GDP by 2030. This translates into an 11 percent increase in economic output, which is equivalent to boosting the average annual growth rate by 0.7 percentage points.⁵

This paper makes three main points.

- The United States is currently stuck in a slow-growth trap, which is holding down wages and living standards. We show that slow productivity growth today across much of the economy is correlated with the failure of “physical” industries such as manufacturing, health care, and construction to make good use of digital technologies, compared to “digital” industries such as professional services, finance, and entertainment. We estimate that the physical industries, which make up roughly 80 percent of the private sector, account for only 35 percent of private infotech investment, and only 40 percent of the telecom usage. A recent paper from the McKinsey Global Institute estimates that the United States has only reached 18 percent of its potential for digitization.⁶
- Using a top-down analysis, we suggest that successfully digitizing physical industries will require a vast increase in remote sensors and remote-controlled devices such as cars, drones, and construction equipment. True, in the short-run, machine-to-machine (M2M) wireless traffic which comprises most of the communications we define as the Internet of Things (IoT) will still only be a small portion of mobile data. Cisco forecasts that M2M wireless traffic in the United States, including wearables, will rise from 3 percent to 11 percent of all mobile data by 2020.⁷ However, that changes in the medium-run. In this paper, we further project that IoT related M2M communications will account for roughly 35-47 percentage percent of mobile data communications by 2030. To put it another way, in order to boost the productivity of the physical industries that make up the majority of the economy, the M2M communications will occupy a much larger share of available bandwidth.
- Achieving this level of connectivity and productivity improvement will require a sharp increase in the capacity of the nation’s mobile

broadband networks. The nature of the capacity increase will depend on the development of technology. Using an analysis based on historical trends, we project that by 2030 it will be necessary to have more than 1900 MHz of spectrum in the sub-mmW bands (3 times the current availability) and at least 1.2 million cell sites (4 times the current level) in order to fully enable the IoT-driven productivity gains in the physical industries over the next fifteen years.⁸ By contrast, if extensive use of the mmW bands becomes technologically and economically feasible, it could offset immediate needs to dramatically increase network capacity but will require the deployment of a vast number of additional small cell sites that will require ongoing maintenance.

The conclusion: Creating vastly more wireless capacity is essential for getting the United States out of the slow-growth trap we are currently stuck in. In order to catalyze the next round of spectrum-enabled economic expansion, policymakers need to focus on freeing up multiples of the current amount of spectrum—both for licensed and unlicensed uses—while creating an economic environment in which it is profitable to build and maintain a greatly expanded number of cell sites.

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Conversely, if policymakers fail to free up enough spectrum, or free up more spectrum for unlicensed rather than licensed operations, or impose regulations that reduce the return on investment that currently fuels spending on telecom infrastructure build-out, the likely outcome will be that the physical industries—which make up the greater part of the economy—will fail to achieve their productivity potential. In that event, all Americans will suffer.

FIGURE 1. DIGITAL INDUSTRIES ACCOUNT FOR TWO-THIRDS OF INFOTECH INVESTMENT

Digital Industry	Share of private sector GDP, 2014	Share of private sector employment, 2014	Share of private sector investment in software, and infotech and communications equipment, 2014
Telecom and broadcasting	2.7%	0.9%	14.6%
Tech*	4.0%	3.2%	16.4%
Content**	2.2%	0.7%	3.5%
Professional, scientific and technical services***	8.5%	7.5%	16.8%
Finance and insurance	8.1%	5.0%	14.0%
Total	25.5%	17.3%	65.2%

*Includes computer and electronic product manufacturing; data processing, Internet publishing, and other information services; and computer systems design

**Includes publishing (excluding Internet publishing); and motion picture and sound recording industries.

*** Excludes computer systems design and includes management of companies and enterprises.

Data: BEA, BLS, PPI calculations

DIGITAL VERSUS PHYSICAL INDUSTRIES

There is currently tremendous debate about why the United States and other developed countries are experiencing slow productivity growth, and what can be done about it.⁹ In particular, the question is why the surging use of the Internet has not provided a bigger boost to growth, productivity, and living standards.¹⁰

In this section we argue that the impact of the Internet—including mobile broadband—has so far been quite uneven. Let's divide the economy into those industries whose output is primarily digital, and those industries whose output is primarily physical.

