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The Economic Impact of Each Additional 100 MHz of Mid-band Spectrum for Mobile

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Project Team

Dr. Hector Lopez
Julien Martin

Contents

Executive Summary

The wireless industry has become a cornerstone of the American economy, influencing nearly every aspect of daily life and business operations. As technology continues to advance, the demand for wireless communication continues to surge, with Americans consuming an astounding 100 billion gigabytes of data in the past year alone. This growing reliance on wireless networks underscores their role as critical infrastructure, essential for facilitating economic transactions, maintaining personal connections, and maintaining national security.

The industry's significant contributions to economic output and job creation further highlight its importance. Wireless enables vast swathes of economic activity, both directly through investments in communication infrastructure and indirectly by enabling new services and improving worker productivity. Over the past decade, wireless has contributed over $5 trillion of GDP and 3 million jobs to the U.S. economy.

Approximately 1.1 GHz of licensed spectrum below 6 GHz has supported this economic growth and employment. However, the wireless industry is rapidly approaching a spectrum deficit that will result in network congestion, thereby hindering the continued growth fueled by the wireless industry. Projections indicate that wireless operators will need at least 400 MHz of additional spectrum by 2027 to meet the needs of the U.S. economy, a deficit that will continue to grow to over 1400 MHz by 2032.

Additional wireless spectrum is fundamental to so many aspects of the U.S. economy. In particular, this study focuses on the economic activity and consumer benefits generated by:

- continued improvements to mobile service to millions of Americans;
- improved fixed broadband coverage and penetration via fixed wireless access (FWA);
- support for industries that rely on mobile connectivity, such as video streaming and cutting-edge VR/AR; and
- support for industries that serve the wireless industry, such as construction and electronic maintenance.

All this economic activity and wireless industry investment enabled by additional licensed spectrum will contribute significantly to the American economy. We estimate that each additional 100 MHz of mid-band spectrum to mobile will generate $264 billion of GDP, about 1.5 million new jobs, and about $388 billion in consumer surplus. The impact of 400 MHz of mid-band spectrum would be $1.1 trillion of GDP, 6.18 million new jobs, and about $1.5 trillion in consumer surplus. Beneficial effects would continue to accumulate beyond 400 MHz, and we estimate that by 2028 even 400 MHz of new 5G spectrum will not be enough to keep up with consumer demand.

Table 1: Summary of the economic impact of allocating each additional 100 MHz of mid-band spectrum to mobile

	GDP ($B)	Employment (M)	Consumer Surplus ($B)
Continued improvements to mobile service to millions of Americans			385
Improving broadband with FWA	40	0.30	3
Supporting industries that rely on mobile connectivity	188	0.93	
Supporting industries that serve the wireless industry	36	0.32	
Total	**264**	**1.55**	**388**

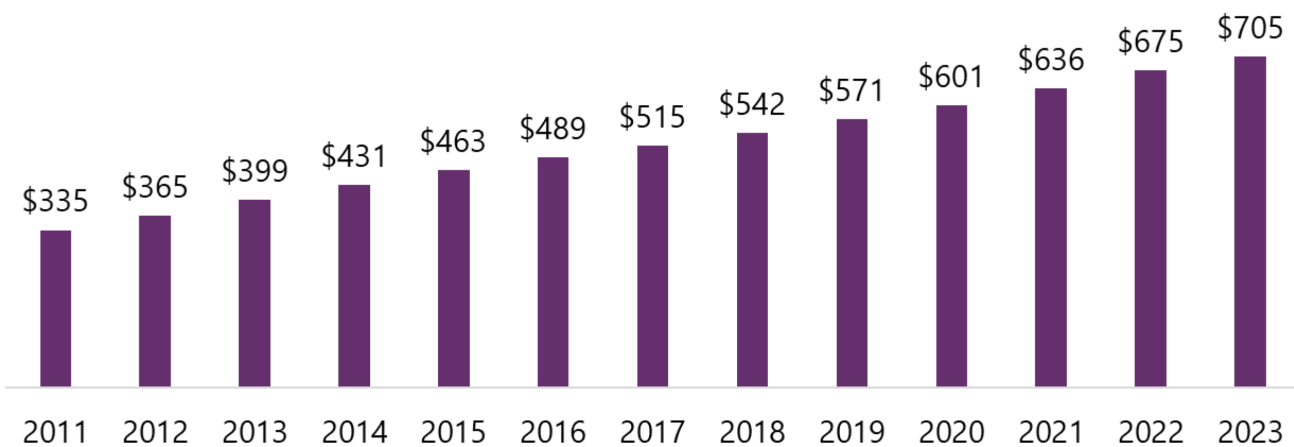
Note: Effect of each 100 MHz up to 400 MHz

1. The importance of the wireless industry to the American economy

The wireless industry is an integral part of the U.S. economy, with wireless communications deeply integrated into how we live and work. Americans consumed 100 billion GBs of data last year, and data traffic continues to grow.[1] From enabling economic transactions to connecting families and defending the nation, wireless networks are not just a convenience, but critical infrastructure. By providing fast, efficient communication, the wireless industry enables vast swaths of economic activity.

The core wireless industry, which includes mobile and wholesale network operators, contributes significantly to the American economy. Figure 1 shows the consistent investments wireless providers make in the U.S.'s communications infrastructure. Since the launch of the first commercial cellular networks, wireless operators have invested over $700 billion in capital expenditures to build and deploy networks throughout the nation.[2] In 2023 alone, the wireless industry invested $30 billion; and this decade, the industry has been the second-largest source of direct investment in the United States.[3] These significant capital investments in infrastructure have allowed wireless providers to expand network coverage, improve service quality, and introduce advanced technologies such as 5G, all of which have translated into substantial economic output. Over the last decade, the core wireless industry generated $270 billion in gross output and $133 billion in GDP annually.[4]

Figure 1: Cumulative wireless industry capital expenditure in the United States, 2011-2024



Source: CTIA Annual Wireless Industry Surveys

[1] Timothy Tardiff, "Wireless Investment and Economic Benefits," AACG (Apr. 2024), available at https://www.ctia.org/news/wireless-investment-and-economic-benefits

