WIFI FORWARD

ASSESSING the ECONOMIC VALUE of UNLICENSED USE in the 5.9 GHz & 6 GHz BANDS

APRIL 2020

TELECOM ADVISORY SERVICES, LLC

Author

Raul Katz (Ph.D., Management Science and Political Science, Massachusetts Institute of Technology) is currently Director of Business Strategy Research at the Columbia Institute for Tele-Information, and President of Telecom Advisory Services, LLC (URL: www.teleadvs.com). Before founding Telecom Advisory Services, he worked for twenty years at Booz Allen Hamilton, where he was the Head of the Telecommunications Practice in North and Latin America and a member of its Leadership Team.

Telecom Advisory Services LLC (TAS) is an international consulting firm specialized in the development of business strategies and public policies for digital and telecommunications companies, governments, and international organizations. Its clients include leading companies in the digital and telecommunications sectors, as well as international organizations such as the International Telecommunications Union, the World Bank, the Inter-American Development Bank, the World Economic Forum, the UN Economic Commission for Latin America and the Caribbean, the GSMA Association, the CTIA, the NCTA, Cable Europe, the Wi-Fi Alliance, and the FTTH Council (Europe).

This study is published by **WifiForward** and funded by a subset of those members. The author is solely responsible for the views expressed in this study.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Federal Communications Commission (FCC) is in the process of making policy decisions that would have significant impact on the economic value of unlicensed spectrum. First, the FCC has proposed to expand the U-NII-3 band (existing Wi-Fi band) by making the bottom 45 MHz of the 5.9 GHz band available to unlicensed use, modeled after the 5.8 GHz Part 15 unlicensed rules.[1] This would create the first widely usable contiguous 160 MHz channel in the United States. Second, the FCC has proposed[2] to permit new unlicensed operations in 1,200 MHz in the 6 GHz band (5.925-7.125 GHz) and, after a notice and comment process, is considering allowing three classes of unlicensed devices: standard-power AFC, low-power indoor (LPI) operating approximately four times lower than standard Wi-Fi and not requiring frequency coordination, and very-low-power devices (VLP) which would be indoors or outdoors, also not requiring frequency coordination because they would operate with 60 times less power than standard-power Wi-Fi.

In this study we first assessed the economic benefits associated with the assignment of 45 MHz of the 5.9 GHz band for unlicensed use by traditional standard-power unlicensed service, and then estimate the value to be generated by allowing the unlicensed use of the 6 GHz band by LPI and VLP devices.[3]

In summary, the total economic value of allowing unlicensed use in the 5.9 GHz and 6 GHz bands will amount at least to $183.44 billion between 2020[4] and 2025.

Opening 45 MHz of the 5.9 GHz band to unlicensed use will generate economic value of $23.042 billion in terms of GDP contribution, and $5.098 billion in consumer surplus between 2020 and 2025.

- **It will generate a contribution of $23.042 billion to the US GDP as a result of faster Wi-Fi download speed between 2020 and 2025.**

Research on the contribution of broadband speeds to economic growth uniformly concludes that faster Internet access has a positive impact on GDP growth. The fixed broadband average download speed in the United States in February 2020 was 137 Mbps.[5] With the deployment of ultra-fast networks, we forecast that by 2022, the average

---

[1] Federal Communications Commission (2019). *Use of the 5.850-5.925 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 19-138, FCC No. 19-129 (rel. Dec. 17, 2019) ("*5.9 GHz NPRM*").

[2] Federal Communications Commission (2018). *Unlicensed Use of the 6 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 18-295, FCC No. 18-147 (rel. Oct. 24, 2018) ("*6 GHz NPRM*").

[3] While focusing on these two subsets (LPI and VLP), we also recognize that a Wi-Fi-like service operating within AFC can also generate economic value.

[4] Benefits already start to be generated in 2020 since enterprise equipment is already being acquired in support of use cases that will be fully enabled by the spectrum proposals.

[5] This metric is based on Ookla/Speedtest daily Internet traffic, as reported in the site. The service measures the bandwidth (*speed*) and latency of a visitor's Internet connection against any of the 4,759 geographically

fixed broadband speed will reach 280 Mbps. On the other hand, based on the current 2.4 GHz and 5 GHz allocation, dual router Wi-Fi speed is estimated at 266.50 Mbps.[6] This is the reason why, if Wi-Fi performance is not upgraded by opening additional spectrum, the in-premise Wi-Fi equipment becomes a network bottleneck. Opening 45 MHz in the 5.9 GHz band will increase the average router capacity to 468.00 Mbps, which will address the Wi-Fi bottleneck for approximately 50% of US households that in 2022 will be purchasing a broadband plan in excess of 150 Mbps. Under this scenario, broadband speeds will continue to grow unencumbered, yielding an economic benefit. While the "return to speed" effect between 2020 and 2025 is $23.04 billion, given the rate at which broadband speeds are growing and the capacity of 160 MHz in 5GHz to handle Wi-Fi traffic in a more efficient fashion than 2.4 GHz, an upside scenario is likely. For example, in 2022, the GDP impact due to faster broadband speed could increase from $7.201 billion to $14.403 billion.

- **Additionally, faster Wi-Fi speed enabled by the 45 MHz channel in 5.9 GHz will yield $5.098 billion in consumer surplus between 2020 and 2025.**

Consumer surplus is defined as the value that consumers receive from purchasing a product for a price that is less than what they would be willing to pay. Market research indicates that US consumers are willing to pay more for faster broadband: approximately $0.11 per additional Mbps at higher speeds. By addressing the bottleneck for users acquiring service in excess of 150 Mbps, average speed will increase to 291.90 Mbps.[7] This increase results in a consumer surplus in 2022 alone of $1.608 billion. That being said, given the rate at which broadband speeds are growing, the upside scenario of $3.153 billion for the same year is likely.

The economic value resulting from allowing unlicensed devices in the 6 GHz band will reach a total economic value of $83.06 billion in GDP contribution, $67.78 billion in producer surplus and $2.92 billion in consumer surplus between 2020 and 2025 (on top of the benefits derived from 5.9 GHz detailed above), as 320 MHz Low Power Indoor channels meet increasing Wi-Fi traffic.

When 5.9 GHz and 6 GHz are opened up and added to the existing unlicensed bands in 2.4 GHz and 5 GHz, the combined spectrum will be able to support eight 160 MHz channels or three 320 MHz channels, which will be a source of additional economic value as Wi-Fi 6 and later technology generations meet increasing Wi-Fi traffic, with

---

dispersed servers located around the world. Each test measures the data rate for the download direction, i.e., from the server to the user computer, and the upload data rate, i.e., from the user's computer to the server.

[6] These estimates are calculated in the RAND study and are based on the router throughput of 173 Mbps for equipment operating in the 2.4 GHz band and 360 Mbps for equipment operating in the 5 GHz. They do not estimate the speed delivered to a single user, which is significantly less.

[7] This is calculated as the projected average fixed broadband download speed to the user device of 280.32 Mbps in 2022 plus 11.58 Mbps which is the increase in speed as a result of addressing the household Wi-Fi bottleneck. The households that will be acquiring broadband service under 150 Mbps will not see any benefit because they will not undergo a Wi-Fi bottleneck.

greater throughput and less latency. The contribution to GDP from return to speed in the 6 GHz band, between 2020 and 2025, is $13.25 billion.

- **The significantly enhanced spectrum capacity for LPI devices in 6 GHz will allow for a broader deployment of IoT devices, with a spillover contribution to the GDP of $44.03 billion.**

While the installed base of M2M devices amounts today to 118 million, it is expected to reach 214 million by 2025, of which 2,800,000 can be directly attributed to the ability of offering wide adoption of indoor devices. Due to spillover effect on the economy, 10% rise in M2M connections has been estimated to yield annual increases of between 0.3% and 0.9% of the GDP. By relying on the low-end coefficient of the GDP impact contribution (0.3% for each 10% increase of the installed base), we estimate that the IoT impact would reach $44.03 billion between 2020 and 2025.

- **The increase in unlicensed channel capacity for LPI devices enables the delivery of ubiquitous, high-throughput wireless connectivity across multiple indoor access points in business facilities, such as industrial plants, enterprise campus, and the like, generating an initial producer surplus from savings in telecommunications equivalent to $54.04 billion between 2020 and 2025.**

The increase in enterprise use cases enabled in part by IoT and VR/AR will generate an exponential growth in data traffic that will be handled by devices operating in unlicensed spectrum, through the combination of the existing 2.4 GHz, the lower 5 GHz, the 45 MHz in the 5.9 GHz and the 6 GHz band. If enterprises would not have access to the 45 MHz in 5.9 GHz and the 6 GHz band, the average Wi-Fi speed would be considerably lower, so companies would not be able to handle the additional traffic triggered by new use cases in an efficient manner. The savings incurred by relying on indoor Wi-Fi equipment rather than relying on cellular service to handle the traffic attributed only to new use cases will reach $15.96 billion between 2020 and 2022. This value will increase further in the long run because the growth in Wi-Fi traffic attributed to changes in 6 GHz spectrum will increase, reaching $38.08 billion between 2023 and 2025.

- **The creation of a VLP device category will enable the deployment of a new generation of AR/VR solutions yielding an overall producer surplus of $13.74 billion for US firms selling hardware, software, and content in the US market between 2020 and 2025.**

US companies selling AR/VR equipment in the US market (which excludes foreign firms selling in the United States and US firms selling abroad) will generate $19.80 billion between 2020 and 2025. Of this amount, $13.74 billion will be producer surplus linked to the availability of unlicensed spectrum in the 6 GHz band.

- **More importantly, the diffusion of AR/VR solutions among US enterprises will yield a spillover contribution to the GDP equivalent to $25.78 billion between 2020 and 2025.**

The adoption of AR/VR among US business will in turn have a spillover effect on productivity, thereby contributing to the growth of GDP. The spillover effects range from improved training to the acceleration of product design and delivery, and the generation of new business models. Considering a highly conservative multiplier of 1.0, spillovers of AR/VR sales of equipment enabled by the 6 GHz proposal and sold in the US by domestic firms will contribute $25.78 billion to GDP between 2020 and 2025.

Beyond the effects that can be directly attributed to each unlicensed spectrum proposal, $13.60 billion in CAPEX savings by cellular carriers and a producer surplus from equipment sales of $1.54 billion will be generated by a combined effect of the eight 160 MHz channels or three 320 MHz channels resulting from the 5.9 GHz and 6 GHz proposals.

- **Cellular operators will benefit in terms of savings of $13.60 billion between 2020 and 2025 by relying on 5.9 GHz and 6 GHz Wi-Fi equipment to off-load an additional portion of 5G-originated traffic.**

Wi-Fi allows cellular service providers to decrease the capital investment and operating expenses required to accommodate exploding data traffic. The estimation of CAPEX savings is predicated on the assumption that in the absence of additional unlicensed spectrum bands, service providers would have to deploy expensive infrastructure to accommodate the growth in traffic. The wireless industry is expected to invest in the United States between $222 billion and $285 billion to deploy 5G through 2025. With an estimated 71% of 5G traffic to be off-loaded to Wi-Fi,[8] the availability of 160 MHz in the 5.9 GHz band will be particularly suited to provide CAPEX relief to cellular operators. It is conservatively assumed that this advantage will become effective for a portion of the suburban (approximately 15%) and rural (roughly 5%) network deployment, which will yield savings of $13.60 billion, which could be invested in extending 5G deployment in rural areas.

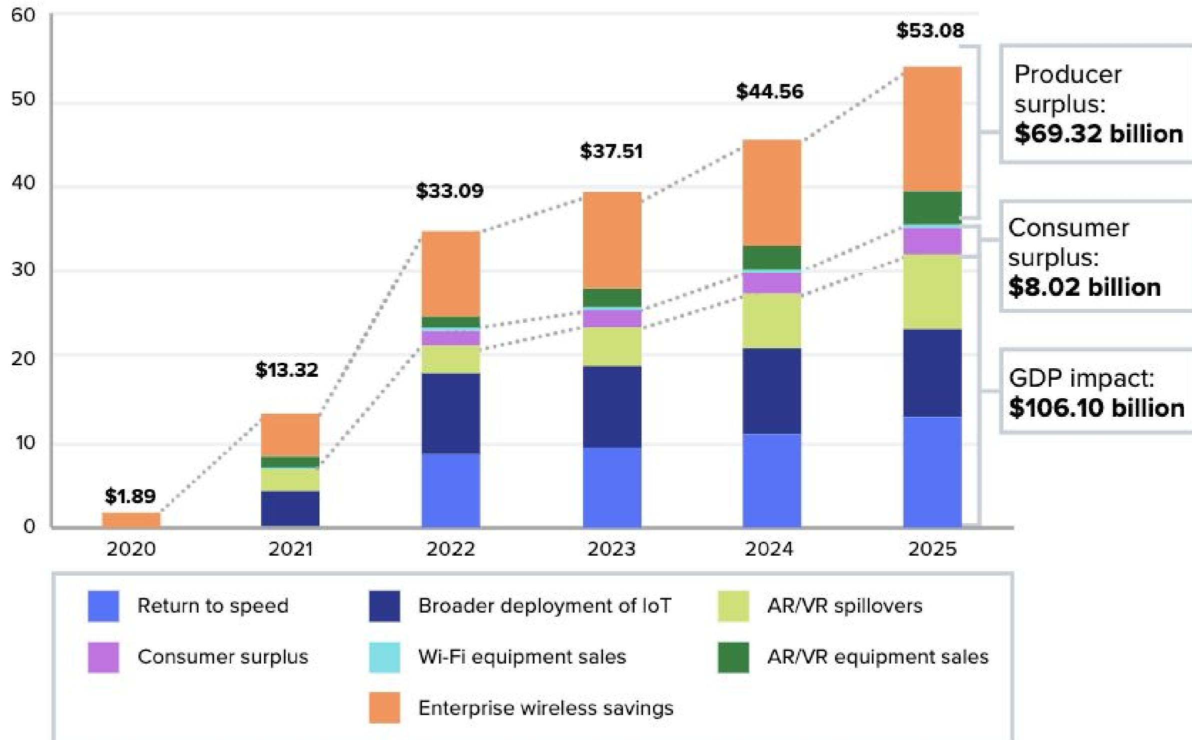
- **Finally, US equipment manufacturers will receive a producer surplus equivalent to $1.54 billion from the margins of 5.9 GHz and 6 GHz enabled Wi-Fi consumer and enterprise equipment sold in the US.**

Revenues for US manufacturers generated from selling equipment operating within the enhanced 5.9 GHz and 6 GHz band between 2020 and 2025 in the United States are expected to reach $3.92 billion. This will yield a producer surplus for US manufacturers of these particular products of $1.54 billion. This benefit is in addition to the one generated by VLP device sales since it refers to indoor Wi-Fi equipment.

[8] This is expected to happen with the increase in unlicensed spectrum. Cisco's 2018-2023 Annual Internet report, Appendix A: Overview of Annual Internet Report methodology ("Several factors influence the fixed and Wi-Fi broadband-speed forecast, including the deployment and adoption of fiber, high-speed DSL, cable broadband adoption, Wi-Fi6 and Wi-Fi 5 technologies as well as overall broadband penetration.").

Again, the total economic value of allowing unlicensed use in the 5.9 GHz and 6 GHz bands will amount at least to $183.44 billion between 2020 and 2025.

Graphic A. Total Economic Value Resulting from the 45 MHz in 5.9 GHz band and the creation of two categories of Low Power Devices in the 6 GHz band (in US$ billions) (2020-2025)



Source: Telecom Advisory Services analysis

As depicted in Graphic A, the annual economic value to be generated by both spectrum proposals will grow over time, reaching $53.09 billion in 2025. The sources of value contributing to the country's GDP are the principal ones, followed by the producer surplus earned by equipment manufacturers and operators of telecommunications networks.[9] While the generation of consumer surplus is relatively small compared to other areas of value creation, our estimate is fairly conservative insofar that it does not address a significant increase in willingness to pay to be borne by end users as a result of the wealth of applications and use cases to be enabled by the spectrum under consideration.

[9] Producer surplus equals, as our calculations indicate, the revenue that a producer receives from selling its goods minus the total cost of production. Since this materializes when a good is sold, producer surplus is strictly speaking part of GDP. Therefore, calculating producer surplus on one hand and GDP on the other and aggregating might be double counting. However, the growth in GDP in this study is calculated from a model that measures the economic impact of an increase in broadband speed based on historical data, at a time when there was not a significant change in the unlicensed spectrum allocation (except marginally on U-NII-3); therefore, the impact on GDP is fundamentally attributed to speed increase and not to producer surplus driven by equipment sales. On the other hand, CAPEX savings incurred by wireless carriers by offloading traffic to Wi-Fi has been occurring for a while, so the historical data might be capturing this effect. Therefore, in this particular case, the effect derived from CAPEX savings will be excluded from totals to avoid double counting.

1. INTRODUCTION

The Federal Communications Commission (FCC) has recently made spectrum policy proposals that would, if adopted, generate billions of dollars in economic value by opening two bands to unlicensed technologies, including Wi-Fi, IoT, and AR/VR devices. There is a significant amount of research-based evidence that unlicensed spectrum has very high social and economic value. In fact, prior research agrees that, contrary to licensed bands where economic value could equate to whatever is paid at auction, the economic value of unlicensed spectrum, such as Wi-Fi, needs to be measured based on the concept of GDP and economic surplus.[10]

The purpose of this study is to extend our previous work on the assessment of the economic value of unlicensed spectrum,[11] by focusing on two specific areas: 1) the economic benefits associated with designating a portion of the 5.850-5.895 GHz band for unlicensed use, and 2) the economic value of creating two categories of devices (Low Power Indoor and Very Low Power) operating in the 6 GHz band. Each area will be studied independently, after which a combined perspective of the economic benefit of both proposals will be presented.

Chapter 2 provides the theoretical framework in support of framing the analyses. Chapter 3 presents first the research evidence of economic benefits to be yielded by allocating 45 MHz in the 5.9 GHz band to unlicensed use. Following that, it details the methodologies, models and results of such benefits. Chapter 4 reviews the methodologies to measure the economic benefits of creating two categories of low power devices in the 6 GHz band and provides the results of the analyses. Chapter 5 provides an aggregate estimate of both proposals.

[10] Thanki, R. (Sept. 8, 2009). *The economic value generated by current and future allocations of unlicensed spectrum*. Perspective Associates; Milgrom, P., Levin, J., & Eilat, A. (2011). *The case for unlicensed spectrum*. Stanford Institute for Economic Policy Research Discussion Paper No. 10-036; Cooper, M. (2011). *The consumer benefits of expanding shared use of unlicensed radio spectrum: Liberating Long-Term Spectrum Policy from Short-Term Thinking*. Washington D.C.: Consumer Federation of America.

[11] Katz, R. (2014a). *Assessment of the economic value of unlicensed spectrum in the United States.* New York: Telecom Advisory Services. Katz, R. (2014b). *Assessment of the future economic value of unlicensed spectrum in the United States.* New York: Telecom Advisory Services. Katz, R. (2018). *A 2017 assessment of the current and future economic value of unlicensed spectrum*. Washington, DC: Wi-Fi Forward. Katz, R. (2018). *The global economic value of Wi-Fi 2018-2023*. New York: Telecom Advisory Services.

2. THEORETICAL FRAMEWORK AND METHODOLOGIES

The following section presents the context and methodologies to be used in the assessment of economic value in the two specific areas outlined above.

2.1. Assignment of 45 MHz in the 5.9 GHz band

As stated in the 5.9 GHz NPRM,[12] the FCC is seeking to supplement the U-NII-3 band (an existing Wi-Fi band) by making the bottom 45 MHz of the 5.9 GHz band available to unlicensed use, modeled after the 5.8 GHz Part-15 unlicensed rules. This would create the first contiguous 160 MHz channel in the United States that is not burdened with DFS government-sharing rules. The FCC believes that designating the band for unlicensed use is likely to generate significant economic impact and seeks comments and analyses regarding this proposal. The 5.9 GHz chapter of this study is responsive to the Commission's request for a reasonable estimate of the economic benefits derived from assigning 45 MHz of the 5.9 GHz band to unlicensed use.