Digital industries include the tech, telecom, and content industries; finance and insurance; and pro-

fessional and business services such as accounting, legal services, engineering and advertising. **Physical industries** include manufacturing, healthcare, construction, agriculture, mining, transportation, public services, real estate, and everything else.

By definition, the primary output of digital industries can be transformed into digital data, and directly manipulated, transmitted and traded by digital means. For example, movies are produced by a combination of physical (actors, sets) and digital (computer animation) means. However, the final product can be transformed into a digital form, making it a digital industry.

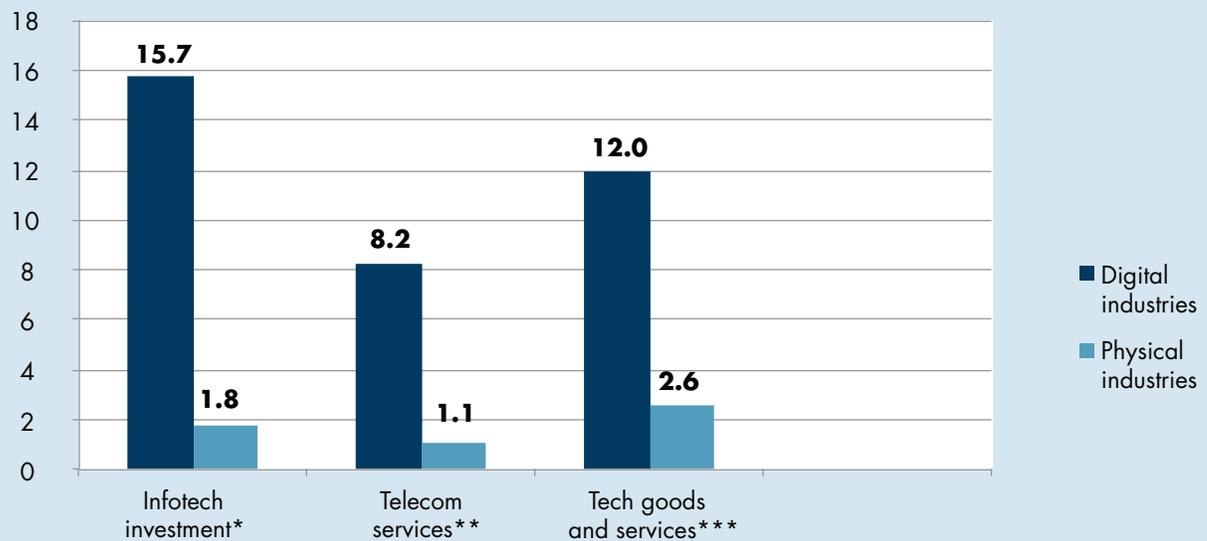
By contrast, the primary output of physical industries cannot be directly manipulated, transmitted, and traded by digital means, even if information technology is used internally. For example, a construction company may use computers. Nevertheless, its main output is comprised of buildings and other structures, which need to be constructed through physical rather than digital manipulation. Similarly, the ultimate output of the health care system is the medical care of patients, which is the result of physical treatment rather than digital transformation.

Figure 1 breaks out the five main categories of digital industries: telecom and broadcasting; tech; content; professional, scientific, and technical services; and finance and insurance. The first two columns show that in 2014, digital industries collectively accounted for only 25 percent of private sector GDP (measured by valued-added), and 17 percent of private-sector employment. Taking these two measures together, it is reasonable to say that digital industries are roughly one-fifth of the private economy.

However, according to figures from the Bureau of Economic Analysis (BEA), digital industries collectively account for 65 percent of private sector investment in information technology equipment, communications equipment, and software (which we will call “infotech investment”). The flip side is physical industries account for only 35 percent of info-tech investment, and more than 80 percent of workers.