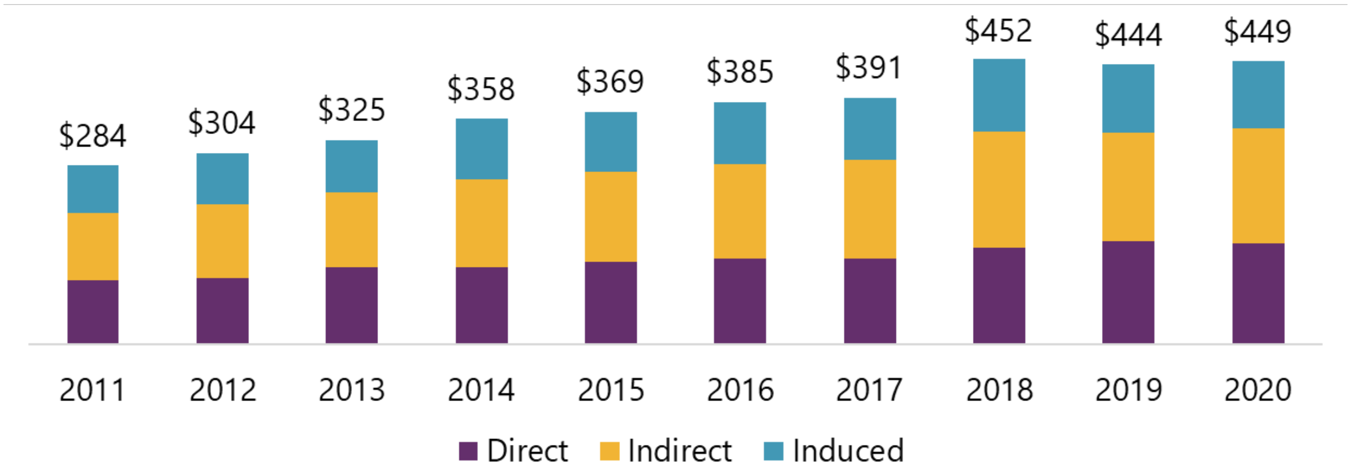
[2] *Ibid.*

[3] *Ibid.*

[4] Compass Lexecon, 2022, The Importance of Licensed Spectrum and Wireless Telecommunications to the American Economy, available at: https://api.ctia.org/wp-content/uploads/2022/12/Compass-Lexecon-Licensed-Spectrum-Report.pdf

Beyond its direct economic contribution to output and GDP, the wireless industry also generates significant indirect benefits through its infrastructure deployment and wider supply chain, as it purchases goods and services like network equipment and software from other industries. And as the wireless industry's workers spend their incomes, they generate additional induced economic effects, multiplying the industry's impact across the economy. Once indirect and induced effects are taken into account, the core wireless industry is estimated to have driven $650 billion in gross output and $376 billion in GDP a year over the last decade. [5] Figure 2 shows that the GDP contribution of the core wireless industry has been steadily growing at a compound annual growth rate of about 5%. By any account, the wireless industry has been a critical driver of the American economy.

Figure 2: GDP contribution of the core wireless industry in the United States, 2011-2020



Source: Adapted from Compass Lexecon Report
Note: The core wireless industry includes network operators and MVNOs and does not include other downstream or upstream industries.

The wireless industry's impact across the economy extends further still. As a general-purpose technology, wireless communication networks fuel the broader economy by enabling innovation and economic activity in other, downstream industries that rely and build upon the services they provide. For example, a recent study by Accenture estimates that 5G networks will contribute an additional $159 billion to the American manufacturing industry's GDP over a 5-year period.[6] Compass Lexecon, meanwhile, find that in 2020 alone the wireless industry broadly contributed $825 billion in GDP; including the effects of the core mobile industry and the broad mobile ecosystem – which includes social networking sites, mobile gaming, smartphone apps, search engines and digital advertising.[7]

Through network expansion and new services, most notably mobile Fixed Wireless Access (FWA), the wireless industry also expands broadband connectivity in under-served areas, creates new competition

5 *Ibid.*

6 Accenture, available at https://www.accenture.com/content/dam/accenture/final/a-com-migration/pdf/pdf-146/accenture-5g-wp-us.pdf

7 Compass Lexecon, 2022

to wired broadband, and promotes inclusive access to the economy. FWA has been pivotal in closing the digital divide and bringing Americans online. In 2022, 90% of new home broadband connections were 5G FWA, and many of these connections were in areas that are underserved by fixed networks such as cable.[8] Numerous studies have established the economic benefits associated with increasing broadband penetration. For example, The World Bank estimates that in developed economies, a 10-percentage point increase in broadband penetration boosts GDP growth by 1.2%.[9] Other studies have found effects of similar magnitudes for developed economies, with concomitant benefits on wages and employment.

By employing workers and enabling up and downstream economic activity, the wireless industry is also a significant driver of employment in the United States. Directly, wireless providers enable a large number of high-quality jobs, employing engineers, technicians, customer service representatives and administrative staff to run their operations. The ongoing expansion of 5G networks is expected to continue to create jobs well into the decade. Indirectly, the wireless industry also supports jobs upstream, as it fuels demand for goods and services in other sectors like manufacturing and software development. Over the last decade, the core wireless industry is estimated to have enabled nearly 2 million jobs per year.[10] In the first half of this decade, meanwhile, 5G is projected to create or transform up to 16 million jobs.[11]

Importantly, the wireless industry also plays a crucial role in closing the digital divide. Studies in the U.S. have found that improving the quality of broadband has a disproportionately positive impact on reducing unemployment in rural areas. According to one study by Lobo *et al.* (2020), unemployment rates are about 0.26 percentage points lower in counties with access to high quality broadband than in counties with lower quality services.[12] This highlights the vital role that the wireless industry plays in levelling the playing field and promoting economic opportunity and inclusive access to the economy.