2.2. Assessment of the value of permitting additional unlicensed technologies in the 6 GHz band

In October, 2018, the FCC presented a Notice of Proposed Rulemaking (NPRM) that recommended opening the 6 GHz band to unlicensed operations. In particular, the Commission sought comment[13] to its proposal to open the band's full 1,200 MHz (5.925-7.125 GHz) to unlicensed devices. After notice and comment, the FCC is now considering three classes of devices:

- Standard power AFC devices: devices operating standard power Wi-Fi (which could be indoors or outdoors), governed by automatic frequency coordination.
- Low Power Indoor devices (restricted to indoor) (LPI), required to be non-weather proofed, plugged into the wall, authorized to use only ¼ of the power of standard-power Wi-Fi (i.e., 250 milliwatts conducted power), which excludes them from the need to be frequency coordinated. This is the closest designation to current Wi-Fi.
- Very Low Power devices (VLP), authorized to power levels 160 times lower than standard-power Wi-Fi, and permitted to be used indoors or outdoors in certain sub-bands. These VLP devices would be capable of operating using multiple extremely wide channels (160 MHz) with sub-millisecond latency performance. The category includes AR/VR headsets, Ultra High Digital Video Streaming, high-speed tethering (watches, ear pods) or entertainment devices in the automobile.[14]

[12] *5.9 GHz NPRM* ¶¶ 13-17.
[13] *6 GHz NPRM.*
[14] FCC ex parte notification from Apple Inc., Broadcom Inc., Facebook Inc., Google LLC, Hewlett Packard Enterprise, Intel Corp., Marvell Semiconductor Inc., Microsoft Corporation, Qualcomm Incorporated (July 2, 2019).

Under this new proposal, industry stakeholders state that LPI and VLP devices not only present minimal harmful interference risk, but also offer enormous economic value. In fact, a wide range of stakeholders, including broadband providers and technology companies, believe that, unless the designation of LPI and VLP devices is fulfilled, the economic value derived from the 6 GHz band would be greatly diminished. If the FCC were to allow only the AFC-controlled device class, or restrict LPI or VLP to too few channels, many core applications and types of devices would be effectively blocked from the band. In light of these considerations, this study will focus on assessing the economic value of these two device category classes—LPI and VLP—by focusing on specific applications and use cases likely to be introduced in the enterprise and consumer markets. While focusing on these two subsets, we also recognize that a Wi-Fi like service operating within AFC can also generate economic value.

2.3. Theoretical framework and methodologies

At the aggregate level, the methodology relied upon in this study is similar to the one used by Milgrom et al. (2011), Cooper (2011) Thanki (2009), and Katz (2014a, 2014b, 2018a, 2018b), whereby the different sources of economic value are estimated independently and then aggregated within a single estimate (this allows cumulating GDP impact, with consumer and producer surplus[15]). Along those lines, we proceeded to identify the sources of economic value, estimate their impact, and then combine them for each proposal and in the aggregate.

We have identified eight sources of economic value to be generated by both proposals:

- The impact on GDP yielded by an increase in average broadband speed resulting from removing the Wi-Fi bottleneck at the customer premise level (also called the "return to speed");
- The consumer surplus derived from faster average broadband speed driven by the additional unlicensed channels in the 5.9 GHz and 6 GHz bands;
- The producer surplus generated by the sale of new Wi-Fi equipment enabled by the additional unlicensed channels;
- The savings in capital investment incurred by cellular operators from offloading cellular traffic to Wi-Fi (this impact will be driven not only by the 5.9 GHz proposal but also the 6 GHz one);
- Broader deployment of IoT devices as additional unlicensed spectrum mitigates the risk of congestion;

[15] As mentioned in the Executive Summary, we consider that cumulating GDP effect and producer surplus on equipment sales is reasonable given that the impact on GDP is fundamentally attributed in our models based on historical data to speed increase and not to producer surplus driven by equipment sales triggered by new unlicensed spectrum allocation. On the other hand, CAPEX savings incurred by wireless carriers incurred by offloading traffic to Wi-Fi has been occurring for a while and could be included in the GDP model estimates. Therefore, in this particular case, the effect derived from CAPEX savings will be excluded from totals to avoid double counting.

- Savings in enterprise wireless traffic as additional Wi-Fi channels provide much needed capacity to support the widespread adoption of new use cases;
- Producer surplus derived from a boost in the sales of AR/VR equipment, software and content as triggered by the VLP designation; and
- The consequent economic spillovers resulting from the additional sales of AR/VR solutions.

As explained above, two FCC proposals are under consideration: the 5.9 GHz and the 6 GHz bands. The 5.9 GHz band would be added to the existing unlicensed bands of 2.4 GHz and 5.8 GHz, creating the first widely usable contiguous 160 MHz channel in the United States. When the 6 GHz band is opened up and added to the existing unlicensed bands in 2.4 GHz and 5 GHz, the combined spectrum will be able to support eight 160 MHz channels or three 320 MHz channels. This unprecedented initiative to make an important portion of the frequency spectrum available to unlicensed use has some important implications in terms of how to estimate its economic value. An analytical challenge involves separating the effects of the 5.9 GHz decision from the 6 GHz proposal.

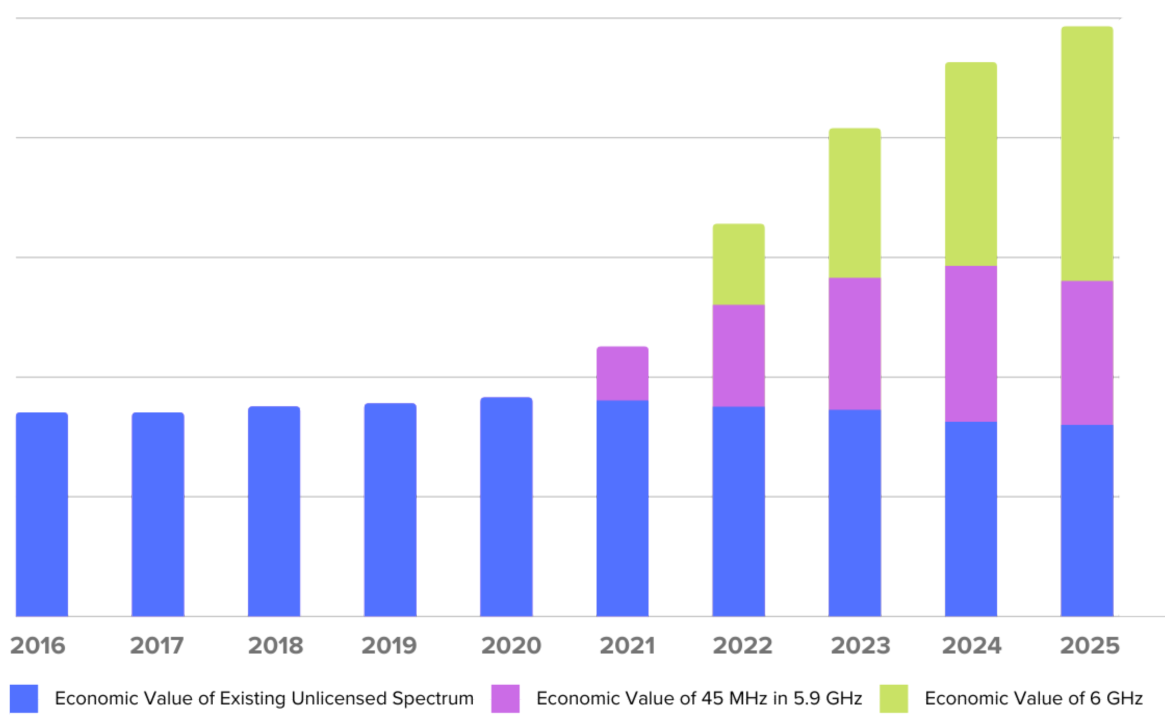
To begin with, the proposals add channels to those already assigned for unlicensed use. Along those lines, it is important to isolate the economic value that is already being generated in the 2.4 GHz and the U-NII-3 band in order to prevent double counting.[16] Once this is done, it is important to differentiate the effects between each of the two proposals under consideration. In some cases, the attribution of economic value is straightforward. For example, the benefit of AR/VR use cases is directly related to the authorization of Very Low Power devices in the 6 GHz band. However, in other cases the economic value results from the combined effect of both proposals. A case in point is the CAPEX savings producer surplus incurred by cellular carriers in their deployment of 5G. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in all unlicensed bands, in particularly 5 GHz and 6 GHz. In this case, we opted to consider the economic value as resulting from the combined impact of both proposals.

A particular analytical challenge of the study is how to assess the economic benefit of enhanced Wi-Fi performance. On the one hand, some economic impact can be directly attributed to the 45 MHz in the 5.9 GHz available for unlicensed use. For example, a dual band router can deliver peak speeds of 1.2 Gbps on 2.4 GHz, 4.8 Gbps on one 5 GHz radio, and 4.8 Gbps on the other 5 GHz radio. While this is not the speed delivered to a single user device, the addition of 45 MHz is expected to have, on an aggregate basis, an impact on total router speed. On the other hand, the addition of 6 GHz to unlicensed use will enable the deployment of a tri-band router configuration operating on 2.4 GHz, 5 GHz, and 6 GHz spectrum. In the 6 GHz band, the router will be capable of providing single user throughput of approximately 2.2 Gbps.

[16] This was conducted in our prior studies cited above.

One approach to estimate the economic value of enhanced Wi-Fi performance would be to measure it on a combined basis, considering both proposals—the 45 MHz in 5.9 GHz and the Low Power Indoor in the 6 GHz band—in the aggregate, as is the case with CAPEX savings by wireless operators discussed above. However, this does not facilitate the estimation of economic impact of each FCC proposal. Our approach assumes that the 5.9 GHz proposal will primarily address the Wi-Fi bottleneck existing at the consumer premise between 2020 and 2022, and that the 6 GHz proposal will be instrumental in tackling the speed challenge between 2023 and 2025. We are cognizant that both proposals could be enacted in the short term. However, when observing the trend in average fixed broadband speeds in US households, we stipulate that the source of economic value of each proposal will shift over time. In other words, the 5.9 GHz will serve to alleviate the immediate spectrum contention, while the 6 GHz will be a larger response beyond 2022. As a result, in the case of Wi-Fi the importance of economic value between spectrum decisions will shift over time (see Figure 2-1).

Figure 2-1. Conceptual representation of the drivers of Wi-Fi economic value



Source: Telecom Advisory Services

As conceptually depicted in Figure 2-1, the economic value of Wi-Fi is composed of three sources: first, the one resulting from existing unlicensed spectrum (this was estimated in our prior studies and is not part of this assessment); second, the one generated by the 45

MHz in the 5.9 GHz band, and third, the one yielded by the 6 GHz proposal. Each source develops at the time Wi-Fi spectrum becomes a bottleneck.

In light of these considerations, each source of value could be attributed in one of three ways:

- Attribute the full economic impact of a source of value creation to a single spectrum proposal (for example, AR/VR solutions are intrinsically linked to the 6 GHz spectrum proposal);
- Do not assign the economic impact of a source of value to a particular spectrum proposal, but recognize that the benefit can be jointly attributed to both of them (for example, CAPEX savings for cellular operators as a result of Wi-Fi off-loading);
- Apportion a source of economic value to the two proposals, but attempt to differentiate the amount of attribution (for example, split the impact of indoor Wi-Fi performance between the 5.9 GHz and the 6 GHz proposals).

Based on these three approaches, the following analytical decisions were made (see Table 2-1).

Table 2-1. Approach to measure sources of economic value

Source of Economic Value	Economic value is the result of 5.9 GHz	Economic value is the result of 6 GHz	Economic value is the result of both spectrum proposals
Return to speed	• Value attributed to impact of 5.9 GHz proposal	• Value attributed to impact of 6 GHz proposal	
Consumer surplus	• Value attributed to impact of 5.9 GHz proposal	• Value attributed to impact of 6 GHz proposal	
Producer surplus from equipment sales			• No attribution by proposal is made
5G CAPEX savings			• No attribution by proposal is made
Broader deployment of IoT		• Value attributed exclusively to 6 GHz Low Power Indoor	
Savings in enterprise wireless traffic		• Value attributed exclusively to 6 GHz Low Power Indoor	
Producer surplus from AR/VR equipment sales		• Value attributed exclusively to 6 GHz Very Low Power	
US Spillovers from AR/VR		• Value attributed exclusively to 6 GHz Very Low Power	

Source: Telecom Advisory Services

At the conclusion of the study, the resulting estimates will be reported following the framework implicit in the table above.

3. ASSESSMENT OF ECONOMIC BENEFITS DERIVED FROM MAKING 45 MHz IN THE 5.9 GHz BAND AVAILABLE FOR UNLICENSED USE

The following chapter presents the assessment of the economic value that can be attributed to the proposal to make 45 MHz in the 5.9 GHz band available to unlicensed use. We begin by providing the prior research evidence supporting the argument that significant economic value will be created. Following this, we present our estimates of benefits.

3.1. Prior research evidence in support of the proposed 5.9 GHz assignment

The economic value of assigning 45 MHz in the 5.9 GHz band is based on four sources:

- The impact on GDP yielded by an increase in average broadband speed resulting from removing the Wi-Fi bottleneck at the customer premise level (also called the "return to speed");
- The consumer surplus derived from faster average broadband speed driven by the same effect as above;
- The producer surplus generated by the sale of new equipment enabled by the additional unlicensed channels in the 5.9 GHz and 6 GHz bands; and
- The savings in capital and operations incurred by cellular operators from offloading cellular traffic to Wi-Fi (this impact will be driven not only by the 5.9 GHz proposal but also the 6 GHz one).

3.1.1. Return to broadband speed

The NPRM[17] raises the issue of whether estimating the contribution to GDP of increases in Wi-Fi throughput is an appropriate way to measure the benefits of introducing unlicensed operations in the 5.9 GHz band. While the answer to this question is in the affirmative, it can be disaggregated into three components:

- Is broadband speed related to GDP?
- Why is Wi-Fi affecting overall broadband speed?
- What is the impact of the 5.9 GHz unlicensed assignment on overall broadband speed?

As will be demonstrated below, research evidence has already generated answers to each of these questions.

Broadband speed and GDP

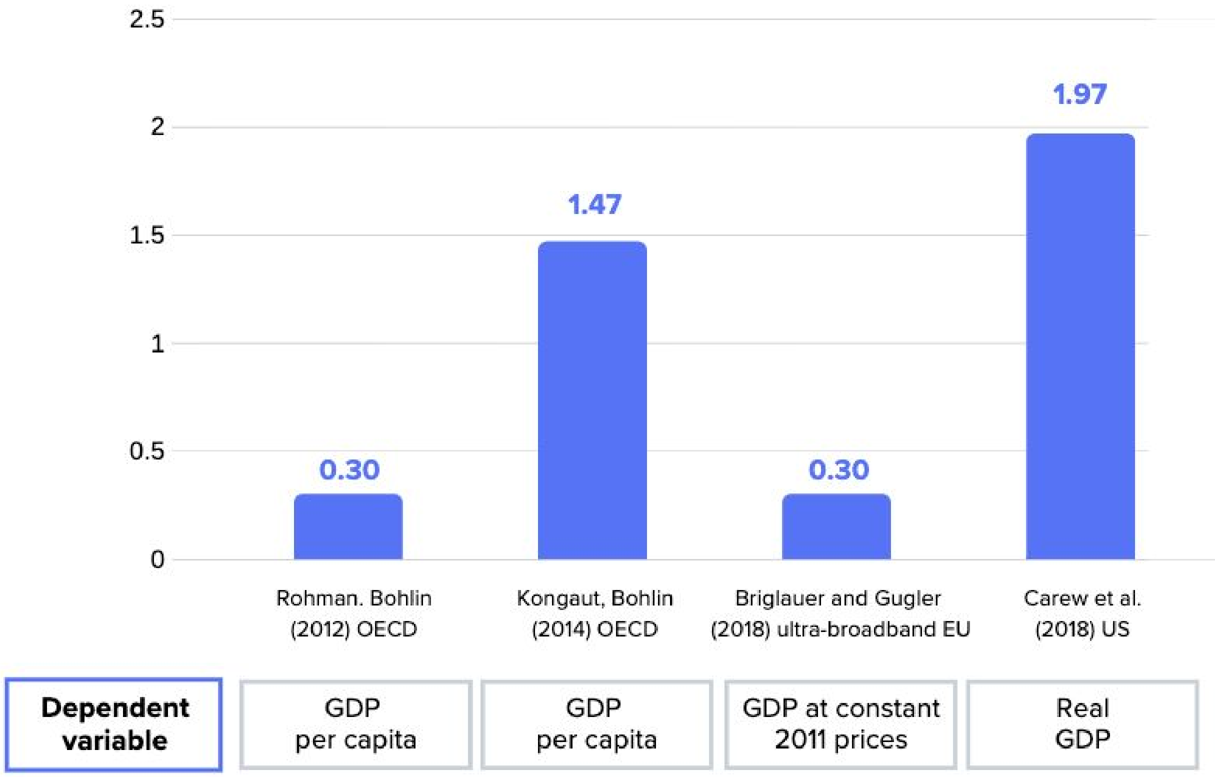
Research on the economic contribution of broadband speeds uniformly concludes that faster Internet access has a positive impact on GDP growth. Three types of effects

[17] *5.9 GHz NPRM.*

explain this relationship. First, faster broadband contributes to an improvement of labor productivity resulting from the adoption of more efficient business processes. Marketing of excess inventories and optimization of the supply chain are two of the effects that might be generated. Second, faster connectivity yields an acceleration of the rate of introduction of new products, services, and the launch of innovative business models. Third, the acceleration of broadband speeds drives a set of network externalities resulting in a restructuring of industry value chains (in other words, faster communications allow enterprises to either outsource operations without any disruption risk or relocate functions to areas with more advantageous input costs).

The compilation of the research evidence generated so far in four econometric studies[18] confirms the existence of these effects (see Graphic 3-1).

Graphic 3-1. Studies measuring the GDP impact on Broadband Speed (impact of 100% increase in speed on GDP) (%)



Source: Compiled by Telecom Advisory Services

[18] We have selected only four studies to review, although research has yielded many more papers (see, for example, Ford, G. (2018). *Is Faster Better? Quantifying the Relationship between Broadband Speed and Economic Growth*. Phoenix Center Policy Bulletin No. 44. Grimes, A., Ren, C., and Stevens, P. (2009). *The need for speed: Impacts of Internet Connectivity on Firm Productivity.* MOTU Working Paper 09-15. Mack-Smith, D. (2006). *Next Generation Broadband in Scotland*. Edinburgh: SQW Limited).

As indicated in Graphic 3-1, while all four studies coincide in concluding that broadband speed has an impact on GDP, the range of contribution varies: 100% (or doubling) increase of broadband speed generates a contribution to GDP ranging from 0.30% to 1.97%. Some of the difference is explained by the methodologies and variables used. For example, Carew et. al (2018) did not include broadband adoption as an independent variable, which means that the effect of speed on GDP subsumes broadband penetration. In other cases, the difference can be explained by the timing of data used. For example, Kongaut, Bohlin (2014) rely on a data panel between 2008 and 2012, while the time series of Rohman, Bohlin (2012) ends in 2010, both moments when the average broadband speed was 8.3 Mbps, which in turn resulted in high impact. That being said, the evidence of the positive effect with regards to the contribution of broadband speed to GDP growth remains consistent.

Wi-Fi and overall broadband speed

The second question implicitly raised by the NPRM is whether Wi-Fi has an impact on broadband speed. When a user accesses the Internet, the speed of access could be significantly higher via a Wi-Fi access point than on either 3G or 4G LTE networks. For example, according to the Cisco Visual Networking Index, in 2018 the average speed of cellular networks in the United States was 19.60 Mbps, while the same value for Wi-Fi was 51.30 Mbps.