In other words, digital industries are far more infotech-intensive than physical industries. Figure 2 shows that annual infotech investment was almost \$16,000 per worker in the digital industries in 2014,

FIGURE 2: DIGITAL VERSUS PHYSICAL INDUSTRIES: TECH/TELECOM SPENDING PER WORKER (THOUSANDS OF DOLLARS)



*Investment in software, information technology and communications equipment.

**Spending on broadcast and telecom services.

***Current spending on computer and electronic products, computer design services, internet and data processing services.

Data: Bureau of Economic Analysis, Bureau of Labor Statistics, PPI calculations

compared to less than \$2,000 per worker in the physical industries.

Similarly, the digital industries purchase much more telecom services per worker than do the physical industries, by a factor of almost eight, as shown in Figure 2.¹¹ And digital industries spend more than four times per worker on tech goods and services. The last category includes purchase of electronic components used in other products, and spending on data processing services, including cloud and “software as service.”

We can combine all three categories—infotech investment, spending on telecom services, and spending on tech goods and services—into one category that we call “business tech/telecom spending.” We calculate that business tech/telecom spending was almost \$36,000 per worker in the digital industries, compared to only \$5,400 per worker in the physical industries.

Given the relative intensity of tech/telecom spending, it should not be surprising, then, that digital

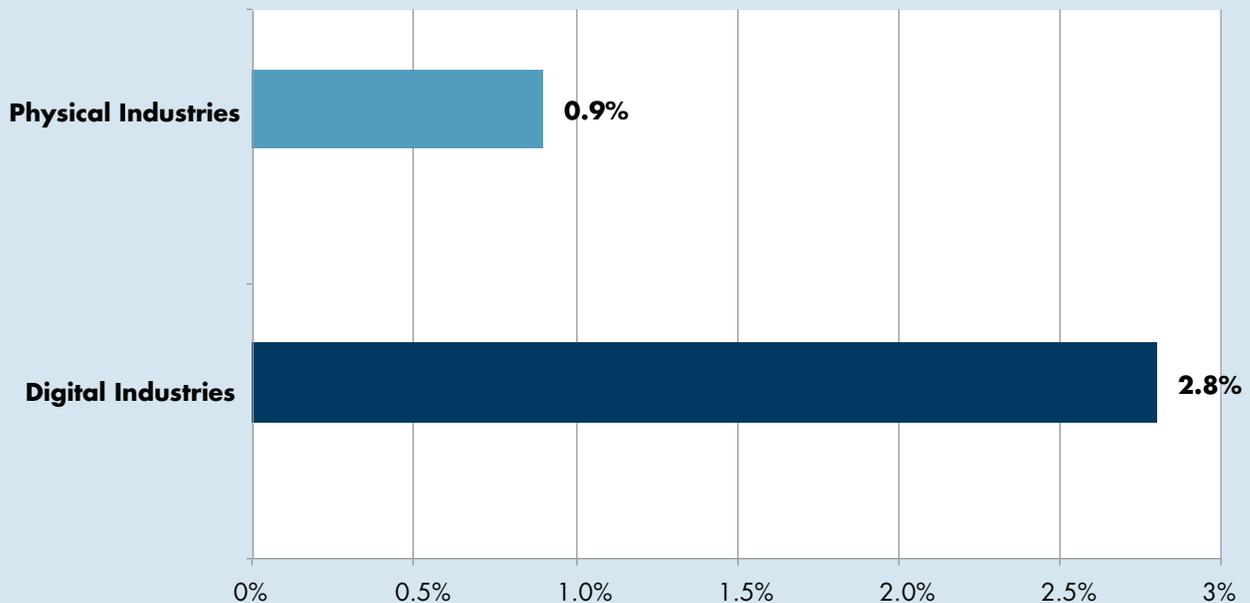
industries have enjoyed much faster productivity growth than the physical industries.