In addition to its direct contribution to the economy, the wireless industry also generates substantial consumer welfare by connecting Americans and offering ever-improving services at lower costs. Today, Americans pay $0.006 per MB of data.[13] This represents a 93% decrease from a decade ago.[14] At the same time, the services offered to consumers are hugely improved. Average mobile broadband

8 CTIA, 2024, CTIA Response to FCC Communications Market Report 2024, available at: https://api.ctia.org/wp-content/uploads/2024/06/240606-FINAL-CTIA-Comments-for-2024-Communications-Marketplace-Report.pdf

9 https://documents1.worldbank.org/curated/zh/178701467988875888/pdf/102955-WP-Box394845B-PUBLIC-WDR16-BP-Exploring-the-Relationship-between-Broadband-and-Economic-Growth-Minges.pdf

10 CTIA, 2024, Annual Survey Highlights, available at: https://api.ctia.org/wp-content/uploads/2024/09/2024-Annual-Survey-Highlights.pdf

11 Accenture, 2021, The Impact of 5G on the United States Economy, available at: https://www.accenture.com/content/dam/accenture/final/a-com-migration/pdf/pdf-146/accenture-5g-wp-us.pdf

12 Lobo, Alam and Whitacre, 2020, Broadband speed and unemployment rates: Data and measurement issues, available at: https://www.sciencedirect.com/science/article/pii/S0308596118303823

13 Cable.co.uk, 2024, The cost of 1GB of mobile data in 237 countries, available at: https://www.cable.co.uk/mobiles/worldwide-data-pricing/

14 Nielsen, 2011, Average U.S. Smartphone Data Usage Up 89% as Cost per MB Goes Down 46%, available at: https://www.nielsen.com/insights/2011/average-u-s-smartphone-data-usage-up-89-as-cost-per-mb-goes-down-46/

speeds in the U.S. are now over 100 Mbps – a thirty-fold increase relative to the North American average of 3 Mbps at the start of the decade.[15] And these benefits are widespread too: some 95% of U.S. adults say they use the internet and 15% access the internet solely via their smartphone.[16] In 2015, the 645 MHz of spectrum licensed for wireless broadband networks was estimated to generate between $5 trillion and $10 trillion in savings for consumers.[17] Given the improvements in service quality and declines in prices, savings should be higher today. Again, this underscores the critical role that the wireless industry plays in supporting America's society and its economy.

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15 Cisco, 2011, Cisco Global Cloud Index: Forecast and Methodology, 2010–2015, available at: https://www.revistacloudcomputing.com/wp-content/uploads/2011/12/Cloud_Index_White_Paper.pdf

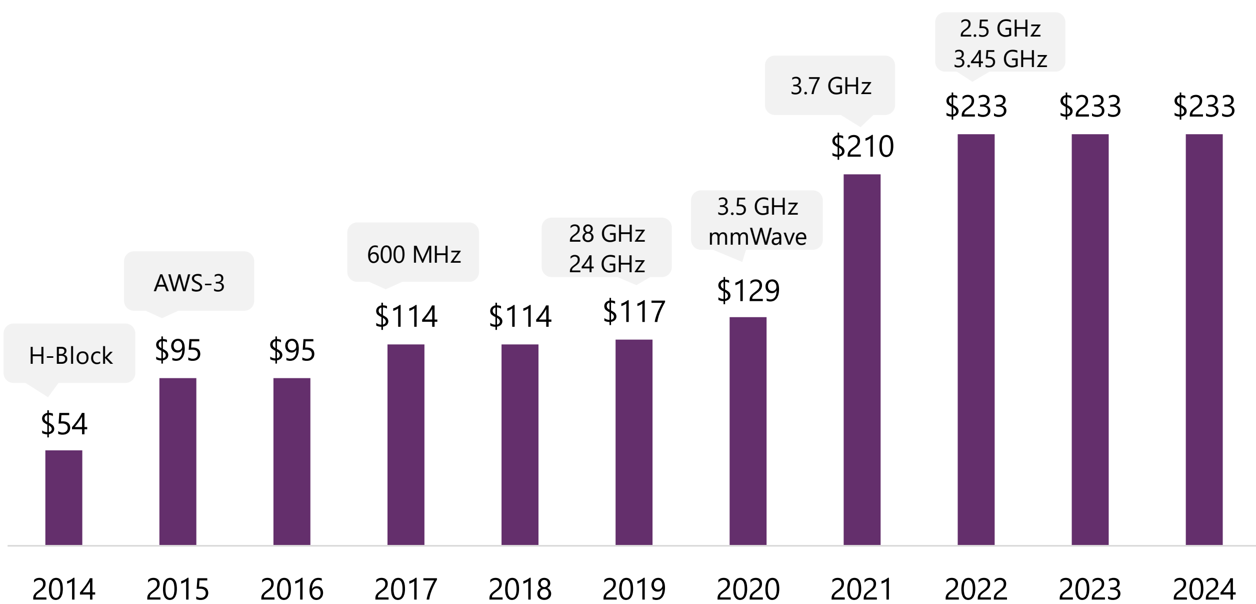
16 Pew Research, 2024, Internet, Broadband Fact Sheet, available at: https://www.pewresearch.org/internet/fact-sheet/internet-broadband/

17 The Brattle Group, 2015, Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy, available at: https://www.brattle.com/wp-content/uploads/2017/10/7801_mobile_broadband_spectrum_-_a_valuable_resource_for_the_american_economy_bazelon_mchenry_051115.pdf

2. The unique role of licensed mid-band spectrum

Radio frequency spectrum has been described as one of the "Nation's most important national resources", owing to its role supporting the wireless industry.[18] The large sums invested by wireless operators on acquiring spectrum licenses demonstrates their vital importance to their networks. Figure 3 shows the cumulative revenues raised for the Treasury by wireless operators from spectrum licenses acquired in FCC auctions since 2014.

Figure 3: Cumulative revenues raised for the Treasury in licensed spectrum by wireless operators since 1994[19]



Source: FCC

Different frequencies within the usable range of wireless spectrum have different characteristics and use cases:

- Low-band frequencies below 1 GHz are ideal for providing wide-area coverage owing to their long-range propagation, and also penetrating deep indoors, but they are in limited supply so cannot support significant capacity;
- Lower mid-band spectrum lies between 1.0 and 3.0 GHz. This set of frequencies comprises core mobile frequencies like the PCS and AWS bands, which have been an integral part of

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18 https://www.whitehouse.gov/briefing-room/presidential-actions/2023/11/13/memorandum-on-modernizing-united-states-spectrum-policy-and-establishing-a-national-spectrum-strategy/

19 FCC, 2022, Fiscal Year 2023 Budget Estimates to Congress, available at: https://docs.fcc.gov/public/attachments/DOC-381693A1.pdf. Values for 2023 and 2024 are the same as 2022 as there have not been any auctions in those years.

wireless operators’ networks for a long time. These bands offer superior capacity to low-band frequencies;

- Mid-band spectrum, which comprises frequencies between 3.0 and 8.5 GHz, holds a unique position in wireless providers' spectrum portfolios, offering a combination of high bandwidth for capacity and good propagation; and
- High-band spectrum above 10 GHz offers exceptionally large capacity, but signals only travel for short distances, making it best suited for use in dense urban areas and venues like stadiums.