Wi-Fi speeds cannot be taken for granted, however. While fixed broadband networks continue to improve performance (witness the deployment of DOCSIS 3.1 standard and the upcoming 10G technology from cable operators, as well as the fiber optic roll-out reaching up to 10 Gbps in certain parts of the country), in-premises routers operating within the 2.4 GHz and lower 5 GHz bands are becoming a network "bottleneck" due to congestion and lack of spectrum needed to support modern speeds. The fixed broadband average download speed in February 2020 in the United States had reached 137 Mbps.[19] With the deployment of ultra-fast networks, we forecast that by 2022, the average fixed broadband speed will reach 280 Mbps.[20] Turning to the Wi-Fi side, based on the current 2.4 GHz and 5 GHz allocation, dual router performance is estimated to be 266.50 Mbps (which results from assuming an even split of traffic between the 2.4 GHz band (at 173 Mbps) and the 5GHz band (at 360 Mbps)).[21] This does not mean, however,

[19] This metric is based on the Speedtest Global Index, https://www.speedtest.net/global-index. The service measures the bandwidth (*speed*) and latency of a visitor's Internet connection against one of 4,759 geographically dispersed servers located around the world. Each test measures the data rate for the download direction, i.e., from the server to the user computer, and the upload data rate, i.e., from the user's computer to the server.

[20] Deployment of 10G networks by the cable industry is expected to begin in 2021. It is assumed that average traffic represents 12.45% of the weighted average download speed of 10 Gbps capacity. (*See* the FCC's *2019 Broadband Deployment Report* indicating that the ratio average to peak speed in the US in June 2018 was 12.75% (94 Mbps/713.5 Mbps)).

[21] These estimates are calculated in the RAND study and are based on the router throughput of 173 Mbps for equipment operating in the 2.4 GHz band and 360 MHz for equipment operating in the 5 GHz band. This

that each user is receiving the total speed. Through the use of multiple bands and spatial streams, routers commonly today have total throughput capabilities well in excess of the speeds they can enable for individual devices. For example, a high-end 802.11ax device can, in theory, handle total throughput of 4.8 Gbps, but each user will receive a throughput under 200 Mbps.[22] Thus, if Wi-Fi performance is not improved by opening additional spectrum, the in-premise equipment becomes a network bottleneck, and the speed experienced by a consumer at home will not be equivalent to that delivered by fixed networks.

To sum up, since Wi-Fi accessibility allows, in general, faster access to the Internet, higher Wi-Fi speeds, enabled by additional spectrum, have a positive contribution to overall broadband speed.

The impact of the 5.9 GHz assignment on overall broadband speed

The next question is whether opening new spectrum in the 5.9 GHz band would affect the overall broadband speed. The FCC has estimated that, by June 2018, 90.1% of US households were able to access broadband service in excess of 100 Mbps and 68.1% could even acquire broadband of at least 1 Gbps (see Table 3-1).

Table 3-1. United States: Fixed Broadband Download Speed Coverage (percent population that can access broadband with at least indicated speed) (2014-2018)

	2014	2015	2016	2017	June 2018
10 Mbps	93.7 %	94.3 %	95.8 %	96.9 %	97.2 %
25 Mbps	89.4 %	89.9 %	91.9 %	93.5 %	93.9 %
50 Mbps	85.2 %	88.5 %	90.3 %	91.6 %	92.2 %
100 Mbps	63.5 %	67.3 %	75.7 %	88.5 %	90.1 %
250 Mbps	4.9 %	21.2 %	43.7 %	58.8 %	73.8 %
1 Gbps	0.0 %	15.0 %	30.0 %	50.0 %	68.1 %

Note: Metrics include download and upload speeds
Source: FCC Broadband Deployment Report 2019; Telecom Advisory Services analysis

Consumers have reacted to these improvements in supply by increasing the speed of the service packages they purchased. The number of subscribers in the US accessing broadband with a plan higher than 100 Mbps jumped from 800,000 in 2013 to 40,600,000 in December 2017.[23]

As explained above, permitting Wi-Fi in the U-NII-4 band will help higher-speed broadband offerings maintain their throughput all the way to end-user devices by

---

assumes that all households have dual band equipment and that traffic is routed 50% at 2.4GHz/50% 5GHz (*see* p. 21-22).

[22] Estimate provided by Broadcom. This refers to the throughput received by each user device (PC, tablet, etc.) within the user premise.

[23] Federal Communications Commission (Aug. 2019). *Internet Access Services: Status as of December 31, 2017*, p. 3.

relieving the “bottleneck” that would otherwise develop, leading to higher adoption of ultra-fast broadband.

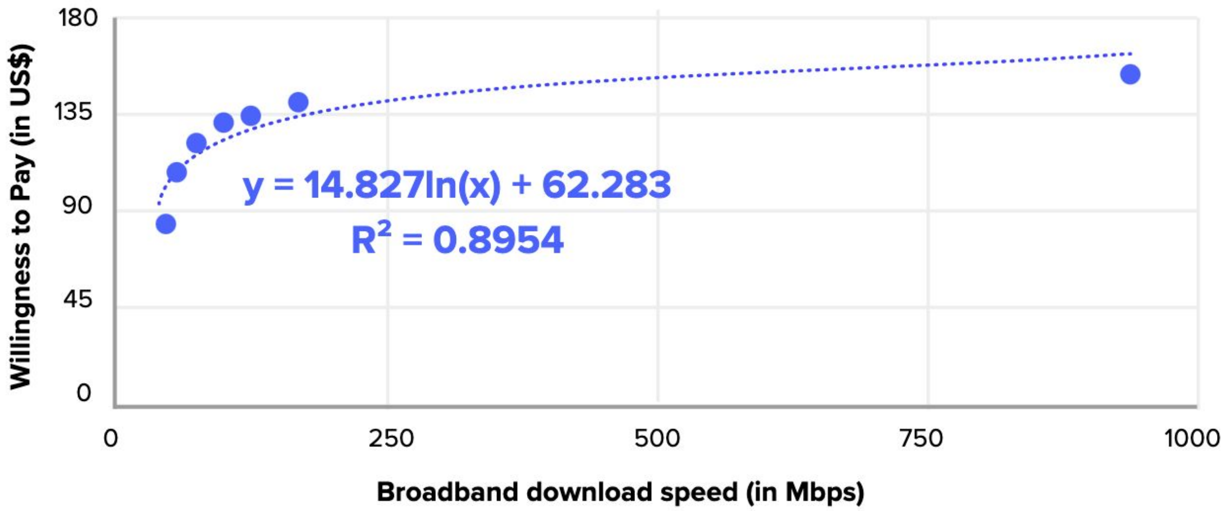
3.1.2. Increase in consumer surplus

While the NPRM discusses the impact of 5.9 GHz on GDP growth, it does not expressly address the increase in consumer surplus. But as other studies demonstrate, this represents another source of economic value. Consumer surplus is defined as the value that consumers receive from purchasing a product for a price that is less than what they would be willing to pay. Early on, Rosston et al. (2010) noted that, in addition to the benefits that consumers receive from broadband adoption (quick access to large amounts of information for learning and health services, access to the world’s largest portal for social and entertainment services and the potential for savings from online shopping), one must also consider consumer preferences and benefits received from the nature of the service, which include speed of access and reliability.

Most studies of consumer surplus derived from faster broadband speed are based on primary research, where users stipulate the amount they would be willing to pay for broadband service (Savage et al. (2004); Greenstein and McDewitt (2011); Liu et al. (2017). Other studies on consumer surplus focus the assessment of how consumers react to variations in price according to their data usage. For example, Nevo et al. (2015) studied hour-by-hour Internet usage for 55,000 US subscribers facing different price schedules. They concluded that consumer surplus for speed is heterogeneous. Consumers will pay between $0 to $5 per month for a 1 Mbps increase in connection speed, with an average of $2.[24] In addition, they stipulated that, with the availability of more content and applications, consumers will likely increase their usage, implying greater time savings and a greater willingness to pay for speed. At the time of the study, the increase in willingness to pay at high speeds dropped by approximately $0.11 per Mbps. This is confirmed by a more recent study. Liu et al. (2017) administered two national, discrete choice surveys of US consumers to measure households’ willingness-to-pay for changes in price, data caps, and speed. The authors found that the valuation of bandwidth is highly concave, with lesser added value beyond 100 Mbps (see Graphic 3-2).

[24] Heterogeneity in willingness to pay for broadband was also highlighted by Rosston et al. (2010).

Graphic 3-2. Log Curve of relationship between broadband speed and consumer surplus (based on Liu et al., 2017)



Source: Liu et al.(2017); Telecom Advisory Services analysis

As reported in this study, US households are willing to pay about US $2.34 per Mbps ($14 total) monthly to increase bandwidth from 4 Mbps to 10 Mbps, US $1.57 per Mbps ($24) to increase from 10 to 25 Mbps, and US $0.02 per Mbps (US $19) for an increase from 100 Mbps to 1000 Mbps.

3.1.3. CAPEX savings from traffic off-loading

This source of economic value was initially analyzed by Milgrom et al. (2011), and Cooper (2012), and further estimated in our prior studies (Katz, 2014a, 2014b, 2018a). As posited in earlier studies, the value of cellular off-loading is based on the congestion relief for licensed spectrum owners that comes from the additional spectrum (Bazelon, 2008).[25] Wi-Fi allows cellular service providers to decrease the capital and operating expenses required to accommodate exploding data traffic. The estimation of savings is predicated on the assumption that, in the absence of additional unlicensed spectrum bands, service providers would have to deploy expensive infrastructure to accommodate the growth in traffic. Thus, the calculation of economic value is based on the portion of capital investments (and potential incremental network operations and maintenance operating

[25] In this context, Wi-Fi acts as a complementary technology compensating for the economic limitations of cellular. In the case of spectrum management, unlicensed frequency bands can enhance the effectiveness of devices that use licensed spectrum. For example, Wi-Fi base stations operating in unlicensed bands can enhance the value of cellular networks by allowing wireless devices to switch to hot-spots, thereby reducing the cost of broadband access and increasing the access speed rate. Consumers accessing the Internet within the reach of a Wi-Fi site can reduce their costs of access by turning off their wideband service. They can also gain additional access speed because the transfer rate of Wi-Fi sites is generally faster than that offered by cellular technology.

expenses) that service providers can avoid when they and consumers shift traffic from cellular networks to Wi-Fi.

3.1.4. Increase of producer surplus as a result of sales of additional customer premise equipment

The first assessment of this source of value of unlicensed spectrum was conducted by Milgrom et al. (2011) in their estimation of economic surplus (consumer and producer) of the sale of Wi-Fi enabled tablets. The underlying premise was that, since tablets were essentially a Wi-Fi connected device, their diffusion would not have occurred if unlicensed spectrum did not exist. This premise supported the analyses conducted by this author (Katz, 2018a, 2018b) estimating the surplus generated by a whole suite of home devices enabled by Wi-Fi (e.g. wireless speakers, security systems, monitoring devices). In the case of the 45 MHz in the 5.9 GHz band, our assessment will address only the manufacturer margins of the sale of equipment that benefits from the 160 MHz channel.

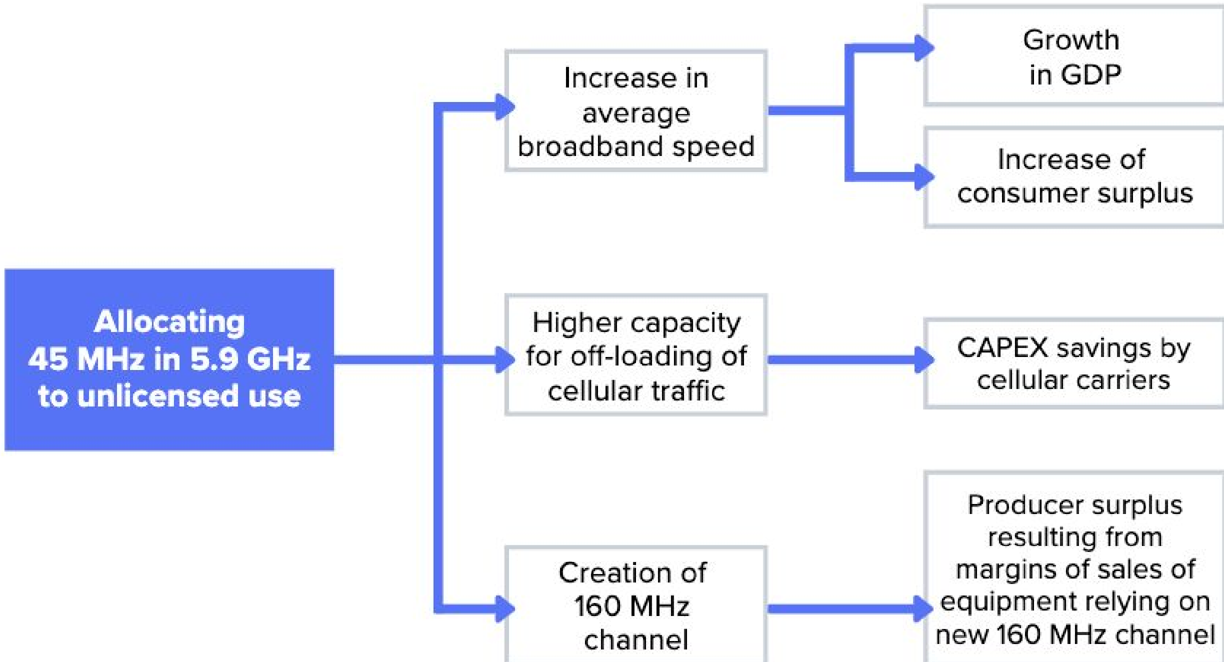
3.1.5. Other sources of economic contribution

Beyond the studies on the contribution of broadband speed to GDP and economic surplus, the broadband speed impact on enterprise productivity has also been studied in terms of its efficiency enhancement and production levels. In a study of Irish firms, Haller et al. (2019) found significant gains in productivity from broadband availability in two particular services sectors: Information & Communication services and Administrative & Support Service Activities. The effects measured for these two sectors were large, equivalent to about a third of the typical variation in productivity. Smaller effects were found, however, in other sectors. These results suggest the benefits of broadband speed for productivity depend heavily upon sector and firm characteristics rather than representing a homogeneous effect. Finally, the Cariolle et al. (2017) study on firms in 62 countries, using World Bank data, detected large impact on firms' average annual sales and sales per worker, and, to a lesser extent, on temporary employment of an increase in email use by firms.

3.1.6. Conclusion

In conclusion, prior research has generated substantial evidence regarding the economic effects of additional broadband speed. These effects are likely to have a similar positive economic impact if the FCC opens the bottom 45 MHz of the 5.9 GHz to unlicensed spectrum. The effects to be addressed in the context of this study are summarized in Figure 3-1.

Figure 3-1. Economic value to be generated by allocating 5.9 GHz to unlicensed use



Source: Telecom Advisory Services

The following section will apply this framework to the estimation of economic value.

3.2. Estimating the economic value derived from making 45 MHz in the 5.9 GHz band available to unlicensed use

Our approach to measuring economic value of unlicensed spectrum focuses first on the new economic growth enabled by the additional unlicensed spectrum channels in the 5.9 GHz band. By including the GDP contribution measurement, we follow Greenstein et al. (2010) and prior literature measuring the economic gains of new goods. In measuring the GDP direct contribution, we strictly consider the revenues added "above and beyond" what would have occurred had the unassigned spectrum been licensed.

As mentioned in chapter 2, we add to this analysis by measuring the economic surplus triggered by the adoption of the technologies operating in the unlicensed network bands. The underlying assumption of this approach is that the unlicensed spectrum resource generates a shift both in the demand and supply curves resulting from changes in the production function of services as well as the corresponding willingness to pay. On the supply side, the approach measures changes in the value of inputs in the production of wireless communications. The most obvious example is whether Wi-Fi enabled by unlicensed spectrum represents a positive contribution to wireless carriers' CAPEX and OPEX insofar as they can control their spending while meeting demand for increased wireless traffic. From an economic theory standpoint, the wireless industry can then increase its output, yielding a marginal benefit exceeding the marginal cost. This results in a shift in the supply curve by a modification in the production costs. To quantify incremental surplus derived from the adoption of technologies operating in the unlicensed spectrum bands, we itemize the number of technologies and applications intricately linked to this environment. We complement the concept of producer surplus with an assessment of the consumer surplus. The assessments of economic value have been estimated for the years 2020 to 2025.

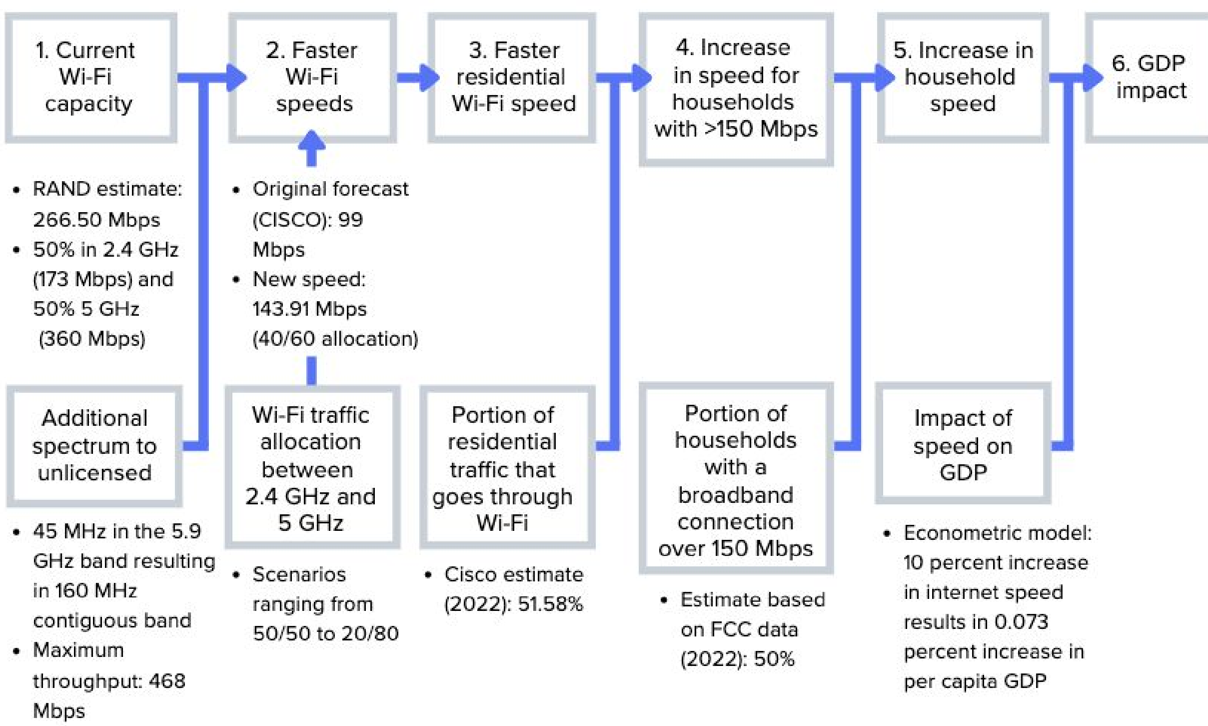
3.2.1. Estimating the return to speed

The value to be generated by the increase in average wireless speed resulting from allocating 45 MHz in the 5.9 GHz band translates into a contribution to the GDP.

Methodology

The key objective is to estimate the future change in average broadband speed based on the improvement in speed for those households undergoing a Wi-Fi bottleneck (those purchasing fixed broadband plan in excess of 150 Mbps now and in the future). As explained above, despite the broadband capacity reaching the house, these users would undergo a "bottleneck" in network performance as a result of spectrum-limited CPE (e.g. Wi-Fi router). Figure 3-2 presents the methodology followed to develop the estimate.

Figure 3-2. Methodology for estimating the Return to Speed on GDP



Source: Telecom Advisory Services

The starting point is the Wi-Fi capacity resulting from no change in spectrum allocation (Step 1). We rely on the RAND study estimates that establish that, based on the current 2.4 GHz and 5 GHz allocation, dual router performance currently reaches 266.50 Mbps, which results from assuming an even split of traffic between the 2.4 GHz band (at 173 Mbps) and 5 GHz band (at 360 Mbps)[26]. If no spectrum changes occur from today, router capacity will remain constant through 2022. Since CISCO VNI projects that by 2022,[27] the Wi-Fi speed will reach 99 Mbps, the ratio of average Wi-Fi speed to router capacity amounts to 37.15%.