As Figure 3 shows, the digital industries have had triple the productivity growth of the physical industries in recent years. For the 14-year period between 2000 and 2014, productivity growth for digital industries have averaged 2.8 percent per year, compared to 0.9 percent for the physical industries. That’s a productivity gap of roughly 2 percentage points annually.

There are several natural implications of this analysis.

- First, the current growth malaise could be significantly ameliorated if the productivity gains in the physical industries could be accelerated to be closer to the digital industries.
- Second, it appears likely that productivity growth in the physical industries could be significantly improved by infotech investment, and spending on telecom and tech goods and services—that is, all the key elements of the connected economy.

FIGURE 3: DIGITAL VERSUS PHYSICAL INDUSTRIES: PRODUCTIVITY GROWTH, AVERAGE ANNUAL RATE, 2000-2014



*Estimates based on full-time equivalent workers.
Data: Bureau of Economic Analysis, PPI calculations*

- Third, such an increase in spending is likely to be expensive and take place over a period of time. Today tech/telecom spending per worker in the digital industries is almost seven times that of the physical industries. Suppose we wanted to reduce that ratio down to two, so that tech/telecom spending per worker in the physical industries was half that of the digital industries. That would require an additional \$1.2 trillion in tech/telecom spending in the physical industries, or 7 percent of GDP.¹² That's huge.

Still, let's suppose that we can boost tech/telecom spending in the physical industries enough to close half the productivity gap. That is, suppose that productivity growth in the physical industries was 1.8 percent per year rather than 0.9 percent, so that the productivity gap was only one percentage point rather than two.

We estimate that digitizing physical industries in this way could add roughly \$2.7 trillion (in 2015 dollars) to U.S. GDP by 2030. This translates into an 11 percent increase in economic output, which

is equivalent to boosting the average annual growth rate by 0.7 percentage points.

HOW WIRELESS ACCELERATES PRODUCTIVITY GROWTH IN PHYSICAL INDUSTRIES

The previous section argued that physical industries greatly lag the digital industries in tech/telecom spending per worker. We further argued that to generate faster productivity growth in physical industries—which make up roughly 80 percent of the private sector—will require a significant increase in tech/telecom spending.

What form will this increase in tech/telecom spending take? Remember that physical industries are about monitoring and controlling physical objects and activities that are perpetually changing and in motion. So we are talking about remote-controlled construction drones that can be used to build large structures for much cheaper than today; self-driving snow-plows that can run 24 hours without a break; production of large-scale composite materials whose temperature has to be precisely measured at many internal points; micro-pumps to

FIGURE 4. PROJECTED M2M MOBILE DATA USAGE

Digital Industry		Mobile data usage, Exabytes per month			M2M as a share of total data use M2M as a share of total data use
		M2M*	All else	Total	
Cisco Estimate	2015	0.01	0.49	0.50	3%
Cisco Forecast Forecast growth rate, 2015-20	2020	0.3 85%	2.6 39%	2.9 42%	11%
PPI Scenario 1 Projected growth rate, 2020-30	2030	5.6 33%	10.4 15%	16.0 19%	35%
PPI Scenario 2 Projected growth rate, 2020-30	2030	9.3 40%	10.4 15%	19.7 21%	47%

*Machine-to-machine(M2M) includes wearables. Percentages are rounded.

Italicized numbers are PPI calculations based on published Cisco data.

Data: Cisco VNI, PPI calculations

precisely control insulin and other hormones in the body; and so forth.

Moreover, the physical world generates an enormous amount of data that cannot be easily simplified. Consider, for example, the video feed from a drone. By one account, a 14-hour intelligence drone flight generates 70 terabytes of data.¹³

Or take health care. Right now a wireless vital signs feed produces a relatively small amount of data to monitor things like heart rate, blood pressure, and skin temperature. But as new types of implantable body sensors are developed, the amount of data that they generate potentially soars.

In such a scenario, wireless bandwidth becomes an important input to productivity in physical industries. We therefore hypothesize that the increase in infotech investment in the physical industries is going to be accompanied by a commensurate increase in wireless demand in order to implement remote monitoring and control.