The C-Band, with frequencies around 3500 MHz, has emerged as the key 5G band worldwide. The outsized share of U.S network traffic now carried over this spectrum evidences its importance. For instance, Verizon, which invested heavily into acquiring C-Band licenses, reports that half of its network traffic is now carried by C-Band spectrum, and it expects this share will grow further.[20] Mid-band spectrum’s critical importance is also reflected in its wide-spread deployment. Ericsson estimates that 85% of the population in North America is covered by mid-band spectrum – only 5% below the reported coverage of low-band spectrum.[21]

To maximize the economic benefits that flow from this high capacity and speed, it is essential that sufficient spectrum is available so that wireless network capacity can keep up with the growing demand for data and provide for new innovative services. Currently, 380 MHz of mid-band is licensed for mobile in the U.S.[22] While this bandwidth may currently be sufficient to meet data demand, recent studies estimate that the U.S. will need between 400 MHz and 2 GHz of additional spectrum to support future traffic growth. For example, Brattle estimates that the U.S. will need an additional 400 MHz by 2027 and 1.4 GHz by 2032.[23] Similarly, the GSMA estimates that densely populated American cities, such as New York, will require between 1 and 2 GHz of additional mid-band spectrum by the end of the decade.[24]

Releasing additional mid-band spectrum suitable to power mobile connectivity is crucial if the U.S. is to retain its status as the global leader in wireless connectivity. Yet, the U.S. is at risk of falling behind, as other countries continue to award spectrum for mobile. China, for example, has already allocated

20 Verizon Communications Inc, 2024, Q2 2024 Earnings Call, available at: https://www.verizon.com/about/sites/default/files/2024-07/2Q24_Transcript_VZ_072224_0.pdf

21 Ericsson, 2023, 5G Network Coverage Outlook, available at: https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/network-coverage#:~:text=North%20American%20service%20providers%20have,at%20the%20end%20of%202023. Ericsson does provide a definition for mid-band in this document

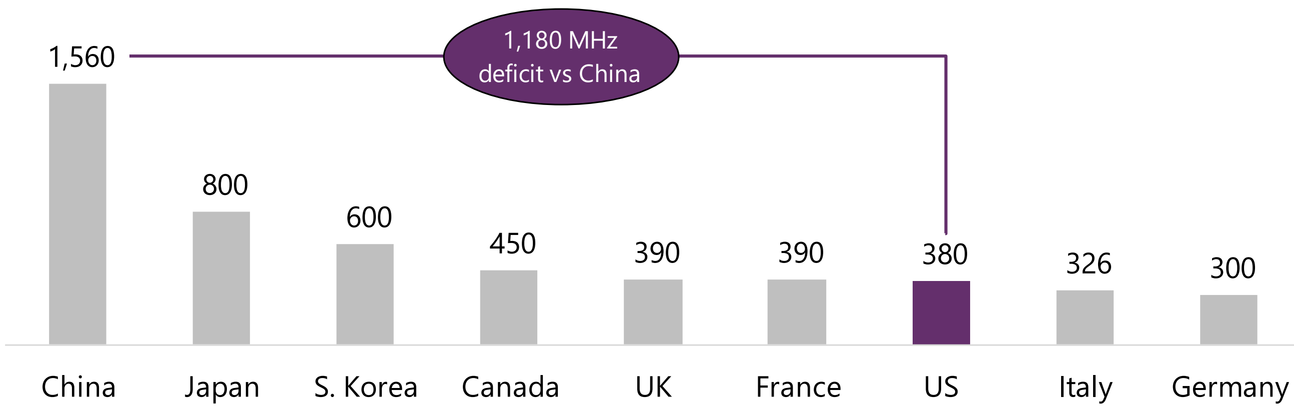
22 FCC, 2022, 2022 Communications Marketplace Report, available at: https://docs.fcc.gov/public/attachments/FCC-22-103A1.pdf

23 Brattle 2023, How much licensed spectrum is needed to meet future demand for network capacity?

24 Coleago, 2021, Estimating the mid-band spectrum needs in the 2025-2030 time frame, available at: https://www.gsma.com/connectivity-for-good/spectrum/wp-content/uploads/2021/07/Estimating-Mid-Band-Spectrum-Needs.pdf

700 MHz of spectrum in the 6 GHz band to meet the demand for mobile data.[25] As a result, China now leads the way in terms of spectrum allocations for mobile, and by 2027, is expected to have released up to1560 MHz of exclusive-use, high-power mid-band spectrum to commercial wireless operators.[26] Meanwhile, the U.S. is expected to lag four of the G7 member countries by 2027 if no additional mobile mid-band spectrum is released.

Figure 4: Mid-band spectrum allocated to mobile in different countries by 2027



Source: Adapted from Analysys Mason, 2022, Comparison of total mobile spectrum in different markets.
Notes: We have removed any spectrum that is not available on an exclusive use, full-power basis.

25 CTIA, 2023, China Commits to 5G Mid-Band Spectrum with 6 GHz Allocation: U.S. Needs Clear Response, available at: https://www.ctia.org/news/china-commits-to-5g-mid-band-spectrum-with-6-ghz-allocation-u-s-needs-clear-response#:~:text=The%206%20GHz%20band%20China,5G%20technology%20in%20the%20band

26 Analysys Mason, 2022, Comparison of total mobile spectrum in different markets, available at: https://api.ctia.org/wp-content/uploads/2022/09/Comparison-of-total-mobile-spectrum-28-09-22.pdf

3. The economic impact of allocating mid-band spectrum to mobile

Allocating additional mid-band spectrum to mobile – in the form of full-power flexible-use licenses – will create value throughout the economy. Although our analysis may not capture all of the benefits over time, in this paper we focus on the impact on mobile consumers, FWA consumers, industries that rely on mobile connectivity, and industries that support the wireless industry:

- Continued improvements to mobile service to millions of Americans.
- FWA consumers will benefit from additional coverage, increased penetration, higher speeds, higher additional data consumption, and lower prices.
- Industries that rely on mobile connectivity, such as video streaming, mobile games, and cutting-edge virtual reality and AI, will enjoy a more robust platform to deliver their services.
- Industries that support the wireless industry will benefit from the additional capital expenditure (capex) required to deploy the spectrum and the additional operational expense (opex) required to maintain the network.