The assignment of 45 MHz in the 5.9 GHz band will increase the average router capacity. We calculate the amount by prorating the speed estimated by the RAND study, which assumed the allocation of the totality of the band currently assigned to Intelligent Transportation Services to unlicensed use. The RAND study estimated that the allocation of the totality of spectrum to unlicensed would increase router throughput in the 5.9 GHz band by 780 Mbps.[28] Rather than considering the totality of the band, we estimated the impact on speed for only 45 MHz of the 5.9 GHz band. To account for an allocation of 45 MHz in 5.9 GHz rather than 75 MHz, which is the one estimated in that study, we applied the following formula: 45/75*780. The resulting increase of 120.9 Mbps of router capacity[29] allows for an increase of average Wi-Fi speed from 99 Mbps to 143.91 Mbps.[30] This calculation assumes that 40 % of the Wi-Fi traffic will be channeled through the 2.4 GHz band (20%) and 5.0 GHz band (20%) vs. the 60% routed through the 5.9 GHz band (Step 2). RAND assumes 50/50, but considering that our calculations are done for 2022, we estimate a 40/60 split.[31]

---

[26] See RAND study, table 5.2, p. 22, Scenario 1.

[27] We use 2022 because: 1) once the change in spectrum allocation is done (assuming that it could happen in 2020), users will start acquiring new routers to handle improved speeds, 2) with the increase in fixed broadband speeds, it is really in 2022 when the Wi-Fi bottleneck becomes more acute. Finally, since the amount of spectrum unlicensed is not increased, the modem capacity will still be the current one (e.g. 266.50 Mbps).

[28] See RAND study, table 5.2, p. 22, Scenario 3.

[29] An important clarification: while this analysis is conducted for a router's total throughput, it is important to establish that the key driver is the perceived performance of a single user, which is less than 468.00 Mbps. Through the use of multiple bands and spatial streams, routers commonly today have total throughput capabilities well in excess of the speeds they can enable for individual devices. For example, a high-end 802.11 ax device can, in theory, handle total throughput of 4.8 Gbps. The addition of 45 MHz in 5.9 GHz has an impact at the device level that could be higher than the total router throughput. This will be critical in the assessment of impact of Low Power Indoor devices in 6 GHz (see section 4.1).

[30] This value was interpolated from two estimates of Wi-Fi speed provided by Cisco for 2018 and 2023 in their Annual Internet Report highlights for the US: first section on speed evolution.

[31] The 50/50 split is assumed for 2.4 GHz and 5.0 GHz bands. The 40/60 split is meant to account for new spectrum changes, whereby 40% of traffic will go through 2.4 GHz and 5.0 GHz (20%/20%), and 60% will go through 5.9 GHz. We make this change from the RAND assumption because we are forecasting band traffic for 2022.

Since this new speed is that for Wi-Fi traffic, but only 51.58%[32] of all IP traffic coming in the household goes through Wi-Fi (CISCO VNI estimate for 2022), the actual increase in average wireless speed will be lower (Step 3). Furthermore, since not all households subscribe to a fixed broadband connection that undergoes a bottleneck at the CPE, we only consider in our analysis US households that have a connection in excess of 150 Mbps (which by forecasting 2022 from the FCC 2017 data we assume to be 50%) (Step 4). This becomes the universe that benefits from the additional 45 MHz spectrum in the 5.9 GHz band. Having removed the spectrum bottleneck, the 2022 forecast of average fixed broadband household speed derived from the Ookla/Speedtest data (described on page 5) is fulfilled. This results in a speed increase of 11.58 Mbps (Step 5). This increase is used to calculate the impact on GDP.

The economic impact coefficient of incremental speed was calculated through an econometric model based on a historical data panel constructed for 49 countries with average data speeds higher than 40 Mbps for a time series between 2008 and 2019.[33] The data comprised 575 observations of quarterly data for:

- Average fixed broadband download speed[34] (source: Speedtest Global Index)
- Gross Domestic Product (at current prices US$) (source: IMF)[35]
- Population (source: IMF)
- Fixed broadband adoption (percent of households with fixed broadband with a speed of at least 256 kbps) (source: International Telecommunication Union)
- Controls for country and time periods

The model includes:

- a control for the previous quarter's GDP, to isolate the inertial effect of country growth
- download speed lagged by four quarters (1 year) to avoid a reversed causality effect
- changes in employment, to isolate the effect on GDP of the evolution of the labor market
- the country's investment rate (% of GDP) lagged by four quarters (1 year) to isolate the effect of investment on GDP
- the fixed broadband penetration rate to separate the broadband adoption effect from the speed effect

[32] This estimate does account for cellular traffic. Cisco divides the traffic in three groups: mobile traffic, fixed/wi-fi and fixed/wireline; the 51.58% value includes only the traffic coming in the dwelling from the fixed network that goes through the Wi-Fi router.
[33] Of the 176 countries published now by speedtest, we could only use a times series to run the model, which limited the number of countries to 159. Of those, we only run the model for those countries that exhibited an average fixed broadband speed higher than 40 Mbps at any point in time.
[34] The data panel on the Speedtest Global Index covers 159 countries.
[35] The models used GDP at current prices in USD since the objective is to measure the impact of GDP in USD, without considering PPP as a deflator.

$$
\begin{aligned}
lnGDP_{it} = \beta_0 + \beta_1 lnGDP_{it-1} + \beta_2 lnDownload\ Speed_{it-4} + \beta_3 lnEmployment_{it} + \beta_4 lnInvestment\ Rate_{i} \\
+ \beta_5 lnFixed\ Broadband\ Adoption_{it} + \delta Country_i + \vartheta Time_t + \mu_{it}
\end{aligned}
$$

The FCC asked how an economic analysis could account for investment in various industries to avoid an omitted variable bias problem.[36] We believe the inclusion of the country's investment rate as percent of GDP lagged by four quarters and broadband penetration rate and the model specification run on a worldwide panel help correct for any omitted variable bias. For example, the inclusion of fixed broadband adoption, which is correlated with broadband speed, allows for capturing a portion of the GDP impact that otherwise would be incorrectly attributed to broadband speed.

With this in mind, the model yields the following results (see Table 3-2).

Table 3-2. Impact of Fixed Broadband Download Speed on GDP

Impact on ln GDP	Download Speed higher than 40 Mbps
Ln Download Speed$_{t-4}$	0.00730 (0.00211) ***
Ln Employment$_t$	0.00458 (0.00165) ***
Ln Investment$_{t-4}$	-0.00085 (0.00481)
Control for Fixed Broadband adoption	0.00284 (0.00414)
Control for growth of previous GDP	0.99454 *** (0.00168)
Country Fixed Effect	Yes
Time Fixed Effect	Yes
Number of countries	49
Observations	575
R-Square	0.9438

***, **, * significant at 1%, 5% and 10% critical value respectively.
Source: Telecom Advisory Services analysis

By applying the coefficient of GDP impact of 0.73% for a 100% increase in speed, we estimate the overall GDP impact resulting from an increase in speed as a result of the allocation of the 45 MHz (Step 6).[37] The coefficient of impact of 100% increase in speed has dropped from 1.97% in the RAND model to 0.73%. The lowering in coefficient is partly due to the inclusion of the two additional variables (investment rate as % of GDP and broadband penetration) but also the fact that, by running the model with an international panel, a larger difference in speed and GDP across countries than among US states better captures the relation between both variables.

---

[36] *See 5.9 GHz NPRM* n.109.

[37] It is important to note that, while the fixed broadband adoption coefficient is not statistically significant, this is due to the fact that the countries included in the sample have extremely high fixed broadband penetration; for these countries, the primary economic impact is not on adoption (e.g. late adopters will have less impact) but on speed.

Results

To reiterate, the results have been estimated starting in 2022 because we estimate that it is in this year that the bottleneck will become critical. The baseline scenario is based on three assumptions:

- Wi-Fi traffic routing is 20% to the 2.4 GHz band, 20% to the 5.0 GHz band, and 60% to the 5.9 GHz band;
- Number of households undergoing a speed bottleneck at the CPE represent 50% of total households (households with broadband service equal or more of 150 Mbps); and
- Share of fixed broadband traffic coming into the dwelling that goes through Wi-Fi rather than wireline ethernet connection is 51.58%.

The first assumption is a slight modification of RAND's original premise that the traffic going through Wi-Fi would be equally split between the 2.4 GHz and 5 GHz bands. Considering that the beginning of our model is the year 2022, we believe that consumers will be gradually shifting their Wi-Fi usage behavior to the more efficient 5 GHz band.

The second assumption is particularly important since we lack FCC data on the percent of broadband lines with 150 Mbps or faster, which is the speed at which households would be experiencing a bottleneck at the Wi-Fi device if additional spectrum would not be assigned. To estimate this, we conducted an analysis of how customers have been migrating across speed tiers over time and used that pattern to build a forecast (see Table 3-3).

Table 3-3. Migration of broadband lines by speed tiers

Number of Connections	2014	2015	2016	2017					
At least 100 Mbps	9.50	15.50	24.50	40.60					
25 to 100 Mbps	34.00	39.20	38.90	34.10					
10 to 25 Mbps	27.50	25.10	23.40	18.30					
3 to 10 Mbps	19.30	16.60	15.00	12.10					
Less than 3 Mbps	7.90	5.80	3.90	3.10					
Total	98.20	102.20	105.70	108.20					
Share of Connections	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
At least 100 Mbps	9.67%	15.17%	23.18%	37.52%	49.05%	58.34%	65.85%	71.94%	76.88%
25 to 100 Mbps	34.62%	38.36%	36.80%	31.52%	26.99%	23.11%	19.79%	16.95%	14.51%
10 to 25 Mbps	28.00%	24.56%	22.14%	16.91%	12.92%	9.87%	7.54%	5.76%	4.40%
3 to 10 Mbps	19.65%	16.24%	14.19%	11.18%	8.81%	6.94%	5.47%	4.31%	3.40%
Less than 3 Mbps	8.04%	5.68%	3.69%	2.87%	2.22%	1.73%	1.34%	1.04%	0.81%

Source: Values through 2017: (FCC (2019). Internet Access Services: Status as of December 31, 2017. Figure 3, p. 5. Values between 2018 and 2022: extrapolation of historical migration patterns.

Considering that in 2022, we estimate that 76.88% of broadband connections will be of 100 Mbps or more, we estimate that 50% of all broadband connections will be of at least 150 Mbps.

The third assumption is based on the data provided by Cisco Visual Networking Index[38] for the United States:

- Total IP fixed traffic going through wireline (e.g. ethernet connections) by 2022: 46%
- Total IP fixed traffic going through Wi-Fi by 2022: 49%

This allows calculating the percent of Wi-Fi traffic as being 51.58% in 2022.

Under the three assumptions mentioned above, the GDP impact would be $7.201 billion in 2022 (see results and calculations in Table 3-4).

Table 3-4. Return to Speed Effect from 45 MHz in 5.9 GHz unlicensed (2022)

	Data	Source
(1) Wi-Fi Speed (Mbps) with current spectrum assigned	99.00	CISCO Estimation for 2022
(2) Average Speed at the router of current spectrum (Mbps)	266.50	RAND Table 5.2, p. 22
(3) Ratio of speed delivered versus router throughput	37.15%	Relationship between Wi-Fi speed/Average Speed Router
(4) Average Speed in 5.9 GHz of 75 MHz band (Mbps)	780.00	RAND
(5) Average Speed in 5.9 GHz of 45 MHz band (Mbps)	468.00	45/75*(4)
(6) Speed with 5.9 GHz with an increase of 45 MHz band (Mbps)	173.85	(5) * (3)
(7) Traffic through the 5.9 GHz Channel	60.00%	Modified assumption based on RAND data; the remaining 20% goes through 2.4 GHz and 20% through low 5 GHz band
(8) Average speed of weighted average (Mbps)	143.91	(6) * (7) + (1-(7)) * (1)
(9) Increase in Wi-Fi Speed (Mbps)	44.91	(8)-(1)
(10) Share of Home Traffic that goes through Wi-Fi	51.58%	CISCO Estimation for 2022
(11) Households that have connections over 150 Mbps	50.00%	Assumption based on estimation of table 3-3
(12) Increase in broadband speed (Mbps)	11.58	(9) * (10)*(11)
(13) Fixed Broadband Speed (at end user device) without Wi-Fi speed improvement (Mbps)	280.32	Estimation for 4Q 2022
(14) Impact speed on GDP	0.73%	Regression model coefficient
(15) Impact on GDP	0.03%	(12)/(13)*(14)
(16) GDP (US$ Billion)	$23,875	IMF Estimation for 2022
(17) Impact (US$ Billions)	$7.201	(15) * (16)

Source: Telecom Advisory Services analysis

[38] Cisco VNI (2018). *Complete Forecast Highlights: United States.*

Importantly, if the new band accommodates more Wi-Fi traffic resulting from higher efficiencies in handling, and the number of households undergoing a speed bottleneck at the CPE increase, the economic value would be higher (see scenarios in Table 3-5).

Table 3-5. Return to Speed scenarios from 45 MHz in 5.9 GHz unlicensed (in $ Billion) (2022)

Percentage of households with broadband service > 150 Mbps	Wi-Fi traffic split between 2.4 GHz/5.0 GHz bands versus 5.9 GHz band			
	50/50	**40/60**	**30/70**	**20/80**
50%	$ 6.001	$ 7.201	$ 8.402	$ 9.602
55%	$ 6.601	$ 7.922	$ 9.242	$ 10.562
60%	$ 7.201	$ 8.642	$ 10.082	$ 11.522
65%	$ 7.802	$ 9.362	$ 10.922	$ 12.482
70%	$ 8.402	$ 10.082	$ 11.762	$ 13.443
75%	$ 9.002	$ 10.802	$ 12.602	$ 14.403

Source: Telecom Advisory Services analysis

While the return to speed effect according to the baseline scenario in 2022 is $7.201 billion, given the rate at which broadband speeds are growing and the capacity of 160 MHz in the 5 GHz band to handle Wi-Fi traffic in a more efficient fashion than in the 2.4 GHz band, the upside scenario of $14.403 is possible. The more likely evolution is a shift in Wi-Fi traffic split as a result of increasing use of content-heavy applications. But it is also possible that we will see an increase beyond 50% in the percentage of households acquiring broadband service equal to or higher than 150 Mbps, although we recognize this is more speculative.

After 2022, the annual GDP impact of assigning 45 MHz in the 5.9 GHz band will be driven by three trends:

- Assuming the introduction of Low Power Indoor devices in the 1,200 GHz, the share of traffic routed through 2.4 GHz radios and 5 GHz radios in tri-band routers will start to decline as more traffic will be routed through higher performance 6 GHz radios;
- The overall share of home-originated Wi-Fi traffic will be increasing; and
- The number of US households acquiring 150 Mbps broadband service will be increasing.

These trends will be affecting the annual contribution to faster speeds resulting from the 45 MHz in 5.9 GHz as follows (see Table 3-6).

Table 3-6. Return to Speed Effect from 45 MHz in 5.9 GHz unlicensed (2022-2025)

	2022	2023	2024	2025	Total
(1) Wi-Fi Speed (Mbps) with current spectrum assigned	99.00	110.00	124.64	141.22	
(2) Average Speed at the router of current spectrum (Mbps)	266.50	266.50	266.50	266.50	
(3) Ratio of speed delivered versus router throughput	37.15%	41.28%	46.77%	52.99%	
(4) Average Speed in 5.9 GHz of 75 MHz band (Mbps)	780.00	780.00	780.00	780.00	
(5) Average Speed in 5.9 GHz of 45 MHz band (Mbps)	468.00	468.00	468.00	468.00	
(6) Speed in 5.9 GHz with an increase of 45 MHz band (Mbps)	173.85	193.17	218.88	248.00	
(7) Traffic through the 5.9 GHz channel	60.00%	40.00%	40.00%	40.00%	
(8) Average speed of weighted average (Mbps)	143.91	143.27	162.33	183.93	
(9) Increase in Wi-Fi Speed (Mbps)	44.91	33.27	37.70	42.71	
(10) Share of Home Traffic that goes through Wi-Fi	51.58%	54.09%	56.57%	59.03%	
(11) Households that have connections over 150 Mbps	50.00%	57.24%	65.52%	75.00%	
(12) Increase in broadband speed (Mbps)	11.58	10.30	13.97	18.91	
(13) Fixed Broadband Speed (at end user device) without Wi-Fi speed improvement (Mbps)	280.32	371.57	492.53	652.87	
(14) Impact speed on GDP	0.73%	0.73%	0.73%	0.73%	
(15) Impact on GDP	0.03%	0.02%	0.02%	0.02%	
(16) GDP Billion US$	$ 23,875	$ 24,671	$ 25,493	$ 26,342	
(17) Impact (US$ Billions)	$ 7.201	$ 4.992	$ 5.279	$ 5.569	$ 23.042

NOTE: Traffic split is as follows: 2022: 20% 2.4 GHz, 20% 5.0 GHz, 60%, 5.9 GHz; 2023: 20% 2.4 GHz, 20% 5.0 GHz, 40% 5.9 GHz, and 20% 6 GHz; 2024: 15% 2.4 GHz, 15% 5.0 GHz, 40% 5.9 GHz, and 30% 6 GHz; 2025: 10% 2.4 GHz, 10% 5.0 GHz, 40% 5.9 GHz, and 40% 6 GHz.

Source: Telecom Advisory Services analysis

Total GDP contribution of the 45 MHz in the 5.9 GHz band between 2022 and 2025 will reach $23.04 billion. The drop in annual contribution between 2022 and the subsequent years will be compensated by the incremental impact of Low Power Indoor usage in the 6 GHz band, which is estimated in section 4.1.

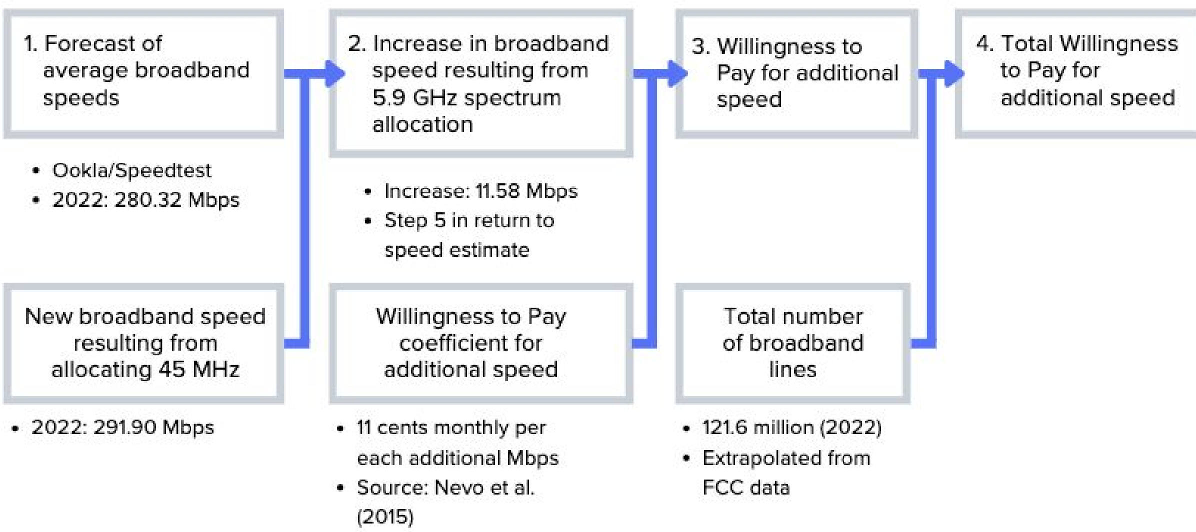
3.2.2. Estimating consumer surplus

The NPRM does not expressly mention the increase in consumer surplus triggered by allocating 45 MHz to unlicensed use. However, as shown above, this move will have a net positive effect in terms of increased router throughput and therefore, average broadband speed. To reiterate, the consumer surplus to be estimated in this case should not be part of the GDP contribution but can be considered as part of the aggregate economic value.

Methodology

The key objective is to estimate the increase in consumers' willingness to pay derived from the acceleration in average broadband speeds resulting from the allocation of an additional 45 MHz in the 5.9 GHz band to unlicensed spectrum. The approach to estimate consumer surplus relies on the same calculations presented above in terms of the increase in Wi-Fi speed but factors them in terms of incremental wireless speed and the consequent impact on willingness to pay (see Figure 3-3).