To assess that demand, we use Cisco's latest forecast of mobile data traffic.¹⁴ According to Cisco's February 2016 report, machine-to-machine (M2M) traffic, including wearables, amounted to 3 percent of U.S. mobile data usage in 2015 (Figure 5). Cisco also

forecasts that M2M will rise to 11 percent of U.S. mobile data usage by 2020, as 5G enables more low-latency "IoT" applications such as connections to cars. Indeed, one of the real gains from 5G will be the beginning of productivity improvements in physical industries.

However, given how far the physical industries have to go to upgrade their infrastructure and usage of telecom and tech, the productivity gains in the physical industries from wireless will only continue to cumulate. Figure 4 lays out two scenarios for 2030. In scenario 1, growth rates for mobile data usage slow significantly from Cisco's 2015-2020 forecast. Scenario 2 has a somewhat higher growth rate for M2M mobile data usage.

In scenario 1, M2M accounts for about one-third of mobile data traffic by 2030. This is the result of the application of wireless for boosting productivity growth in physical industries, which is necessary for achieving faster levels of economic growth. In scenario 2, M2M accounts for almost half of mobile data traffic in 2030.

Note that there is widespread disagreement about how much of an additional burden M2M, which largely comprises the IoT will be on mobile broadband networks. Some believe that the plethora

FIGURE 5. ONE SCENARIO FOR ACHIEVING 2030 CAPACITY GOALS*

	Historical record, annual growth rate	Projected growth rate (2015-2030)	Increase from today to 2030	Comments
Number of cell sites	15% (1994-2014)	9%	2014: 300K 2030: 1.2 million	Figure refers to macro/pico cells only. Including smaller cells would greatly increase number
Spectrum	7% (1995-2016)**	7%	2016: 735 MHz** 2030: 1900 MHz	Figure refers only to sub-mmW spectrum
Spectral efficiency	10% (1990-2010)	7%	Spectral efficiency increases by a factor of 3 from 2015 to 2030	
Combined	35%	25%	Capacity of mobile data networks increases by a factor of roughly 30 between 2015 and 2030.	
Time to doubling	2.3 years	3 years		

This table corresponds to Scenario 1 in Figure 4.

*Without extensive use of mmW bands.

**Based on projected results of 2016 spectrum auction.

Data: CTIA, Rysavy Research, PPI calculations

of low-bandwidth, low-power devices will be handled on a separate network. There will be more and more high-bandwidth applications, just as software became progressively more and more powerful as people came up with new uses. For example, Volvo and Ericsson are partnering on new high-bandwidth applications for connected cars.¹⁵

POLICY AND THE POTENTIAL OF THE IOT

What does this have to do with future generations of wireless network technologies? M2M communications that comprise the IoT will still be only a small share of total mobile traffic in 2020. But by 2030, IoT related M2M could amount to half of mobile data traffic, according to our analysis. The projections in Figure 4 suggest that the capacity of mobile broadband networks will have to increase by a factor of 30-40 times between 2015 and 2030 in order to support large productivity gains in the physical industries. Will there be sufficient capacity in the mobile broadband networks to support such traffic?

Although the technological path of mobile broadband over the next fifteen years may not be a straight line, the future is certain to include the creation of additional low-power, wide-area networks to primarily handle M2M communications and the use of mmW bands for mobile data. The latter, in particular, would change the geometry of mobile data. Higher frequencies, such as the ones outlined in the FCC's October 2015 Notice of Proposed Rule Making, will likely require the deployment of much smaller and many more cell sites.

We can frame the basic policy issues that need to be tackled in order to get the maximum productivity from the physical industries. In keeping with the high-level nature of this exercise, we assume that the capacity of the mobile broadband networks is determined by the amount of available spectrum, the number of cell sites, and the spectral efficiency of cellular radios.¹⁶ For today's technologies, it's reasonable to think of these factors being multiplicative.

A shift to mmW or some other technology over the next fifteen years would alter this equation, but the basic principle would stay the same: To get good gains in wireless capacity, we need to have a combination of gains in all three areas.