We measure the economic impact of allocating each additional 100 MHz to mobile by estimating its impact on three metrics: gross domestic product (GDP), employment, and consumer surplus. GDP is a measure of value added to the economy, that is, the value of the gross output of an industry minus the value of the intermediate inputs required to produce the output. The additional GDP produced by the spectrum allocation is a measure of the value of the additional goods and services that can be consumed by final demand. Employment represents the number of additional one-year jobs. Consumer surplus is a measure of consumer benefit and is the difference between what consumers would be willing to pay and what they actually pay.

For all metrics, we estimate the impact of allocating mid-band spectrum by comparing a situation with additional spectrum against a counterfactual in which the spectrum is not allocated. Table 2 shows the metrics estimated for each channel affected by the spectrum allocation and deployment.

Table 2: The sources of the economic value of allocating mid-band spectrum to mobile

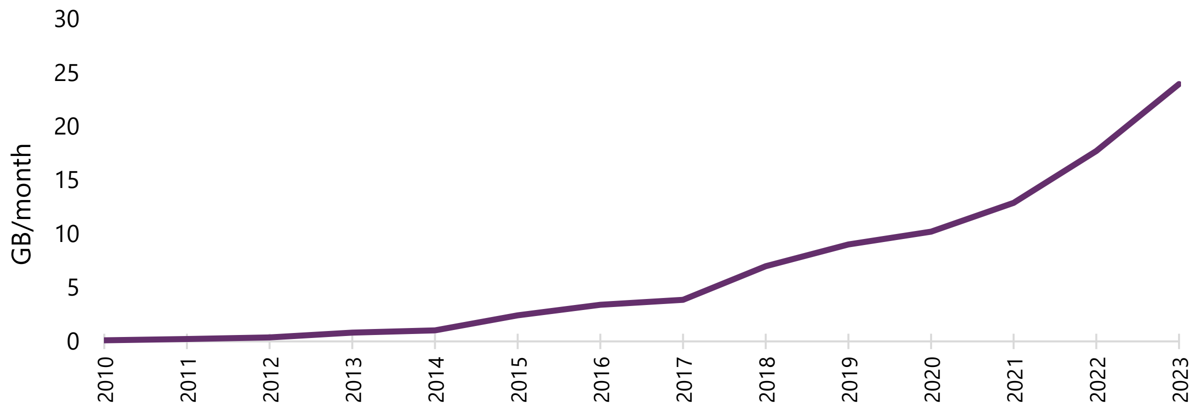
Channel	GDP	Employment	Consumer Surplus
Better mobile service at no additional cost			*
Improving broadband with FWA	*	*	*
Supporting industries that rely on mobile connectivity	*	*	
Supporting industries that serve the wireless industry	*	*	

We estimate the effect of each additional 100 MHz by first estimating the impact of 400 MHz and then dividing by four. Therefore, throughout the paper, we report the marginal impact of adding 400 MHz of spectrum and the average effect of 100 MHz (up to 400 MHz). Conceptually, we would expect the first 100 MHz to have a larger effect than the last 100 MHz, but we do not estimate the impact of 100 MHz blocks individually. However, the sum of the first four 100 MHz blocks would equal the effects reported in this paper. Beneficial effects would continue to accumulate beyond 400 MHz, and we estimate that by 2028 even 400 MHz of new 5G spectrum will not be enough to keep up with consumer demand. However, estimating the economic benefits beyond 400 MHz is outside this paper's scope.

3.1. Continued improvements to mobile service to millions of Americans

Mobile consumers will be the prime beneficiaries of the additional spectrum. Wireless operators will deploy and operate the spectrum to meet future growth in mobile data consumption. Figure 5 presents historical data on mobile data consumption from 2010 to 2023, measured in GB per month. The graph reveals significant growth in mobile data usage, reaching an average of 24 GB per month in the United States in 2023.

Figure 5: Historical mobile data traffic per capita in the U.S.



Source: TeleGeography. Note: Includes FWA.

For example, 15 years ago, data-intensive applications such as video streaming and video calls on mobile were not commonplace, whereas nowadays, they represent a typical consumer experience. For the most part, consumers have not had to pay additional dollars for the ever-increasing capabilities of mobile networks.

One way of estimating the value to consumers of the increased data consumption possible with the additional mid-band spectrum is to estimate the consumer surplus produced by the spectrum. The consumer surplus is the difference between the value consumers would be willing to pay and what they actually pay.

Without additional spectrum, networks would eventually become congested. Plans tiered by consumption would likely come back, and those consumers wishing to add additional data would pay more. This difference, what consumers would be willing to pay without additional spectrum and what they pay with spectrum, is the consumer surplus produced by the spectrum.

To estimate the impact of the spectrum on consumer surplus, we use previous research that links the price of the spectrum and consumer surplus. Conceptually, the price is inherently linked to the consumer surplus because both are based on comparing a future with and without additional spectrum. Table 3 shows the results of previous research linking spectrum prices and consumer surplus. Specifically, these papers show that the spectrum produces between 0.9 and 1.35 annual dollars of consumer surplus for every dollar of auction price.

Table 3: Consumer surplus to price multipliers

Paper	Consumer Surplus to Price Multiplier
Hazlett & Munoz 2004[a]	0.9
Hazlett & Munoz 2009[b]	1
Rosston 2003[c]	1.35

Source: (a) Hazlett and Munoz, 2004, A Welfare Analysis of Spectrum Allocation Policies," Joint Center: AEI-Brookings Joint Center for Regulatory Studies.
(b) Hazlett and Munoz, 2009, A welfare analysis of spectrum allocation policies. RAND Journal of Economics Vol. 40 No. 3: 424-454.

(c) Rosston, 2003, The long and winding road: the FCC paves the path with good intentions. Telecommunications Policy 27: 501-515.

We use the two most recent auctions to estimate the price of 400 MHz of mid-band spectrum: the C-Band (3.7 GHz) and the 3.45 GHz auctions. The C-Band achieved a total price of $94 billion for 280 MHz, and the 3.45 GHz achieved a total price of $22 billion for 100 MHz.[27] Table 4 shows the prices paid at the time of the auctions. The prices paid are not directly comparable because the volume of MHz available varied, and the C-Band prices are based on the 2010 census population and the 3.45 GHz on the 2020 census population. To address this, we calculate the price per MHz pop in 2025 US dollars by (a) using inflation to adjust the prices paid to 2025 prices[28]; and (b) applying a 2025 population projection to obtain 2025 prices per MHz-Pop.[29]

Table 4: Recent mid-band spectrum prices

	Total price paid	**MHz**	**Price paid $ MHz-Pop**	**2025 Price $ MHz-Pop**
C-Band	94.17	280	1.10	1.17
3.45 GHz	22.51	100	0.68	0.79
MHz-Pop Weighted Average				**1.07**

Source: NERA Economic Consulting

Combining the consumer multipliers and the average price for the mid-band spectrum, we obtain an implied annual consumer surplus of between $128 billion and $192 billion. We use three different discount rates typically used to discount spectrum consumer surplus to calculate the cumulative impact of allocating the spectrum.[30] Table 5 shows the present value for discount rates of 5%, 7.5%, and 10% using the multipliers identified in the three research papers on this subject.