Figure 3-3. Methodology for estimating Consumer Surplus from 45 MHz in 5.9 GHz unlicensed



Source: Telecom Advisory Services

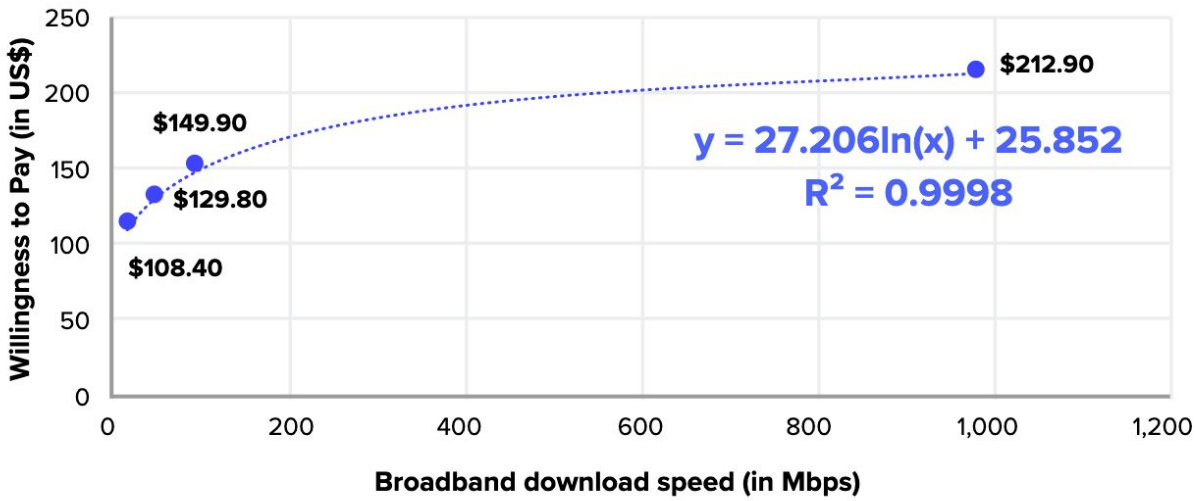
As calculated based on the broadband speed compiled by Ookla/Speedtest, the expected average broadband speed in 2022 in the United States will be 280.32 Mbps. By addressing the bottleneck for users acquiring service in excess of 150 Mbps, average speed will increase to 291.90 Mbps, which results in a net increase in speed of 11.58 Mbps (calculated in Step 5 in the methodology for estimating the return to speed in section 3.2.1).

The next step is to estimate what consumers would be willing to pay for the additional speed. As in the case of RAND, the analysis conducted for this study relies on the data specifying the relationship between speed and consumer surplus generated in the Nevo et al. (2016) study.[39] This research provides empirical evidence for the United States stating that consumers' willingness to pay (WTP) to improve broadband speed by 1 Mbps ranges from nearly zero to just over US $5.00. The range is determined by heterogeneity in WTP, although the average value is US $2.02, and the median is US $2.48.

[39] Nevo, A., Turner, J., and Williams, J. (Mar. 2016). "Usage-based pricing and demand for residential broadband", *Econometrica*, vol. 84, No.2, p. 441-443.

Furthermore, the study also indicates that the higher speed does indeed generate substantial surplus. However, due to a declining marginal value of speed, speeds of more than 10 times those offered by the typical broadband plans imply only 1.5 times the surplus.[40] The data provided in the Nevo et al. (2016) study allows estimating a log curve depicting the relationship between willingness to pay and speed (see Graphic 3-3).

Graphic 3-3. Log Curve of relationship between broadband speed and willingness to pay (based on Nevo et al., 2016)



Note: Based on data points of table VII and table VI of Nevo et al., 2016.
Source: Nevo et al.(2016); Telecom Advisory Services analysis

According to the data of the Graphic 3-3, an increase in speed from 92.50 Mbps to 977.90 Mbps (ten times) increases willingness to pay from $149.90 to $212.90 (close to 1.5 times). The equation linking speed to consumer surplus was then used to estimate the value to be derived by faster download speeds enabled by the newly assigned 45 MHz of the 5.9 GHz band to unlicensed use. For this purpose, the difference between average download speed enabled by 5.9 GHz and current average download speed as increased annually at the current growth rate was multiplied by the coefficient of the log curve as depicted in the Graphic 3-3 (Step 3). This results in an additional $1.10 per month (or $13.22 per year). Estimating, based on FCC data that by 2022, the number of broadband subscribers acquiring service in excess of 150 Mbps will rise to 121.6 million, the total consumer surplus is calculated (Step 4).

[40] This finding is consistent with the evidence provided in Liu et al. (2017), who found that the shape of households' valuation of broadband speed is concave. "Households are willing to pay about $2.34 per Mbps ($14 total) monthly to increase bandwidth from 4 Mbps to 10 Mbps, $1.57 per Mbps ($24) to increase from 10 to 25 Mbps, and only $0.02 per Mbps ($19) for an increase from 100 Mbps to 1000 Mbps."

Results

As mentioned before, the results have been estimated for 2022. The baseline scenario is based on the same two assumptions as before:

- Wi-Fi traffic routing is 20% to the 2.4 GHz band, 20% to the 5.0 GHz band, and 60% to the 5.9 GHz band; and
- Number of households undergoing a speed bottleneck at the CPE (50.00 % of total households with broadband service[41]).

Under these two assumptions the consumer surplus impact would be $1.608 billion in 2022 (see results and calculations in Table 3-7).

Table 3-7. Consumer Surplus from 45 MHz in5.9 GHz unlicensed (2022)

	Data	Source
(1) Average 2022 Fixed Broadband Download Speed (at end user device)	280.32	Estimation for 4Q 2022 based on Ookla/Speedtest
(2) Increase in broadband inside the house as a result of relieving the Wi-Fi bottleneck (Mbps)	11.58	Line 12 in table 3-4
(3) New Average Fixed Broadband Download Speed	291.90	(1) + (2)
(4) Willingness to Pay for average download speed	179.18	Equation in graphic 3-2
(5) New Willingness to Pay for average download speed	180.28	Equation in graphic 3-2
(6) Additional Monthly Consumer surplus	$1.10	(5) - (4)
(7) Additional Yearly Consumer Surplus	$13.22	(6) * 12
(8) Fixed Broadband Connections (Millions)	121.62	Estimation using FCC historical data
(9) Impact (USD Millions)	$1,608	(7)*(8)

Source: Telecom Advisory Services analysis

The increase of the average household in consumer surplus is $13.22 (the households with bottleneck will have an increase higher than that, but the households with no bottleneck will have $0); this is the value multiplied by the total number of connections.[42]

As with the impact on GDP described above, if the new band accommodates more Wi-Fi traffic resulting from higher efficiencies in handling, and the number of households undergoing a speed bottleneck at the CPE increases, the economic value would be higher (see scenarios in Table 3-8).

[41] In Table 3-3 we estimate that by 2022, 76.88% of total households will have more than 100 Mbps. Based on that, we assume that 50% of the total connections will be equal or higher than 150 Mbps.
[42] In Table 3-4 we indicate that the increase in speed of 11.58 Mbps will be for all households on average.

Table 3-8. Consumer surplus scenarios from 45 MHz in 5.9 GHz unlicensed (in $ Billion) (2022)

Percentage of households with broadband service > 150 Mbps	Wi-Fi traffic split between 2.4 GHz/5.0 GHz bands versus 5.9 GHz band			
	50/50	40/60	30/70	20/80
50%	$ 1.344	$ 1.608	$ 1.869	$ 2.129
55%	$ 1.476	$ 1.765	$ 2.051	$ 2.336
60%	$ 1.608	$ 1.921	$ 2.233	$ 2.542
65%	$ 1.739	$ 2.077	$ 2.413	$ 2.746
70%	$ 1.869	$ 2.233	$ 2.593	$ 2.950
75%	$ 1.999	$ 2.388	$ 2.772	$ 3.153

Source: Telecom Advisory Services analysis

While the consumer surplus effect according to the baseline scenario is $1.608 billion, given the rate at which broadband speeds are growing and the capacity of 160 MHz in 5GHz to handle Wi-Fi traffic in a more efficient fashion than 2.4 GHz, the upside scenario of $3.153 is also likely.

As in the case of the return to speed analyzed above, the annual consumer surplus generated by faster Wi-Fi will also be influenced by the same trends that evolve after 2022. These trends will be affecting the annual contribution to faster speeds resulting from the 45 MHz in 5.9 GHz as follows (see Table 3-9).

Table 3-9. Consumer Surplus from 45 MHz in 5.9 GHz unlicensed (2022-2025)

	2022	2023	2024	2025	Total
(1) Average 2022 Fixed Broadband Download Speed (at end user device)	280.32	371.57	492.53	652.87	
(2) New Average Download Speed	291.90	381.87	506.50	671.78	
(3) Willingness to Pay for average download speed	179.18	186.85	194.52	202.18	
(4) New Willingness to Pay for average download speed	180.28	187.59	195.28	202.96	
(5) Additional Monthly Consumer surplus	$1.10	$0.74	$0.76	$0.78	
(6) Additional Yearly Consumer Surplus	$13.22	$8.93	$9.13	$9.32	
(7) Fixed Broadband Connections (Millions)	121.62	124.49	127.44	130.45	
(8) Impact (USD Millions)	$1,608	$1,111	$1,164	$1,216	$ 5,098

Source: Telecom Advisory Services analysis

Total consumer surplus associated with the 45 MHz in the 5.9 GHz band between 2022 and 2025 will reach $5.098 billion. As in the case of return to speed, the drop in consumer surplus between 2022 and the subsequent years will be compensated by the incremental impact of surplus derived from Low Power Indoor usage in the 6 GHz band, which is estimated in section 4.2.

3.2.3. Estimating producer surplus derived from Wi-Fi equipment sales

Beyond the consumer surplus estimated above, another dimension of economic surplus is based on the margin captured by US manufacturers of equipment enabled by the 45 MHz in 5.9 GHz and the 6 GHz spectrum that is sold in the US market[43]. Such products include the following (see Table 3-10):

Table 3-10. Locally Manufactured Wi-Fi enabled equipment

Market segment	Equipment
Consumer and SOHO	• Pure access points (802.11n (Dual Band), 802.11n/802.11ac, 802.11ad (WGIG), 802.11ac/802ad (dual band), 802.11n/802.11ac/802.11ac (tri-band) • PC Cards, USB adapters, PCI adapters
Enterprise	• Independent access points (802.11n (Dual Band), 802.11n/802.11ac, 802.11ad (WGIG), 802.11ac/802.11ad (dual band), 802.11n/802.11ac/802.11ad (tri-band), 11ax, 11ax/802.11ad, 11ah)

Source: ABI Research

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus.

We are cognizant that some of these products are already being sold under the current unlicensed spectrum assignment. However, since our estimates start in 2020, it is fair to assume that revenues (and gross profits) will be driven by future spectrum allocations. Furthermore, the estimates are based only on the incremental revenues generated after accounting for the natural increase in equipment sales growth. In other words, part of the revenues generated by Wi-Fi equipment is not due to the new spectrum proposals but resulting from prior spectrum allocations.

Once the list of equipment is defined, we compiled statistics on US shipments of US manufactured equipment. With these statistics, we calculate average retail value and gross margins. The margin represents producer surplus.

Results

Revenues for US manufacturers generated from selling equipment operating within the enhanced 5 GHz band between 2020[44] and 2022 is expected to reach $318 million in the consumer/SOHO market and $1,269 million in the enterprise market in the United States. The difference between both markets results from the fact that US manufacturers have a much stronger market position in the enterprise segment than in the consumer segment (see Tables 3-11 and 3-12).

[43] We exclude the surplus of foreign based manufacturers because that should be attributed to economies out of the US. Similarly, the surplus generated by US manufacturers on their sales abroad is also excluded because it is dependent on unlicensed spectrum rules enacted overseas.

[44] It is assumed that equipment sales start taking place as soon as spectrum changes are enacted. Without changes in spectrum rules, equipment sales are assumed to remain flat, driven primarily by replacement rate and natural increase in Wi-Fi households.

Table 3-11. Revenues from 5.9 GHz Consumer and SOHO enabled equipment sales

	2020	2021	2022	Total	Sources
(1) Total Consumer Access Point	47.8	48.7	48.7		ABI Research
(2) Band 5.9 GHz Consumer Access Point	46.7	47.4	48.4		ABI Research
(3) Share of Band 5.9 GHz Consumer Access Point	97.55%	97.26%	99.38%		(2)/(1)
(4) Total North America Revenue for Consumer Access Point	3,175.8	3,135.7	3,060.9		ABI Research
(5) Share of Revenue from US market	89.70%	89.70%	89.70%		Pop USA/Pop N.A.
(6) Total US Revenue for Consumer Access Point, with 5.9 GHz Capability	2,778.9	2,735.7	2,728.5		(3)*(4)*(5)
(7) Revenue from Consumer Access Point due to 5.9 GHz changes	684.5	641.3	634.1		Increase of (6) in relation with 2017 value
(8) Total revenues due to 5.9 GHz between 2020 and 2022 for Consumer Access Point (US$ Million)				$ 1,960	
(9) Revenue generated in US for US manufacturers of Consumer Access Point (US$ Million)				$ 318	

Sources: ABI Research. Wireless Connectivity Technology Segmentation Addressable Markets, 1Q2018. Telecom Advisory Services analysis

Table 3-12. Revenues from 5.9 GHz Enterprise enabled equipment sales (2020-2022)

	2020	2021	2022	Total	Sources
(1) Total Consumer Access Point	5.202	5.153	4.958		ABI Research
(2) Band 5.9 GHz Consumer Access Point	5.160	5.135	4.958		ABI Research
(3) Share of Band 5.9 GHz Consumer Access Point	99.19%	99.65%	100.00%		(2)/(1)
(4) Total North America Revenue for Consumer Access Point	2,110.7	2,215.7	2,287.4		ABI Research
(5) Share of Revenue from US market	89.70%	89.70%	89.70%		Pop USA/Pop N.A.
(6) Total US Revenue for Consumer Access Point, with 5.9 GHz Capability	1,877.9	1,980.5	2,051.7		(3)*(4)*(5)
(7) Revenue from Consumer Access Point due to 5.9 GHz changes	415.2	517.8	589.0		Increase of (6) in relation with 2017 value
(8) Total revenues due to 5.9 GHz between 2020 and 2022 for Enterprise equipment (US$ Million)				$ 1,522	
(9) Revenue generated in US for US manufacturers of Enterprise equipment (US$ Million)				$ 1,269	

Sources: ABI Research. Wireless Connectivity Technology Segmentation Addressable Markets, 1Q2018. Telecom Advisory Services analysis

In the absence of forecast data beyond 2022, we extrapolated the growth between 2020 and 2022 through 2025 (see Table 3-13).

Table 3-13. US Revenues from 5.9 GHz and 6 GHz enabled equipment sales

		2020	2021	2022	2023	2024	2025	Total
Total sales	**Consumer**	$ 684	$ 641	$ 634	- - -	- - -	- - -	- - -
	Enterprise	$ 415	$ 518	$ 589	- - -	- - -	- - -	- - -
	Total	$ 1,100	$ 1,159	$ 1,223	$ 1,290	$ 1,360	$ 1,435	$ 7,567
US Manufacturers	**Consumer**	$ 111	$ 104	$ 103	- - -	- - -	- - -	- - -
	Enterprise	$ 346	$ 432	$ 491	- - -	- - -	- - -	- - -
	Total	$ 457	$ 536	$ 594	$ 677	$ 772	$ 879	$ 3,915

Sources: ABI Research. Wireless Connectivity Technology Segmentation Addressable Markets, 1Q2018. Telecom Advisory Services analysis

Of this amount, we calculate the manufacturer gross profit by using the prorated margin estimated by CSI markets of 39.44%.[45] This yields a producer surplus for US manufacturers of these particular products of $1,544 million.

3.2.4. Estimating CAPEX savings generated from traffic off-loading

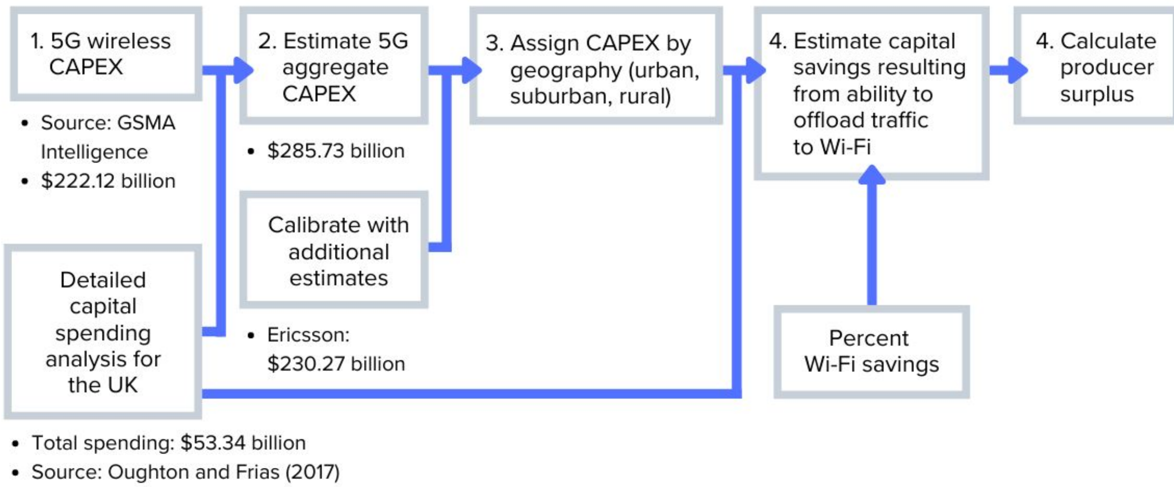
Following the observations in the RAND study, we opted to develop an estimation of cellular operator savings in CAPEX resulting from the additional Wi-Fi off-loading capacity offered by 45 MHz in the 5.9 GHz band. 5G networks promise faster speeds, lower latency, and greater capacity to mobile users. However, 5G network operators cannot deliver on that promise without robust Wi-Fi networks to carry the majority of that traffic. Cisco estimates that 71% of 5G mobile traffic will be offloaded to Wi-Fi by 2022, even more offload than we have seen from lower speed networks in the past. The availability of 160 MHz in the 5GHz band is particularly suited to accommodate that.

Methodology

The key objective is to estimate the savings in capital investment as a result of an increase in traffic offloading with Wi-Fi benefits from the additional 45 MHz, but more importantly, the ability to leverage 160 MHz within a single contiguous channel (see Figure 3-4).

[45] This is based on the estimation of the gross margin for the communications equipment industry in 2019. CSI Market Inc., *Industry Profitability Ratios*, https://csimarket.com/Industry/industry_Profitability_Ratios.php?ind=1012.

Figure 3-4. Methodology for estimating CAPEX savings



Source: Telecom Advisory Services

The analysis starts with an estimate of 5G deployment costs, absent the Wi-Fi offloading benefit. One approach (Step 1) is to sum wireless CAPEX estimated by GSMA Intelligence for the United States between 2019 and 2025: $222.12 billion.[46] As an alternative approach, we rely on the only known rigorous cost estimation of 5G deployment to date: the one developed by Oughton and Frias (2016) for OFCOM in the United Kingdom. The authors' baseline case estimates a CAPEX of $53.34 million, of which urban coverage investment amounts only to $890 million, while suburban deployment demands $7.13 billion, and rural coverage $45.32 billion (see Table 3-14).

Table 3-14. United Kingdom: 5G Investment

	Town/City Population (Million)	Population distribution	5G CAPEX ($ billion)	5G CAPEX (%)	CAPEX per POP
Urban (cities >1 million)	19.4184	29%	$0.89	1.66%	$45.71
Suburban	36.1584	54%	$7.13	13.37%	$197.16
Rural	11.3832	17%	$45.32	84.97%	$3,981.22
Total	66.96	100%	$53.34	100%	$796.58

Source: Oughton and Frias (2017). Exploring the cost, coverage and rollout implications of 5G in Britain; Telecom Advisory Services analysis

Using capital investment per POP as a starting point (which does not include spectrum acquisition costs), deployment costs for networks aimed at providing 5G services in the United States are calculated (Step 2).