First we will project out a possible scenario to achieve a 30 times increase in capacity based on historical trends, without extensive use of mmW bands. This corresponds with Scenario 1 in Figure 4. Then we will consider how our scenario changes using mmW bands.

Start by noting that a 30 times increase in capacity over 15 years is equivalent to wireless capacity doubling every three years. This is a rapid increase that cannot be achieved without additional spectrum.

Indeed, doubling over three years is equivalent to a 25% increase each year. Without use of mmW bands, there are many ways of achieving this outcome, but one scenario combines three different trends: a 9% expected average annual increase in the number of cell sites¹⁷; a 7% expected average annual increases in available spectrum outside the mmW bands; and a 7% expected average annual increase in ‘spectral efficiency.’

Of course, this is just one scenario. Achieving a 40 times increase would require faster growth in one or more of these components. But no matter what the exact numbers, the key questions are:

- Can wireless providers make the business case to their investors that will justify spending the billions necessary to build and upgrade at least 1.2 million cell sites nationally, as projected by 2030? This would require 60,000 new cell sites a year, while maintaining and refitting 20,000 older sites each year.
- Can regulators vastly increase the amount of available licensed spectrum by 2030 (not including mmW)?

Note that if less spectrum is available, the difference can in theory be made up by more cells. However, small cells are not a complete answer. As wireless technology expert Peter Rysavy noted:

“Small cells, such as femtos in homes and indoor and outdoor picocells, can yield large capacity gains, but multiple difficulties must be addressed, including backhaul, power, management, interference, site acquisition, and local zoning approval.”¹⁸

All of these issues mean money. So less spectrum means more cells, and more need for investment in building and maintaining those cell sites.

Now let’s consider what 2030 would look like with extensive use of mmW bands. On the plus side, the rapidly growing use of M2M communications for physical industries would run into fewer spectrum constraints.

On the other hand, it seems likely that extensive use of mmW bands will require many small cells with relatively sophisticated electronics. It’s not unreasonable to think in terms of millions of cell sites.

More spectrum must be freed up. The incentive auction will help, but it’s far from enough. In the short run, policymakers must get government agencies to release or share precious spectrum.

Fifteen years off in the future, there’s truly no way to estimate how much such a network could cost to build and maintain. However, what is clear that it’s a mammoth undertaking that requires financing.

How can policymakers and regulators best encourage private sector investment in mobile data networks? What’s needed is a two-prong approach. First, more spectrum must be freed up. The incentive auction will help, but it’s far from enough. In the short run, policymakers must get government agencies to release or share precious spectrum. In the medium run, the FCC must open up as much high frequency millimeter wave (mmW) as possible.

Equally important, the new networks will likely require millions of cell sites in the United States to provide sufficient capacity. Building and maintaining those many cell sites will, in turn, require massive investments by mobile providers.

From that perspective, regulators will have to be careful to steer clear of imposing well-meaning rules on mobile operators that have the effect of reducing the return on investment. If that happens, wireless networks will not reach their potential in terms of contributing to productivity growth.

CONCLUSION

The only way to raise living standards is to increase productivity growth in the physical industries, such as healthcare, manufacturing, and construction. These industries lag far behind the digital industries in tech/telecom spending per worker. As a result, boosting productivity growth in these industries

requires vastly greater usage of tech and telecom. In particular, the physical industries will need to make much greater use of wireless M2M data in order to link sensors and remote equipment able to manipulate physical objects. We project that the industrial IoT—largely comprised of wireless M2M—demand will rise by a factor of at least 30 between 2015 and 2030.

The result could be an acceleration of productivity growth in the physical industries that adds roughly \$2.7 trillion (in 2015 dollars) to U.S. GDP by 2030. This translates into an 11 percent increase in economic output, which is equivalent to boosting the average annual growth rate by 0.7 percentage points.

This outcome, however, presupposes a regulatory environment that supports the necessary expansion of capacity of mobile broadband networks over the next 15 years.

ACKNOWLEDGEMENT

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