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27 The C-band price includes gross proceeds, accelerated relocation payments to satellite companies, and relocation payments.

28 IMF Data Portal, Inflation rate, average consumer prices (Annual percent change), last retrieved November, 2024, available at: https://data.imf.org/?sk=4FFB52B2-3653-409A-B471-D47B46D904B5&sId=1485878855236

29 The 2025 sticker price per MHz-Pop is weighted based on each Partial Economic Area (PEA) population. To estimate the population for each PEA in 2025, we first calculated the population for each county in 2025 using data from the U.S. Census Bureau, available here: https://www.census.gov/data/tables/time-series/demo/popest/2020s-counties-total.html. We then aggregated the county populations to determine the total population for each PEA.

30 See, for example, Bazelon and McHenry, 2015, Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy. Available at: https://api.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf

Table 5: Present value of the consumer surplus

	Surplus to price multiplier	Implied annual consumer surplus ($B)	PV @ 5% ($B)	PV @ 7.5% ($B)	PV @ 10% ($B)
Hazlet & Munoz 2004[a]	0.9	128	2,561	1,707	1,280
Hazlet & Munoz 2009[b]	1	142	2,845	1,897	1,423
Rosston 2003[c]	1.35	192	3,841	2,561	1,920

Source: Ibid and NERA Economic Consulting

Given the high uncertainty in future spectrum prices in this band, we use the 10% discount rate to be conservative in our estimation. The future mid-band spectrum may be allocated at lower prices than the C-Band or 3.45 GHz since 400 MHz would more than double the stock of the mid-band spectrum. However, the alternative could be true, and the new spectrum could be as valuable, or even more valuable, given mounting capacity pressures and operators' desire to expand FWA and other services. We use the most recent auction data as we do not estimate future spectrum prices in this paper. Table 6 shows our selected consumer surplus. We show the marginal impact of adding 400 MHz and the average effect for each piece of 100 MHz.

Table 6: Consumer surplus associated with a better mobile service at no additional cost

	400 MHz	100 MHz
Concept	**Consumer Surplus ($B)**	**Consumer Surplus ($B)**
Hazlet & Munoz 2004[a]	1,280	320
Hazlet & Munoz 2009[b]	1,423	356
Rosston 2003[c]	1,920	480
Average	**1,541**	**385**

Source: Ibid.

3.2. Improving broadband with FWA

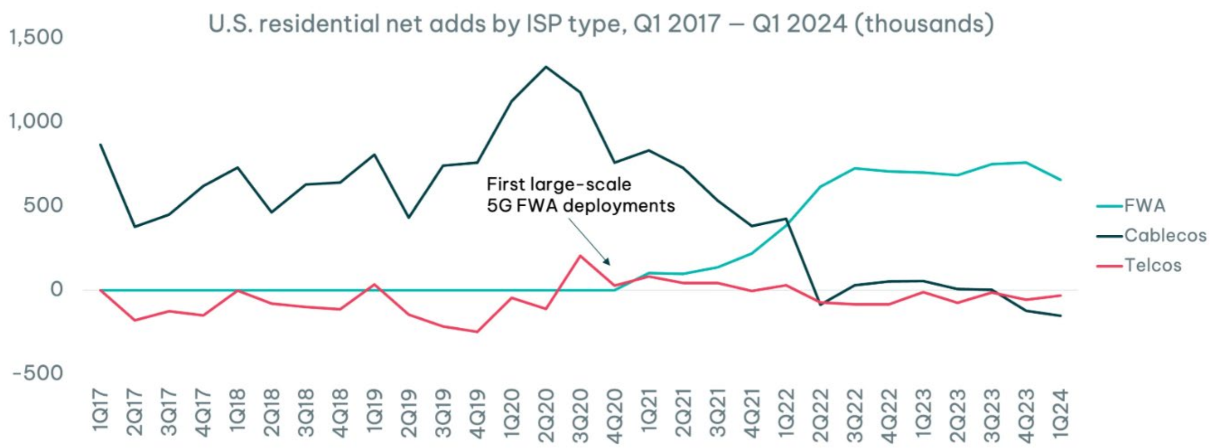
5G Fixed Wireless Access (FWA) is the fastest-growing terrestrial broadband technology.[31] In 2024, FWA accounted for nearly all of the net broadband additions and one of the largest terrestrial footprints.[32] Figure 6 shows the FWA adoption in the U.S. Starting around the fourth quarter of 2020, 5G FWA has accounted for the large majority of net adds in the fixed broadband market. This

31 Singer and Urschel, 2023, Competitive Effects of Fixed Wireless Access on Wireline Broadband Technologies. Available at: CTIA - Competitive Effects of Fixed Wireless Access on Wireline Broadband Technologies

32 Opensignal, 5G Fixed Wireless Access (FWA) Success in the US: A Roadmap for Broadband Success Elsewhere?, Available at: 5G Fixed Wireless Access (FWA) Success in the US: A Roadmap for Broadband Success Elsewhere? | Opensignal

tremendous growth has been achieved despite the capacity limitations faced by network operators. For example, T-Mobile reports a waiting list of over 1 million to become fixed wireless customers.[33]

Figure 6: FWA adoption growth in the U.S.



Source: Opensignal[34]

This expansion has generated great consumer benefits through lower prices and additional broadband coverage.[35] Additional mid-band spectrum for mobile will further improve FWA's capacity and economics. In particular, adding 400 MHz of mid-band to the existing 380 MHz of licensed spectrum will essentially double the mid-band capacity available for FWA. The additional capacity will increase the benefits of competition and penetration.