[46] By 2025, GSMA Intelligence estimates that 5G coverage would have reached 88%.

Table 3-15. United States: 5G Investment

	Town/City Population (Million)	Population distribution	5G CAPEX ($ billion)	5G CAPEX (%)	CAPEX per POP
Urban (cities >1 million)	88.34	27%	$4.04	1.41%	$45.71
Suburban	173.42	53%	$34.19	11.97%	$197.16
Rural	62.17	19%	$247.50	86.62%	$3,981.22
Total	327.20	99%	$285.73	100%	$796.58

Source: Oughton and Frias (2017). Exploring the cost, coverage and rollout implications of 5G in Britain; Telecom Advisory Services analysis

However, considering the other two estimates of 5G investment that were developed and breaking them down by geography, we downward adjusted the CAPEX estimate (Step 3).

Table 3-16. United States: 5G Investment (in US$ billion)

	Oughton and Frias	Ericsson	GSMA
Urban (cities >1 million)	$ 4.04	$ 3.25	$ 3.13
Suburban	$ 34.19	$ 27.56	$ 26.58
Rural	$ 247.50	$ 199.46	$ 192.40
Total	$ 285.73	$ 230.27	$ 222.12

Source: Telecom Advisory Services analysis

Considering the cost decomposition of Oughton and Frias (2016), as well as that of the other estimates, the 5G investment under an exclusive licensed spectrum framework will remain significant for suburban ($26.58 billion) and rural ($192.40 billion) areas. In this context, unlicensed spectrum becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands. A comparative analysis of CAPEX for 5G base station of pico cell vs. carrier grade Wi-Fi hotspot indicates a cost advantage of the latter amounting to 81%.[47] It should be noted that the Wi-Fi advantage in hybrid networks becomes even more relevant under the 6 GHz spectrum given the hot-spot capacity to handle large volumes of traffic.

The estimation of CAPEX savings is based on the GSMA Intelligence aggregate CAPEX estimate of $222.12 billion. By relying on the geographic disaggregation of Oughton and Frias and Ericsson, we estimate that the total CAPEX will be split as follows: $3.13 billion in urban areas, $26.58 billion in suburban settings, and $192.40 billion in rural geographies. We conservatively assume that Wi-Fi will not be critical in sustaining investment in urban areas, but that it will play a significant role in suburban and rural geographies. Based on the cost advantage of carrier grade Wi-Fi, we assume that it will

[47] Nikolikj, V. and Janevski, T. (2014). "A Cost Modeling of High-Capacity LTE-Advanced and IEEE 802.11ac based Heterogeneous Networks, Deployed in the 700 MHz, 2.6 GHz and 5 GHz Bands," *Procedia Computer Science* 40 (2014) 49-56.

become effective for a portion of the suburban (approximately 15%) and rural network (approximately 5%) deployment. Therefore, using the GSMA estimation of $26.58 billion for suburban coverage and $192.40 billion for rural coverage, the implementation of Wi-Fi hotspots leveraging the 160 MHz in 5 GHz, complemented with 6 GHz, will yield CAPEX savings of $13.60 billion.[48] These will be critical in terms of allowing carriers to extend their 5G coverage further into rural geographies.

For purposes of building a consolidated estimate of economic value, it is assumed that cellular carrier CAPEX savings are already accounted in GDP impact of broadband speed.

3.2.5. Conclusion

The estimation of economic value of assigning 45 MHz in the 5.9 GHz band to unlicensed use was structured around four sources. Combining those GDP estimates with the estimated consumer and producer surplus, but excluding CAPEX savings figures, total economic value is estimated at $29.68 billion (see Table 3-17).

Table 3-17. Total Economic Value Resulting from allocating 45 MHz in the 5.9 GHz band to Unlicensed Use (in $ billion)

Source of Economic Value	2020	2021	2022	2023	2024	2025	Total
1. Increase in GDP from faster broadband speed	$0.000	$0.000	$7.201	$4.992	$5.279	$5.569	$23.042
2. Consumer surplus from faster broadband speed	$0.000	$0.000	$1.608	$1.111	$1.164	$1.216	$5.098
3. Producer surplus from equipment enabled by 160 MHz channel	$0.180	$0.211	$0.234	$0.267	$0.304	$0.347	$1.544
TOTAL ECONOMIC VALUE	$0.180	$0.211	$9.043	$6.370	$6.747	$7.132	$29.684
CAPEX savings by traffic off-loading (*)	$0.000	$2.720	$2.720	$2.720	$2.720	$2.720	$13.600

(*) Effect already included in GDP impact of line (1), so excluded from total to avoid double counting
Source: Telecom Advisory Services analysis

It should be noted that the growth in economic value over time is reflective of gradual impact of spectrum proposals. Initially, the only value is generated by the margin of Wi-Fi equipment sales. Over time, cellular carriers will benefit from CAPEX savings in their 5G deployment, while the economy and consumers will benefit from faster broadband speed.

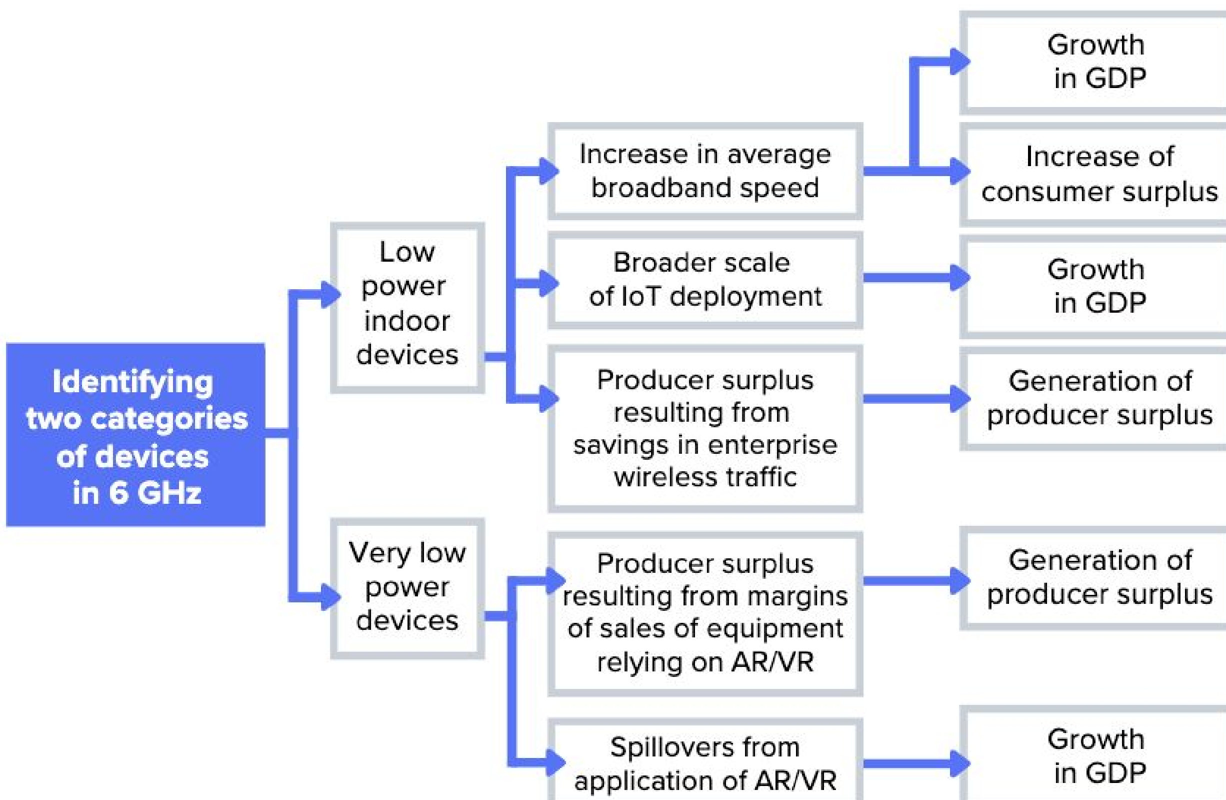
[48] An additional contribution could include Wi-Fi-like service operating within AFC channels.

4. ASSESSMENT OF ECONOMIC BENEFITS DERIVED FROM MAKING THE 6 GHz BAND AVAILABLE TO UNLICENSED USE

When 6 GHz is opened up and added to the existing unlicensed bands in 2.4 GHz and 5 GHz, the combined spectrum will be able to support eight 160 MHz channels or three 320 MHz channels, which will be a source of additional economic value. The first effect will result in the enabling of faster home broadband speeds beyond the levels achieved by the assignment of 45 MHz in the 5.9 GHz band. Moreover, the addition of channels in 6 GHz will enable providers to deliver the fast next-generation speeds to businesses, industrial facilities, hospitals, ports, railyards, and airports across the country. The estimation of economic value in this domain will focus around the new applications and use cases.

The economic value derived from the creation of two categories of low power devices (Low Power Indoor and Very Low Power) operating in the 6 GHz band will be structured around two types of effects (see Figure 4-1).

Figure 4-1. Economic value to be generated by creating two categories of devices in the 6 GHz band



Source: Telecom Advisory Services analysis

The creation of the Low Power Indoor device categories, the first category as suggested in the NPRM, will drive the development of three sources of economic value. In the first place, the 6 GHz band (jointly with the pre-existing unlicensed spectrum) will allow supporting eight 160 MHz channels, or three 320 MHz channels. This capacity will allow further increase in Wi-Fi speed and capacity. The assignment of 45 MHz in 5.9 GHz will alleviate the bottleneck effect at the customer premise but, as expected, broadband speeds will continue to grow over time, which will in turn require additional unlicensed spectrum to address any resource constraints. By the end of 2025, the average broadband speed will reach 653 Mbps, and peak speed will greatly exceed 1 Gbps. In this context, the additional channels at 6 GHz will represent an adequate answer to enable further growth in total device speed. 6 GHz will enable a router with tri-band configuration (2.4 GHz, 5 GHz, and 6 GHz), to deliver 1.2 Gbps on 2.4 GHz, 4.8 Gbps on one 5 GHz radio, 4.8 Gbps on the other 5 GHz radio, and 2.2 Gbps on the 6 GHz channel. In sum, once consumers have 6 GHz, there should be no difference between what they get from a computer plugged into a fiber port and a Wi-Fi 6E signal in their home. This will yield a return to speed and consumer surplus beyond that what was calculated for the 45 MHz in 5.9 GHz in sections 3.2.1. and 3.2.2.

In addition, the assignment of 1,200 MHz in the 6 GHz band will result in a broader scale IoT deployment. While IoT roll-out has already been proceeding for a number of years, large scale deployment has suffered from the risk of congestion. Along those lines, the additional unlicensed spectrum recommended in the NPRM will mitigate congestion and, therefore, provide a boost to the growth of IoT. As research has shown, the use cases associated with IoT (such as predictive maintenance, asset tracking, smart grid demand management, traffic coordination, and the like) has an impact on GDP growth. The increase in unlicensed channel capacity enables more extensive delivery of ubiquitous, high throughput wireless connectivity across multiple access points in business facilities, such as industrial plants, enterprise campus, and the like. This will allow firms to leverage Wi-Fi infrastructure and generate further savings in the use of wideband wireless communications.

At the same time, the creation of a Very Low Power device category will enable the deployment of a new generation of AR/VR solutions, with two sources of economic value. First, the growth of firms producing AR/VR hardware, software and content will result in new revenues, which when considering the implicit margins, will lead to new producer surplus. Secondly, as research at the use case level indicates, the new AR/VR applications will drive a spillover impact on productivity, with the consequent growth of GDP.

The following chapter presents methodologies and results for measuring the economic value associated with each of these five impact areas. We believe that the creation of these two new device categories will drive other effects beyond the five that are being analyzed in this paper (such as enhanced indoor home connectivity and higher quality video streaming). However, these effects have been already quantified in the impact on consumer surplus resulting from additional speed discussed in section 3.2.2.

4.1. Further return to speed yielded by 6 GHz spectrum

As estimated in section 3.2.1, the allocation of 45 MHz in the 5.9 GHz band yielded an increase of Wi-Fi speed from 99 Mbps to 143.91 Mbps. This, in turn, allowed for an increase in average broadband speed of 11.58 Mbps, which resulted in a total GDP impact between 2022 and 2025 of $23.042 billion. Beyond 2022, and consistent with the roll-out of faster broadband offerings, the average broadband speed will continue to increase, reaching 652.87 Mbps by 2025. By extrapolating the growth of households, we estimate that 75% of all households will be acquiring more than 150 Mbps service by 2025.

At this point, tri-band routers operating within 2.4 GHz, 5 GHz and 6 GHz will become critical to accommodate the increase in the number of devices and their usage. The 6 GHz average speeds will be close to the peak speeds (~2.2 Gbps). A single 160 MHz channel will be provided to a single user because there are enough 160 MHz channels to deliver to each class of client devices (e.g., smart phones, TVs, computers, cameras). In short, 6 GHz will drive single user throughput from 200-600 Mbps to 2.2 Gbps. However, it is important to mention that while some devices will benefit from this speed, other ones routed through the 2.4 GHz band will share into 1.2 Gbps speed. Accordingly, we have assumed that out of the total capacity required in the household, in 2023 (the first year where tri-band routers will be adopted in significant quantities) 40% will still be routed through the 2.4 GHz and 5.0 bands (20% each), 40% through the 5.9 GHz band, and 20% through the 6 GHz band. This routing pattern will shift over time reaching 10% in 2.4 GHz, 10% in 5 GHz, 40% in 5.9 GHz and 40% in 6 GHz in 2025. We recognize that the performance at the devices receiving traffic in the 6 GHz channel will be 2.2 Gbps.

These two drivers—the increase in average fixed broadband speed and the higher performance of Wi-Fi routers—will result in an additional return to speed, with the consequent contribution to GDP (see Table 4-1).

Table 4-1. Return to Speed Effect from Low Power Indoor Devices in 6 GHz

	2023	2024	2025	Sources
(1) Wi-Fi Speed (Mbps)	110.00	124.64	141.22	CISCO Estimation for each year
(2) Average Speed of current routers (Mbps)	266.50	266.50	266.50	RAND
(3) Ratio between Wi-Fi speed delivered/Average Router throughput	41.28%	46.77%	52.99%	(1)/(2)
(4) Max Speed in 2.4 GHz Channel (Mbps)	1228.80	1228.80	1228.80	See note[49]
(5) Max Speed in 6 GHz Channel (Mbps)	2252.80	2252.80	2252.80	See note[50]
(6) Speed in 6 GHz band (Mbps)	201.67	228.50	258.91	(5)/(4)*(2)*(3)
(7) Traffic through the 6 GHz Channel	20.00%	30.00%	40.00%	Assumption based on amount of traffic going through 6 GHz channel
(8) Average speed of weighted average (Mbps)	128.33	155.80	188.30	(6)*(7)+(1-(7))*(1)
(9) Increase in Wi-Fi Speed (Mbps)	18.33	31.16	47.07	(8)-(1)
(10) Share of Home Traffic that goes through Wi-Fi	54.09%	56.57%	59.03%	CISCO Estimation for each year
(11) Households that have connections over 150 Mbps	57.24%	65.52%	75.00%	Assumption based on FCC data
(12) Increase in broadband speed (Mbps)	5.68	11.55	20.84	(9)*(10)*(11)
(13) Fixed Broadband Speed (Mbps)	371.57	492.53	652.87	Estimation for 4Q of each year
(14) Impact speed on GDP	0.73%	0.73%	0.73%	Regression model coefficient
(15) Impact on GDP	0.01%	0.02%	0.02%	(12)/(13)*(14)
(16) GDP (US$ Billion)	$ 24,671	$ 25,493	$ 26,342	IMF Estimation for each year
(17) Impact (US$ Billions)	$ 2.751	$ 4.364	$ 6.138	(15)*(16)

Source: Telecom Advisory Services analysis

Assuming that the GDP contribution generated by faster broadband speeds enabled by 6 GHz will start to materialize in 2023, the total value between 2023 and 2025 will reach US $13.253 billion.

4.2 Additional consumer surplus resulting from 6 GHz unlicensed spectrum

Following the same set of assumptions, faster speeds enabled by 6 GHz will generate consumer surplus beyond that one created by the assignment of 45 MHz in the 5.9 GHz

[49] In order to convert from Gbps to Mbps, we multiply 1.2 Gbps (see paragraph above "while some devices will benefit from this speed, other ones routed through the 2.4 GHz band will share into 1.2 Gbps speed") by 1.024 (conversion ratio from Gb to Mb).

[50] In order to convert from Gbps to Mbps we multiply 2.2 Gbps (see paragraph above "We recognize that the performance at the devices receiving traffic in the 6 GHz channel will be 2.2 Gbps.") by 1.024 (conversion ratio from Gb to Mb).

band. The increase in this case is driven the boost in Wi-Fi speed enabled by the new tri-band routers operating in 2.4 GHz, 5 GHz, and 6 GHz (see Table 4-2).

Table 4-2. Consumer Surplus derived from Low Power Indoor Devices in 6 GHz

	2023	2024	2025	Sources
(1) Average Fixed Broadband Download Speed	371.57	492.53	652.87	Estimation for 4Q of each year
(2) New Average Download Speed	377.25	504.08	673.71	(1) + Increase in speed estimated in return to speed (Table 4-1)
(3) Demand for average download speed	186.85	194.52	202.18	Equation in graphic 3-2
(4) New Demand for average download speed	187.26	195.15	203.04	Equation in graphic 3-2
(5) Additional Monthly Consumer surplus	$0.41	$0.63	$0.85	(4)-(3)
(6) Additional Yearly Consumer Surplus	$4.95	$7.57	$10.26	(5) * 12
(7) Fixed Broadband Connections (Millions)	124.49	127.44	130.45	Estimation using FCC historical data
(8) Impact (USD Millions)	$616	$964	$1,338	(6)*(7)

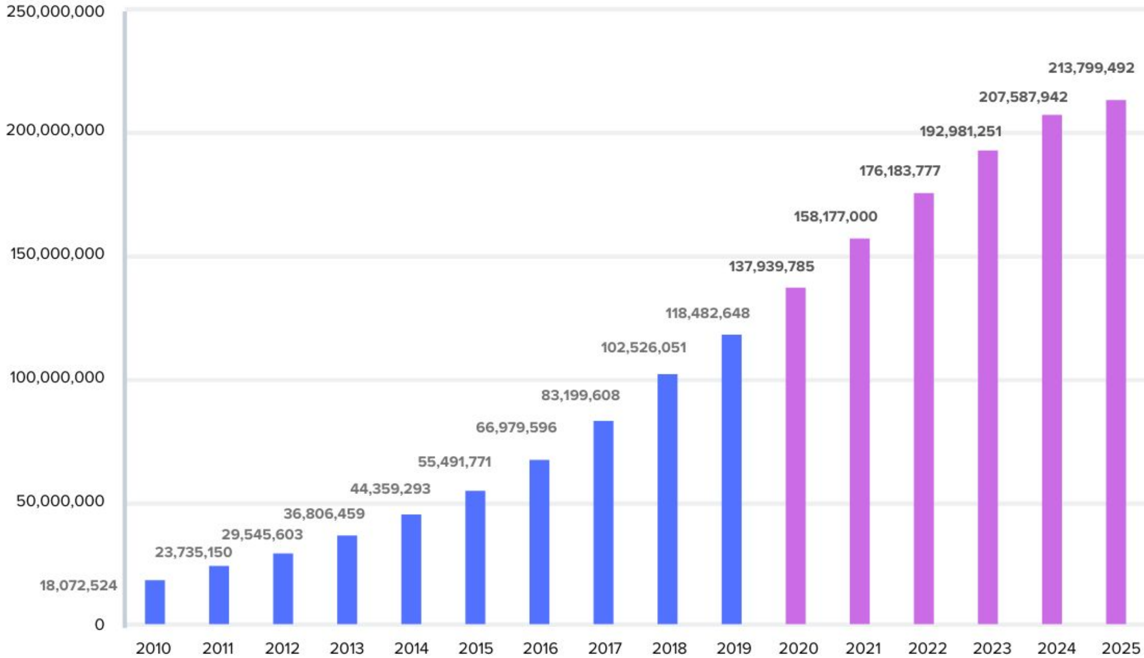
Source: Telecom Advisory Services analysis

Total consumer surplus associated with Low Power Indoor devices between 2023 and 2025 will reach $2.918 billion. As in the case of return to speed, the drop in consumer surplus between 2022 and 2025 derived from the assignment of 45 MHz in 5.9 GHz band will be compensated by the ever-increasing incremental impact of surplus derived from Low Power Indoor usage in the 6 GHz band.

4.3 Broader deployment of IoT

Considering, as mentioned above, that IoT devices have been deployed for a number of years, the economic value estimation of "broader" deployment resulting from the combination of a significant amount of spectrum capacity requires teasing out the impact due to the natural growth of IoT based on the extrapolation of current penetration rates. M2M adoption as a metric of IoT deployment (the only available indicator to measure IoT), has reached an installed base of 118 million in 2019 (see Graphic 4-1).

Graphic 4-1. United States: Installed base of M2M devices (2010-2025)



Source: GSMA Intelligence

Starting with a 2021 installed base of 158,177,000 M2M devices, we estimate the growth that will have taken place between 2020 and 2021 that can be exclusively attributed to the allocation of additional spectrum allocation to indoor Wi-Fi devices (1,808,753). This estimate is calculated based on measuring the difference between the increase of 16.42% and an extrapolation of the trend which would indicate deployment increasing by 15.11%[51] (see Table 4-3).

Table 4-3. United States: Evolution of M2M devices (2020-2025)

	[redacted]					
M2M installed base	137,939,785	158,177,000	176,183,777	192,981,251	207,587,942	213,799,492
Y-o-Y growth rate	16.42%	14.67%	11.38%	9.53%	7.57%	2.99%
Natural growth rate	15.11%	13.36%	10.07%	8.22%	6.26%	1.68%
Growth rate due to 6 GHz	1.31%	1.31%	1.31%	1.31%	1.31%	1.31%
M2M deployment due to 6 GHz	1,808,753	2,074,116	2,310,233	2,530,492	2,722,024	2,803,474

Source: GSMA Intelligence; Telecom Advisory Services analysis

[51] The M2M device installed base time series between 2010 and 2019 indicates a gradual deceleration since 2017. To estimate the future evolution of the natural growth rate, we averaged the forecast growth between 2019 and 2021 and subtracted that value to 2020 growth in installed base (which resulted in 1.31% growth); from that point on, the natural growth was calculated as the difference between the growth in M2M installed base and the increase due to the 6 GHz proposal; thus, while the overall growth in installed base is diminishing, the increase rate in M2M devices due to 6 GHz remains constant.

IoT adoption, measured here through M2M devices, has a contribution to GDP growth through the multiplicity of use cases that improve efficiency in processes such as preventive maintenance, production monitoring and the like. To estimate this, we rely on a coefficient of GDP impact calculated through an aggregate simple production function which estimates that a 10% rise in M2M connections results in annual increases in GDP of between 0.3% and 0.9%.[52]

By relying on the low-end coefficient of the GDP impact contribution (0.3% for each 10% of the installed base), we estimate that in 2021, the impact of IoT would range between 0.02% and 0.04% of GDP. Considering that the US GDP in 2021 will reach $23,096 billion (source: IMF), it is estimated that the IoT impact for 2021 would reach $4.54 billion (see Table 4-4).

Table 4-4. United States: GDP Contribution of IoT Deployment Boost caused by 6 GHz (2020-2025)

	2020	2021	2022	2023	2024	2025
M2M deployment due to 6 GHz	1,808,753	2,074,116	2,310,233	2,530,492	2,722,024	2,803,474
Growth rate due to 6 GHz	1.31 %	1.31 %	1.31 %	1.31 %	1.31 %	1.31 %
Impact of 1% M2M Growth on GDP	0.03 %	0.03 %	0.03 %	0.03 %	0.03 %	0.03 %
Level of development of the New Bands	0.00 %	50.00 %	100.00 %	100.00 %	100.00 %	100.00 %
Impact on GDP (%)	0.00 %	0.02 %	0.04 %	0.04 %	0.04 %	0.04 %
GDP (US$ Billion)	$ 22,289	$ 23,096	$ 23,875	$ 24,671	$ 25,493	$ 26,342
Impact (US$ Billion)	$ 0.00	$ 4.543	$ 9.392	$ 9.705	$ 10.028	$ 10.362

Source: GSMA Intelligence; Frontier Economics; Telecom Advisory Services analysis

Cumulative impact of enhanced IoT deployment driven by 6 GHz spectrum proposals will reach $44.03 billion by 2025.

4.4 Savings in enterprise wireless traffic

The deployment of the enterprise applications based on IoT and AR/VR (which is analyzed below) among other use cases will generate an exponential growth in data traffic that will be handled by devices operating in unlicensed spectrum, through the combination of the existing 2.4 GHz, the lower 5 GHz, the 45 MHz in the 5.9 GHz band and the 6 GHz band. Notwithstanding the fact that cellular networks will not be able to handle the extremely high throughput, low latency required by these applications, an approach to assess the economic value of this traffic would be to determine what the savings from cellular usage to enterprises implied by using unlicensed spectrum might be if they were to rely on high-capacity Wi-Fi devices.
The methodology to assess this benefit proceeds by multiplying the average price per Gigabyte of wireless data transmitted by wideband networks, which we calculate by

[52] *See* Frontier Economics (2018). *The economic impact of IoT: putting numbers on a revolutionary technology.*

averaging the most economic "dollar per GB" (for the least expensive plans for 4G speeds) plan of major wireless carriers.
In 2018, Cisco VNI and Telecom Advisory Services analysis estimated that for 2019 total business Internet traffic will reach 89.65 billion GB, of which 35.50 billion GB would have been transported through Wi-Fi access points. In 2019, an updated Cisco traffic forecast based on the explosion of IoT and AR/VR applications, among other factors, increased total Internet traffic reaching 116.63 billion GB, of which 49.06 billion GB was routed through Wi-Fi[53] (see Table 4-5).

Table 4-5. United States: Enterprise Wireless Traffic (2019-2025)

ESTIMATION WITH CISCO 2016/2021 FORECAST							
Total Annual traffic	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
(1) Share of Business Internet Traffic by Wi-Fi	39.60%	41.27%	43.00%	44.81%	46.69%	48.65%	50.70%
(2) Total Business Internet Traffic ('000'000 Gb)	89,648.69	112,722.05	141,733.92	178,212.73	224,080.29	281,753.02	354,269.30
(3) Total Wi-Fi business traffic ('000'000 Gb)	35,501.95	46,515.45	60,945.59	79,852.27	104,624.23	137,081.01	179,606.60
ESTIMATION WITH CISCO 2017/2022 FORECAST							
Total Annual traffic	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
(1) Share of Business Internet Traffic by Wi-Fi	42.07%	44.26%	46.57%	49.00%	51.56%	54.25%	57.07%
(2) Total Business Internet Traffic ('000'000 Gb)	116,628.23	144,457.13	178,926.34	221,620.31	274,501.58	340,000.96	421,129.27
(3) Total Wi-Fi business traffic ('000'000 Gb)	49,062.80	63,939.62	83,327.41	108,593.95	141,521.83	184,434.10	240,358.23

Source: Cisco Visual Networking Index (2017), (2019)

Each growth forecast was converted to dollar values based on the price per GB[54] (see Table 4-6).

[53] Cisco's new forecast includes in its assumption set the deployment of Wi-Fi 6.
[54] The average price per GB in February 2020 was $3.92 based on AT&T Mobile Share Plus 9GB: $60/9 Gigabytes cap ($6.66), Verizon Connected Home: $150/40 Gigabytes cap ($3.75), Sprint 50 GB Mobile Hotspot: $50/50 Gigabytes cap ($1.00), and T-Mobile Magenta Plus: $85/20Gigabytes cap (for 4G LTE Hot spot data) ($4.25). However, since we use mid-year prices for this calculation, we extrapolate the price decline curve for June 2020, which yields $3.77. While these a residential prices, the savings are calculated on the basis of the price trend where residential prices are correlated with enterprise.

Table 4-6. United States: Cost of Enterprise Internet Traffic (2019-2025) (IN US$)

	2019	2020	2021	2022	2023	2024	2025
Price per GB	$4.18	$3.77	$3.39	$3.05	$2.75	$2.47	$2.22
CISCO 2016/2021 forecast (000'000)	$ 148,490.99	$ 175,163.73	$ 206,627.57	$ 243,743.12	$ 287,246.95	$ 338,515.44	$ 398,934.45
CISCO 2017/2022 forecast (000'000)	$ 205,210.77	$ 240,778.12	$ 282,510.03	$ 331,474.71	$ 388,549.69	$ 455,451.78	$ 533,873.34

Source: Cisco Visual Networking Index (2017), (2019); Telecom Advisory Services analysis

We assume that part of the growth was driven by "natural" growth (that is to say, the extrapolation of historical growth rate by averaging the growth rate between 2018 and 2019 and between 2017 and 2018), and another portion was triggered by Wi-Fi traffic stimulated by changes in 6 GHz (see Table 4-7).

Table 4-7. United States: Enterprise Wireless Traffic: Total growth vs. growth triggered by broader Wi-Fi traffic (2019-2025) (in '000'000 US$)

	2019	2020	2021	2022	2023	2024	2025
Difference in CISCO forecasts	$ 56,719.78	$ 65,614.39	$ 75,882.46	$ 87,731.85	$ 101,302.75	$ 116,936.34	$ 134,938.89
Difference in forecasts due natural growth	$ 56,719.78	$ 63,904.60	$ 71,089.41	$ 78,274.23	$ 90,382.16	$ 104,330.43	$ 120,392.28
Difference due to 6GHz changes	$ 0	$ 1,709.79	$ 4,793.05	$ 9,457.62	$ 10,920.58	$ 12,605.91	$ 14,546.61

Source: Cisco Visual Networking Index (2017, 2019); Telecom Advisory Services analysis

The sum of the difference due to broader Wi-Fi traffic between 2020 and 2025 will reach $54.03 billion.

4.5. Producer surplus derived from sale of Virtual Reality and Augmented Reality solutions

Virtual Reality (VR) is already being used within a wide array of areas, ranging from the gaming industry and entertainment, to training and simulation, including training in the medical field. Other areas of application include education and culture, sports, live broadcasting, real estate, advertising, architecture and the arts. On the other hand, Augmented Reality (AR) has an almost limitless range of uses in a wide variety of areas, be it commerce, technical applications, work processes or education. VR and AR serve both consumers and professional users that can be private and public. The AR/VR solutions market is developing at a fast pace driven by a broad range of applications (see Table 4-8).

Table 4-8. Examples of AR/VR applications

Sector	Domain	Use Case	Example
Health Care	**Diagnostic**	Augmented reality has the potential to help patients before they are diagnosed with Alzheimer or Dementia.	Altoida is a company that develops virtual and augmented reality tools to predict the onset of mental illness in older patients, specifically neurodegenerative diseases.[55]
	Surgical procedures	Platforms that combine visualization and display technologies with a new class of operating robots to support remote surgical interventions.	Medivis, a company specialized in augmented reality suites in the health care domain, offers an augmented reality holographic visualization tool that guides surgical navigation, which the company claims can decrease complications and improve patient outcomes, while lowering surgical costs.[56]
	Training in ER procedures	Since pediatric emergencies are rare, doctors have little training experience for helping children in emergencies, and traditional mannequin-based simulations are expensive.	VR is helping doctors at Children's Hospital Los Angeles be better prepared for real life scenarios by helping doctors learn their knowledge gaps. The program has also been expanded to 11 other sites, including Johns Hopkins and Stanford University health systems.[57]
Retailing	**Guest engagement**	The purpose is to provide customers with mall-wide Wi-Fi coverage, combined with guest engagement content as part of marketing campaigns.[58]	Retailers are experimenting with the roll-out of enhanced Wi-Fi based portal and analytics platforms deployed in brick and mortar facilities.
Entertainment	**Event enhancing**	Augmented reality can make experiences, like concerts, more enjoyable and interactive. It has the potential to completely change how the audience interacts with the event environment.	In 2019, the Coachella music festival had a first-of-its-kind AR equipped stage that hoped to change how people interacted with music, concerts, and each other. By pointing their phone at the tent, guests could see outer space-themed images.[59]

[55] Shieber, J. (May 30, 2019). "Using augmented reality, Altoida is identifying the likely onset of neurodegenerative diseases," *Techcrunch*.
[56] Shieber, J. (Feb. 21, 2019). "Robotics, AR and VR are poised to reshape health-care, starting in the operating room," *Techcrunch*.
[57] Oculus Blog (Aug. 29, 2018). "Immersive Education: CHLA and Oculus Expand VR Medical Training Program to New Institutions," https://www.oculus.com/blog/immersive-education-chla-and-oculus-expand-vr-medical-training-program-to-new-institutions/. *See also* Oculus (2020). "VR for the ER: Preparing for emergencies before they happen," https://www.oculus.com/vr-for-good/stories/preparing-for-emergencies-before-they-happen/?locale=en_US.
[58] *See* example of American Dream Megamall, one of the largest US malls located in New Jersey.
[59] Cirisano, T. (Apr. 12, 2019). "Inside Coachella's First-Ever Augmented Reality equipped stage," *Billboard*.

Oil and Gas	**Maintenance**	Oil firms have adopted AR headsets and glasses, which superimpose digital images on what the wearer sees in real life to fix problems on rigs, refineries and plants. The technology transmits information in real-time to experts located anywhere in the world, who can then respond with instructions and guidance to a technician on-site.	Fieldbit, among many firms, is creating[60] technology that aims to prevent technician issues and oil spills in the oil and gas industry. This emerging technology is already being used by Chevron, BP, and Baker Hughers.
Mining	**Emergency rescue operations training**	Virtual reality creates situations that are impossible to recreate in the physical world in order to train rescue personnel.	Volunteer rescuers with Ontario Mine Rescue are navigating emergency underground simulations just like this one, thanks to VR training scenarios created in partnership with NORCAT. These training scenarios enable rescue volunteers to hone their emergency-response skills in a safe but realistic environment.[61]

Source: Compilation by Telecom Advisory Services

The development and diffusion of AR/VR applications in the production side of the economy is being driven by an ecosystem comprised of firms ranging from software development to hardware production and content creation. The United States has a leading position in the global VR and AR market. R&D for hardware and software is focused around Silicon Valley with IT giants such as Google, Apple and Facebook. Additionally, the content production is concentrated around big gaming studios and production studios in Los Angeles. The margins of enterprises engaged in the development of AR/VR solutions represents a key source of economic value dependent on the designation of the Very Low Power device category within the 6 GHz band. This amount should be considered as producer surplus as was the case of equipment sold within the Wi-Fi space.

Methodology

The key objective is to estimate the producer surplus generated in the United States as a result of the sales of AR/VR applications produced by domestic firms (see Figure 4-2).

[60] Margit, M. (2019). *How Augmented Reality is Transforming the Oil Industry.*

[61] Oculus (2020). "VR for Safety: Mine rescue teams discover a new tool for training," https://www.oculus.com/vr-for-good/stories/mine-rescue-teams-discover-a-new-tool-for-training/?locale=en_US.

Figure 4-2. Methodology for estimating US Producer Surplus in the AR/VR space

Source: Telecom Advisory Services

Our starting point is the sales of AR/VR applications and systems within the United States between 2019 and 2023 (although one could potentially include overseas sales of solutions). Sales are broken down by the three components of the ecosystem: hardware, software, and content, but each component is restricted to the US firms, because the purpose is to estimate the value generated by the domestic producers (it should be noted that some of the sales in the US market are generated by foreign firms). Once sales by US firms in the US market are calculated, producer surplus is estimated based on standard margin metrics: 39.44% for hardware, and 77.46% for software and content.

Results

IDC estimates that the US AR/VR market was $2.6 billion in 2019 and projected to reach $ 10.00 billion by 2021. We have chosen to extrapolate the market at a more conservative 32.30% annual rate of the virtual reality market through 2025 (see Table 4-9).

Table 4-9. Worldwide AR/VR market (2019-2025) (in US$ billions)

	2019	2020	2021	2022	2023	2024	2025
United States	$ 2.60	$ 5.10	$ 10.00	$ 19.61 (*)	$ 38.46 (*)	$ 56.94 (*)	$ 84.30 (*)
Western Europe	$ 7.90	$ 3.30	$ 6.74				
Japan		$ 1.80	$ 16.16				
China		$ 5.80					
Other regions		$ 2.80					
TOTAL	$ 10.50	$ 18.80	$ 32.90				

(*) Growth rate assumed to be 32.30%

Source: IDC (2019). Worldwide Spending on Augmented and Virtual Reality Expected to Reach $18.8 Billion in 2020; 2021-25: Statista (2019). Virtual Reality Market revenue in the United States from 2014 to 2025.

Based on the ecosystem breakdown developed by Ecorys, a market research firm, component sales were estimated for the United States (see Table 4-10).

Table 4-10. United States: AR/VR market by component (2020-2025) (in US$ billions)

	2020	2021	2022	2023	2024	2025
Hardware	$ 1.67	$ 3.28	$ 4.33	$ 5.73	$ 7.59	$ 10.04
Software	$ 1.15	$ 2.26	$ 2.99	$ 3.96	$ 5.23	$ 6.93
Content	$ 2.28	$ 4.46	$ 5.91	$ 7.81	$ 10.34	$ 13.68
TOTAL	$ 5.10	$ 10.00	$ 13.23	$ 17.51	$ 23.16	$ 30.64

Source: IDC (2019). Ecorys (2016); Telecom Advisory Services analysis

Of these sales, a portion was generated by US companies (assumed to be 50% in the hardware component, and 90% in the other two) (see Table 4-11).

Table 4-11. United States: AR/VR sales by US firms by component (in US$ billions)

	2020	2021	2022	2023	2024	2025
Hardware	$ 0.83	$ 1.63	$ 2.16	$ 2.86	$ 3.78	$ 5.00
Software	$ 1.04	$ 2.03	$ 2.69	$ 3.56	$ 4.71	$ 6.23
Content	$ 2.05	$ 4.02	$ 5.32	$ 7.03	$ 9.30	$ 12.31
TOTAL	$ 3.92	$ 7.68	$ 10.17	$ 13.45	$ 17.79	$ 23.54

Source: IDC (2019). Ecorys (2017); ABI Research; Telecom Advisory Services analysis

By multiplying each sales estimate by the operating margins (39.44% for hardware and 77.46% for software and content), the producer surplus for the AR/VR industry was estimated (see Table 4-12).

Table 4-12. United States: Producer surplus derived from AR/VR sales by US firms by component (in US$ billions)

	2020	2021	2022	2023	2024	2025
Hardware	$ 0.33	$ 0.64	$ 0.85	$ 1.13	$ 1.49	$ 1.97
Software	$ 0.80	$ 1.58	$ 2.09	$ 2.76	$ 3.65	$ 4.83
Content	$ 1.59	$ 3.11	$ 4.12	$ 5.45	$ 7.21	$ 9.54
TOTAL	$ 2.72	$ 5.33	$ 7.05	$ 9.33	$ 12.35	$ 16.33

Source: IDC (2019). Ecorys (2016); ABI Research; CSI Market Inc*: Industry Profitability ratios; Telecom Advisory Services analysis*

However, it is clear that a portion of this surplus is not due exclusively to the designation of Very Low Power devices within the 6 GHz band. The development of AR/VR has already begun before this potential spectrum change. Therefore, the producer surplus estimated in table 4-8 needs to be broken down between the portion that is due to the "natural" growth in the industry and the boost resulting from the spectrum designation mentioned above. In the absence of any precise metric, we applied the ratio used to determine the impact on Wi-Fi equipment sales from the allocation of 45 MHz in 5.9 GHz band ranging between 24.58% of sales in 2021 and 28.87% in 2025 (see section 3.2.4. above). Based on this analysis, the producer surplus to be generated by US AR/VR firms from sales in the US market between 2021 and 2025 will amount to US $13.74 billion (see Table 4-13).