In terms of competition, Singer and Urschel estimate that the consumer benefits associated with more choice and price competition in the fixed market owing to the availability of mobile FWA are around $6 billion annually. Table 7 shows the breakdown of benefits by market type and benefit channel. At current prices, some consumers switch from cable or fiber to FWA, whereas others choose to stay with their existing technologies. The switchers benefit from an improved match between the service they need and the price they pay. Those who decide to stay benefit from the lower prices offered by cable and fiber providers in response to the FWA provider's offerings.

33 Fierce Network, 2024. The 1 million people on T-Mobile's fixed wireless waiting list will get a little help from fiber, Available at: https://www.fierce-network.com/broadband/fiber-will-help-1-million-people-t-mobiles-fixed-wireless-waiting-list

34 Opensignal, 5G Fixed Wireless Access (FWA) Success in the US: A Roadmap for Broadband Success Elsewhere?, Available at: 5G Fixed Wireless Access (FWA) Success in the US: A Roadmap for Broadband Success Elsewhere? | Opensignal

35 https://www.ctia.org/news/fcc-shows-how-wireless-is-delivering-much-needed-home-broadband-competition-closing-the-digital-divide

Table 7: Yearly consumer benefits of FWA in markets with existing service

Market type	Benefits from switching per annum ($M)	Price savings owing to competition ($M)	Total ($M)
Cable	369	5,735	6,104
Cable/Fiber	27	219	246
Total	**396**	**5,954**	**6,350**

Source: Singer and Urschel (2023)

A critical assumption in Singer and Urschel's research is that FWA providers obtain all the spectrum they need to compete effectively with other terrestrial technologies. They do not estimate the spectrum requirements to materialize the benefits they estimate. However, they mention that GSMA estimates that an additional 2 GHz of mid-band spectrum is needed to sustain FWA delivering a download data rate of 100 Mbps in rural communities in the longer term.[36] Based on these estimations, we attribute 20% of the total benefits to the additional 400 MHz in consideration in this paper. In addition, we estimate the preset value of these benefits based on a discount rate between 5% and 10%. Our calculations are presented in Table 8.

Table 8: Present value of the consumer benefits associated with 400 MHz of additional mid-band spectrum

Market type	Total ($M)	Benefit of 400 MHz ($M)	PV @ 5% ($M)	PV @ 7.5% ($M)	PV @ 10% ($M)
Cable	6,104	1,221	24,416	16,277	12,208
Cable/Fiber	246	49	982	655	491
Total	6,350	1,270	25,398	16,932	12,699

Source: NERA Economic Consulting

We estimate the benefits of additional penetration in three steps. First, we identify the impact of the additional spectrum on broadband coverage. Second, we estimate the impact of the marginal coverage on national broadband penetration. Finally, we use previous research to identify the impact of increases in penetration on GDP and employment.

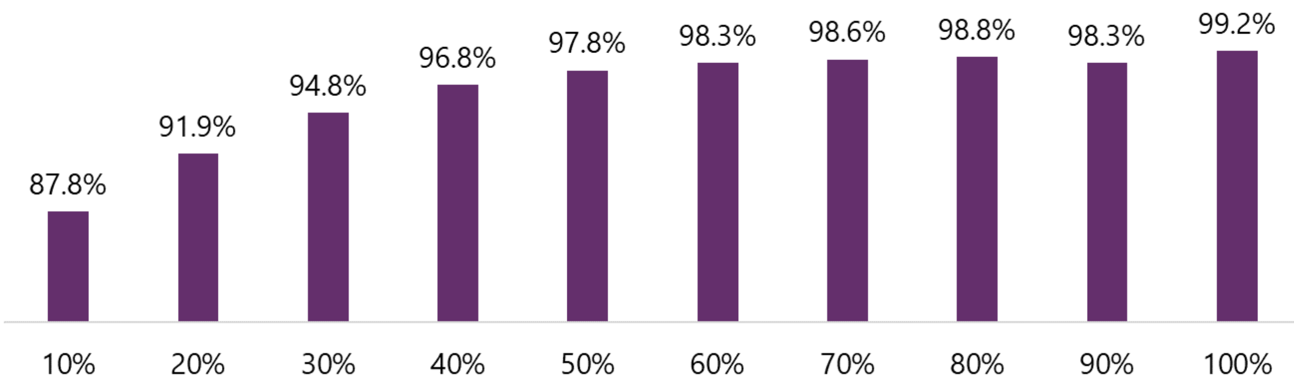
According to the latest national broadband map released by the FCC, 96.2% of the country is covered by terrestrial technologies.[37] Terrestrial technologies include cable, fiber, FWA, and others. Figure 7 shows terrestrial coverage by county density decile. We ordered all counties by residential unit density and created buckets containing 10% of the country's total residential units. We show the coverage of

36 Singer and Urschel, 2023, Competitive Effects of Fixed Wireless Access on Wireline Broadband Technologies. Available at: CTIA - Competitive Effects of Fixed Wireless Access on Wireline Broadband Technologies

37 https://broadbandmap.fcc.gov/data-download. November 13 2024.

terrestrial technologies for each bucket. The data shows that more densely populated counties have greater coverage.

Figure 7: Terrestrial broadband penetration by density decile



Source: NERA analysis of FCC data
Note: Each column represents 10% of the residential locations in the U.S. The first column represents the least-dense 10%, and the last column the most-dense 10%.

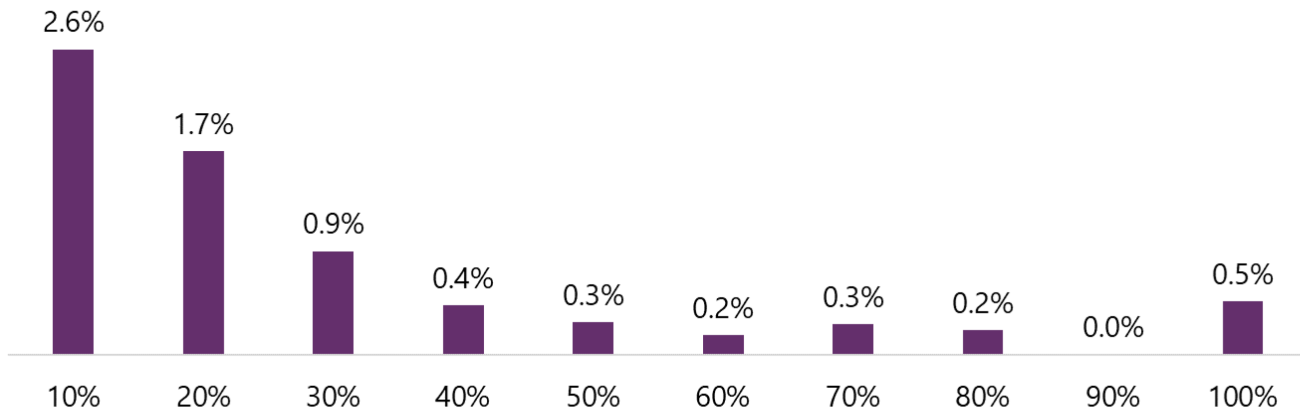
We first focus on the impact of the spectrum on coverage. In our estimation, we consider a location covered by FWA if the base stations that can serve the location have enough capacity to provide the service. Therefore, additional spectrum increases coverage by expanding the capacity of existing base stations and increasing the profitability of new ones. We use county unit density to estimate the impact of additional spectrum on additional coverage.