Table 4-13. United States: AR/VR sales by US firms by component attributed to the designation of Very Low Power devices within the 6GHz band (2020-2025) (in US$ billions)

	2020	2021	2022	2023	2024	2025	Total
Total Producer Surplus (from Table 4-8)	$ 2.72	$ 5.33	$ 7.05	$ 9.33	$ 12.35	$ 16.33	$ 53.11
Total Producer Surplus due to VLP designation	$ 0.00	$ 1.31	$ 1.80	$ 2.49	$ 3.42	$ 4.72	$ 13.74

Source: IDC (2019). Ecorys (2016); ABI Research; CSI Market Inc*: Industry Profitability ratios; Telecom Advisory Services analysis*

4.6. Spillovers from Virtual Reality and Augmented Reality

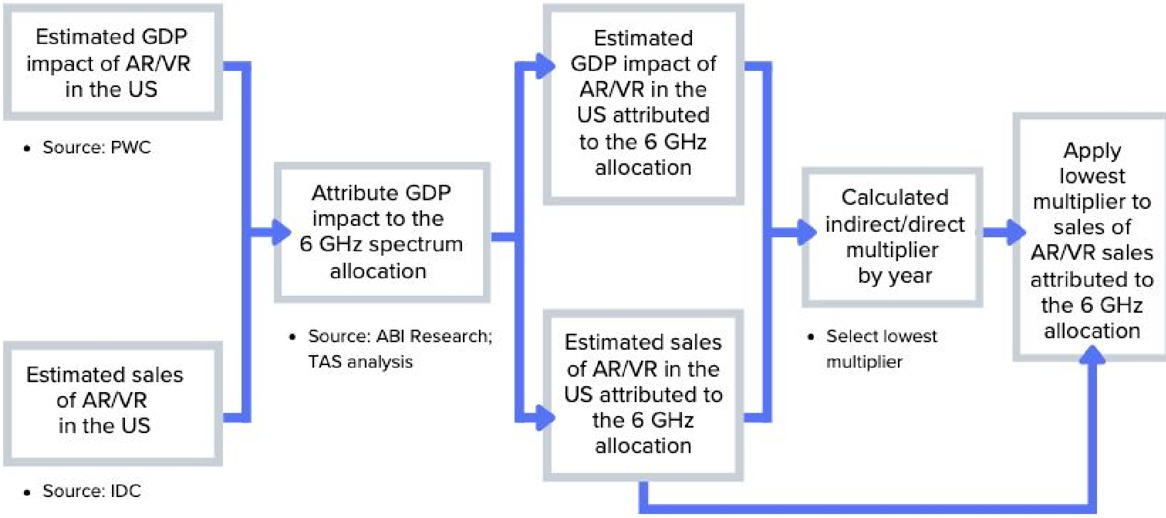
The adoption of AR/VR among US business will in turn have a spillover effect on productivity, thereby contributing to the growth of GDP. The spillover effects range from improved training to the acceleration of product design and delivery. For example, automotive companies are already incorporating virtual reality in their product development processes to reduce the time incurred between initial design and physical modelling. AR glasses also help warehouse workers provide parts information for engineers and technicians in the field. Finally, as shown in the applications table above, AR/VR solutions can be used to sell and showcase products in retailing.

Estimating spillover effects of AR/VR is a not a trivial exercise considering the embryonic adoption of some of these use cases. For example, PwC estimates that the United States will benefit from a boost to GDP equivalent to $148.80 billion between 2020 and 2022.[62] We believe this estimate to be overoptimistic, since if we consider that total sales in AR/VR in the US between 2020 and 2022 reaches $28.33 billion (see Table 4-10), the implicit indirect/direct multiplier would be 4.25 (or ($148.80-$28.33)/$28.33).

Since the objective is to estimate the spillover effect of AR/VR sales by US firms in the domestic market resulting from the growth driven by designating VLP devices as part of the 6 GHz band, our points of departure are the total GDP contribution of AR/VR, as estimated by PwC, and the sales of AR/VR components as estimated by IDC. These two parameters allow estimating the indirect (that is to say spillover) contribution of AR/VR to the US economy (see Figure 4-3).

[62] This estimate was derived from assuming a productivity boost derived from adoption of use cases and incorporating this to a General Equilibrium model built from the GTAP database. However, detailed analysis is not disclosed (*see* PWC (2019). *Seeing is believing: how virtual reality and augmented reality are transforming business and the economy*).

Figure 4-3. Methodology for estimating US spillovers of AR/VR



Source: Telecom Advisory Services

Both starting values are reduced by the proportion that can be attributed to the impact of 6 GHz spectrum allocation of VLP devices (in other words, it would be wrong to estimate that the whole economic value of the AR/VR is driven by the spectrum changes). Once the amount to be attributed in both GDP contribution and direct sales is estimated, the annual indirect to direct multiplier can be calculated. The lowest multiplier value is applied to sales of AR/VR in the US market to calculate the total spillovers (see Table 4-14).

Table 4-14. United States: GDP Contribution resulting from AR/VR Spillovers (2021-2025) (in US$ billion)

	2021	2022	2023	2024	2025	
1. AR/VR total contribution to GDP	$ 49.00	$ 68.20	$ 91.20	$ 122.60	$ 171.90	From PwC paper
2. Share due to 6 GHz	24.58%	25.59%	26.64%	27.73%	28.87%	Sales of 5.9 GHz equipment attributed to spectrum change
3. Portion of GDP contribution attributed to 6 GHz spectrum change	$ 12.04	$ 17.45	$ 24.29	$ 34.00	$ 49.63	Line 1 * line 2
4. Portion of AR/VR sales attributed to 6 GHz spectrum change	$ 2.46	$ 3.39	$ 4.66	$ 6.42	$ 8.85	AR/VR sales attributed to 6 Hz spectrum change
5. Indirect GDP contribution of AR/VR	$ 9.58	$ 14.06	$ 19.63	$ 27.58	$ 40.78	Line 3 - line 4
6. Indirect/direct multiplier	1.00	1.00	1.00	1.00	1.00	Max relationship between indirect/direct effect
7. Indirect impact	$ 2.458	$ 3.386	$ 4.663	$ 6.423	$ 8.846	Line 4 * Line 6

Source: PwC; IDC; Telecom Advisory Services analysis

Total spillover value of AR/VR in the United States between 2021 and 2025 is $25.78 billion.

4.7. Conclusion

The estimation of economic value of derived from the creation of two categories of low power devices (Low Power Indoor and Very Low Power) operating in the 6 GHz band was structured around six sources (see Table 4-15).

Table 4-15. Total Economic Value Resulting from the creation of two categories of Low Power Devices in the 6 GHz band (in US$ billions) (2020-2025)

	Source of Economic Value	2020	2021	2022	2023	2024	2025	Total
Low power indoor	Return to speed	$0.000	$0.000	$0.000	$2.751	$4.364	$6.138	$13.253
	Consumer surplus	$0.000	$0.000	$0.000	$0.616	$0.964	$1.338	$2.918
	Broader deployment of IoT	$ 0.000	$ 4.543	$ 9.392	$ 9.705	$ 10.028	$ 10.362	$44.030
	Savings in enterprise wireless traffic	$ 1.710	$ 4.793	$ 9.458	$ 10.921	$ 12.606	$ 14.547	$54.035
Very Low power	US Sales of AR/VR equipment by US firms	$ 0.000	$ 1.310	$ 1.805	$ 2.486	$ 3.424	$ 4.716	$13.741
	US Spillovers from AR/VR	$ 0.000	$ 2.458	$ 3.386	$ 4.663	$ 6.423	$ 8.846	$25.776
TOTAL		**$1.710**	**$13.104**	**$24.041**	**$31.142**	**$37.809**	**$45.947**	**$153.753**

Source: Telecom Advisory Services analysis

Total economic value resulting from the creation of two categories of low power devices (Low Power Indoor and Very Low Power) operating in the 6 GHz band will reach $153.75 billion between 2020 and 2025.

5. TOTAL ECONOMIC VALUE

As explained above, two FCC proposals are under consideration: the 5.9 GHz band and the 6 GHz band. The 5.9 GHz band would be added to the existing unlicensed bands of 2.4 GHz and 5.8 GHz. When the 6 GHz band is opened up and added to the existing unlicensed bands in 2.4 GHz and 5 GHz, the combined spectrum will be able to support eight 160 MHz channels or three 320 MHz channels.

We have identified eight sources of economic value to be generated by both proposals:

- The impact on GDP yielded by an increase in average broadband speed resulting from removing the Wi-Fi bottleneck at the customer premise level (also called the "return to speed");
- The consumer surplus derived from faster average broadband speed driven by the additional unlicensed channels in the 5.9 GHz and 6 GHz bands;
- The producer surplus generated by the sale of new Wi-Fi equipment enabled by the additional unlicensed channels;
- The savings in capital investment incurred by cellular operators from offloading cellular traffic to Wi-Fi (this impact will be driven not only by the 5.9 GHz proposal but also the 6 GHz one);
- Broader deployment of IoT devices as additional unlicensed spectrum mitigates the risk of congestion;
- Savings in enterprise wireless traffic as additional Wi-Fi channels provide much needed capacity to support the widespread adoption of new use cases;
- Producer surplus derived from a boost in the sales of AR/VR equipment, software and content as triggered by the VLP designation; and
- The consequent economic spillovers resulting from the additional sales of AR/VR solutions.

As stated in chapter 2, it was important to differentiate the effects between each of the two proposals under consideration. In some cases, the attribution of economic value has been straight forward. For example, the benefit of AR/VR use cases is directly related to the authorization of Very Low Power devices in the 6 GHz band. However, in other cases the economic value results from the combined effect of both proposals. A case in point is the capex savings producer surplus incurred by cellular carriers in their deployment of 5G. In this case, we opted to consider the economic value as resulting from the combined impact of both proposals.

Another analytical challenge of the study was how to assess the economic benefit of enhanced Wi-Fi performance. We opted to disaggregate the economic benefit estimation between each proposal. Our approach assumed that the 5.9 GHz one will primarily address the Wi-Fi bottleneck existing at the consumer premise between 2020 and 2022, and that the 6 GHz proposal will be instrumental in tackling the speed challenge between 2023 and 2025. We are cognizant that both proposals could be enacted in the short term. However, when observing the trend in average fixed broadband speeds in

US households, we stipulated that the source of economic value of each proposal will shift over time. In other words, the 5.9 GHz will serve to alleviate the immediate spectrum contention, while the 6 GHz will be a larger response beyond 2022.

A third factor to be addressed was whether the producer surplus estimates were already included in the GDP growth calculation. In this case, we considered that the margin on equipment sales were not included in the GDP growth, but the CAPEX savings incurred by cellular carriers should be. Thus, while quantifying it, we excluded this last benefit from the total value.

To sum up, the economic value of both spectrum proposals is estimated as follows (see Table 5-1).

Table 5-1. Total Economic Value Resulting from the 45 MHz in 5.9 GHz band and the creation of two categories of Low Power Devices in the 6 GHz band (in US$ billions) (2020-2025)

Source of Economic Value	Economic value is the result of 5.9 GHz	Economic value is the result of 6 GHz	Economic value is the result of both spectrum proposals
Return to speed	$23.04	$13.25	
Consumer surplus	$5.10	$2.92	
Producer surplus from equipment sales			$1.54
Broader deployment of IoT		$44.03	
Savings in enterprise wireless traffic		$54.04	
Producer surplus from AR/VR equipment sales		$13.74	
US spillovers from AR/VR		$25.78	
TOTAL	$ 28.14	$ 153.76	$ 1.54
5G CAPEX savings (excluded from totals to avoid double counting)			$13.60

Source: Telecom Advisory Services

By 2025, the total cumulative value from all sources will reach $183.44 billion (see Table 5-2).

Table 5-2. Total Economic Value Resulting from the 45 MHz in 5.9 GHz band and the creation of two categories of Low Power Devices in the 6 GHz band (in US$ billions) (2020-2025)

Source of Economic Value	Trigger	2020	2021	2022	2023	2024	2025	Total
Return to speed	5.9 GHz	$0.00	$0.00	$7.20	$4.99	$5.28	$5.57	$23.04
	6 GHz	$0.00	$0.00	$0.00	$2.75	$4.36	$6.14	$13.25
	Subtotal	$0.00	$0.00	$7.20	$7.74	$9.64	$11.71	$36.29
Consumer surplus	5.9 GHz	$0.00	$0.00	$1.61	$1.11	$1.16	$1.22	$5.10
	6 GHz	$0.00	$0.00	$0.00	$0.62	$0.96	$1.34	$2.92
	Subtotal	$0.00	$0.00	$1.61	$1.73	$2.13	$2.55	$8.02
Producer surplus from equipment sales	5.9 GHz and 6 GHz	$0.18	$0.21	$0.23	$0.27	$0.30	$0.35	$1.54
Broader deployment of IoT	6 GHz - Low Power Indoor	$0.00	$4.54	$9.39	$9.71	$10.03	$10.36	$44.03
Savings in enterprise wireless traffic	6 GHz - Low Power Indoor	$1.71	$4.79	$9.46	$10.92	$12.61	$14.55	$54.04
Producer surplus from AR/VR equipment sales	6 GHz - Very Low Power	$0.00	$1.31	$1.80	$2.49	$3.42	$4.72	$13.74
US spillovers from AR/VR	6 GHz - Very Low Power	$0.00	$2.46	$3.39	$4.66	$6.42	$8.85	$25.78
TOTAL		$1.89	$13.31	$33.08	$37.52	$44.55	$53.09	$183.44
5G CAPEX savings (excluded from total)	5.9 GHz and 6 GHz	$0.00	$2.72	$2.72	$2.72	$2.72	$2.72	$13.60

Source: Telecom Advisory Services analysis

BIBLIOGRAPHY

ABI Research (2018). *Wireless Connectivity Technology Segmentation Addressable Markets*, 1Q2018.

Bai, Y. (2016). *The Faster, the Better? The Impact of Internet Speed on Employment*. Working paper available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2772691.

Briglauer, W. and Gugler, K. (2018). *Go for Gigabit? First evidence on economic benefits of (Ultra-) Fast broadband technologies in Europe*. Center for European Economic Research Discussion Paper No. 18-020.

Bezegová, E.; Ledgard M.; Molemaker, R-J; Pia Oberč, B; Vigkos , A. (2017). *Virtual Reality and its potential for Europe*. Brussels: Ecorys.

Carew, D., Martin, N., Blumenthal, M., Armour, P., and Lastunen, J. (2018). *The potential economic value of unlicensed spectrum in the 5.9 GHz Frequency band: insights for allocation policy*. RAND Corporation (Rand study).

Cariolle, J., Le Goff, M. and Santoni, O. (2018). Broadband infrastructure deployment, digital vulnerability, and local firm performance in developing and transition countries.

Cirisano, T. (2019). “Inside Coachella’s First-Ever Augmented Reality equipped stage”, *Billboard*, 4/12/2019.

Cisco (2017, 2019). *Visual Networking Index*.

CSI Market Inc. *Industry Profitability ratios* retrieved in: https://csimarket.com/Industry/industry_Profitability_Ratios.php?ind=1012.

Cooper, M. (2011). *The consumer benefits of expanding shared use of unlicensed radio spectrum: Liberating Long-Term Spectrum Policy from Short-Term Thinking*. Washington DC: Consumer Federation of America.

Federal Communications Commission (2019). *Use of the 5.850-5.925 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 19-138, FCC No. 19-129 (rel. Dec. 17, 2019).

Federal Communications Commission (2018). *Unlicensed Use of the 6 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 18-295, FCC No. 18-147 (rel. Oct. 24, 2018).

Federal Communications Commission (2020). *Broadband Deployment Report 2019.* Washington DC.

Federal Communications Commission (2019). *Internet Access Services: Status as of December 31, 2017* (August).

Ford, G. (2018). *Is Faster Better? Quantifying the Relationship between Broadband Speed and Economic Growth*. Phoenix Center Policy Bulletin No. 44.

Frontier Economics (2018). *The economic impact of IoT: putting numbers on a revolutionary technology.*

Greenstein and McDewitt (2011) Greenstein, S. and McDevitt, R. C. (2009), *The global broadband bonus: Broadband Internet's impact on seven countries*. Available at http://ictlinkedworld.com/eng/pdfs/ICT_Chapter_II_B.pdf Accessed 1st October 2011.

Grimes, A., Ren, C., and Stevens, P. (2009). *The need for speed: Impacts of Internet Connectivity on Firm Productivity*. MOTU Working Paper 9-15.

Haller, S. and Lyons, S. (2019). *Productivity is higher among service firms when broadband becomes available, but not all*. ESRI Research Bulletin, January.

Hasbi, M. (2017). *Impact of Very High-Speed Broadband on Local Economic Growth: Empirical Evidence,* 14th International Telecommunications Society (ITS) Asia-Pacific Regional Conference: "Mapping ICT into Transformation for the Next Information Society", Kyoto, Japan, 24-27 June, 2017, International Telecommunications Society (ITS), Kyoto.

IDC (2019). *Worldwide Spending on Augmented and Virtual Reality Expected to Reach $18.8 Billion in 2020.*

Katz, R. (2014a). *Assessment of the economic value of unlicensed spectrum in the United States*. New York: Telecom Advisory Services.

Katz, R. (2014b). *Assessment of the future economic value of unlicensed spectrum in the United States*. New York: Telecom Advisory Services.

Katz, R. (2018a). *A 2017 assessment of the current and future economic value of unlicensed spectrum*. Washington, DC: Wi-Fi Forward.

Katz, R. (2018b). *The global economic value of Wi-Fi 2018-2023*. New York: Telecom Advisory Services.

Kongaut, Chatchai; Bohlin, Erik (2014). *Impact of broadband speed on economic outputs: An empirical study of OECD countries*, 25th European Regional Conference of the International Telecommunications Society (ITS), Brussels, Belgium, 22-25 June 2014, International Telecommunications Society (ITS), Brussels.

Liu, Y-H; Prince, J., and Wallsten, J. (2018). *Distinguishing bandwidth and latency in households' willingness-to-pay for broadband internet speed*.

Lobo, B., Alam, R., Whitacre, B. (2019). *Broadband speed and unemployment rates: data and measurement issues*. (April 12).

Mack-Smith, D. (2006). *Next Generation Broadband in Scotland*. Edinburgh: SQW Limited.

Margit, M. (2019). *How Augmented Reality is Transforming the Oil Industry.*

Milgrom, P., Levin, J., & Eilat, A. (2011). *The case for unlicensed spectrum*. Stanford Institute for Economic Policy Research Discussion Paper No. 10-036.

Nevo, A., Turner, J., and Williams, J. “Usage-based pricing and demand for residential broadband”, *Econometrica*, vol. 84, No.2 (March), 441-443.

Nikolikj, V. and Janevski, T. (2014). “A Cost Modeling of High-Capacity LTE-Advanced and IEEE 802.11ac based Heterogeneous Networks, Deployed in the 700 MHz, 2.6 GHz and 5 GHz Bands”, *Procedia Computer Science* 40 (2014) 49-56.

Oughton and Frias (2017). *Exploring the cost, coverage and rollout implications of 5G in Britain.*

PWC (2019). *Seeing is believing: how virtual reality and augmented reality are transforming business and the economy.*

Rohman, Bohlin, E. (2013).*Socio-economic effects of broadband speed*. Ericsson 3/221 01-FGB 101 00003.

Rosston, G., Savage, S. and Waldman, D. (2010), *Household demand for broadband internet service*. Available at http://siepr.stanford.edu/system/files/shared/Household_demand_for_broadband.pdf.

Savage, S. J. and Waldman, D. (2004), ‘United States Demand for Internet Access’, *Review of Network Economics*, Vol. 3(3), pp.228–47.

Shueber, J. (2019). “Using augmented reality, Altoida is identifying the likely onset of neurodegenerative diseases”, *Techcrunch*, May 30.

Shrieber, J. (2019) “Robotics, AR and VR are poised to reshape health-care, starting in the operating room”. *Techcrunch*, February 21.

Statista (2019). *Virtual Reality Market revenue in the United States from 2014 to 2025.*

Thanki, R. (2009). *The economic value generated by current and future allocations of unlicensed spectrum*. Perspective Associates. Sept. 8.

Whitacre, B., Gallardo, R., Strover, S. (2014). “Does rural broadband impact jobs and income? Evidence from spatial and first-differenced regressions”, *The Annals of Regional Science* (October 2014) 53(3):649-670.

WIFI FORWARD

@wififorward wififorward.org