In particular, we assume that with an additional 400 MHz of mid-band spectrum, FWA coverage in a given country would be similar to today's coverage of a county with 2.05 times its density – an increase proportional to the spectrum holdings. Previous research by the GSMA has found that the number of units that can be served from a single base station is proportional to the spectrum holding. In particular, a base station can support 90 users with 400 MHz, 315 with 1.4 GHz, and 540 with 2.4 GHz.[38]

We estimate that adding 400 MHz of mid-band spectrum will increase the total number of residential units covered by 1.1 million, or 0.7% of the total residential units. Figure 8 shows the increase by county decile. Based on our estimation, the increase will be more pronounced in the sparser counties where terrestrial deployment with other technologies is more expensive. Our calculation also assumes a modest increase in coverage in some of the top 10% more densely populated counties. While these counties enjoy a relatively high terrestrial coverage, FWA providers still have the potential to increase coverage if they can secure the capacity needed to serve their customers.

[38] GSMA and Coleago Consulting, 2021. Estimating the mid-band spectrum needs in the 2025-2030 time frame (Global Outlook), available at: [Estimating-Mid-Band-Spectrum-Needs.pdf.]

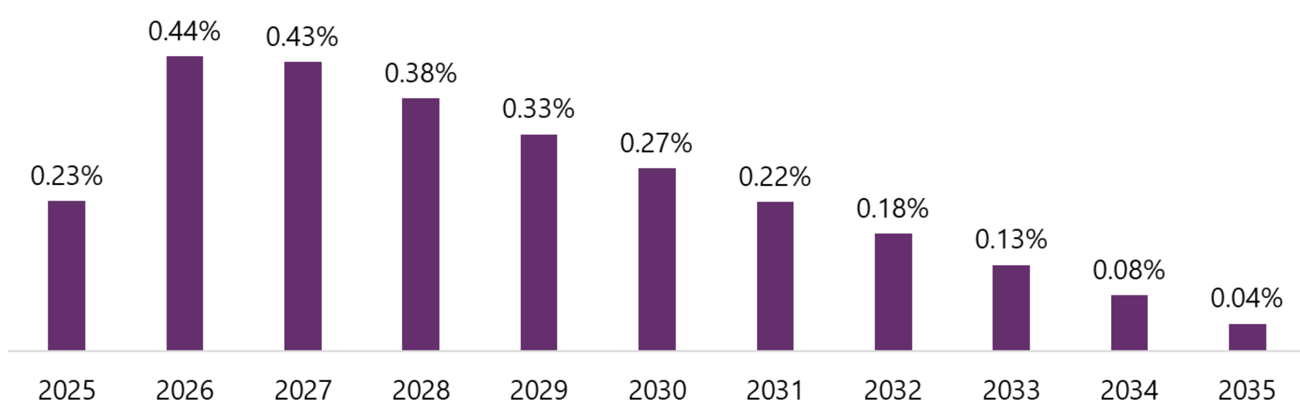
Figure 8: Increase in coverage associated with an additional 400 MHz of mid-band spectrum



Source: *NERA Economic Consulting*

To estimate the impact on penetration, we assume that other terrestrial technologies eventually would cover the same residential units by 2035. That is, the additional spectrum would create an initial increase in penetration but gradually fade out when compared to a counterfactual in which other terrestrial technologies would eventually reach the same coverage and penetration. We assume that the additional penetration caused by the spectrum would reach a peak of 50% of the newly covered residential units and slowly fade out by 2035. Figure 9 shows the increased broadband penetration caused by the additional spectrum.

Figure 9: Increase in penetration associated with an additional 400 MHz of mid-band spectrum



Source: *NERA Economic Consulting*

Finally, we use employment and GDP forecasts and results from the literature to estimate the impact of the increased penetration on GDP and employment. The Bureau of Economic Analysis estimated that GDP was 27.36 trillion in 2023.[39] We use a constant 2% annual growth rate to project GDP until

[39] Source: Bureau of Economic Analysis, 2024, Gross Domestic Product (Second Estimate), available at: https://www.bea.gov/sites/default/files/2024-11/gdp3q24-2nd.pdf

2035. Regarding jobs, the Bureau of Labor Statistics projects that total jobs will grow from 169.9 million in 2023 to 176.6 million in 2033.[40] We complement these forecasts with literature estimations. In particular, the ITU has estimated that a 1% increase in penetration increases GDP by 0.1856%.[41] Similarly, Crandall et al. 2007 estimated that a 1% increase in penetration increases jobs by between 0.2% and 0.3%.[42] Our estimated economic impact is shown in Table 9.

Table 9: Economic impact of increased FWA penetration associated with 400 MHz

	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
GDP ($ B)	12.1	24.3	24.3	21.7	19.0	16.3	13.6	10.9	8.2	5.5	2.7
Employment ('000)	96.3	190.0	187.2	164.1	141.5	119.6	98.2	77.4	57.3	37.6	18.5

Source: NERA Economic Consulting

3.3. Supporting industries that rely on mobile connectivity

The wireless industry provides essential services that support a wide range of other industries and economic activity. Originally, the wireless industry supported basic communications via text messaging and voice calls. Today, it enables much richer forms of interaction, allowing people to share not only messages and voice calls, but also photos, videos, and other forms of content through social media platforms. This has given rise to companies like Meta and Snapchat, which collectively generated $139 billion in output in the U.S. in 2024 and account for 35% of total mobile network traffic.

Likewise, the motion picture and sound recording industry has been transformed by allowing people to consume content on their mobile devices, wherever they are. Video and audio streaming generated 32% of network traffic in 2024 and services like Netflix and Spotify generated $70 billion in output in the U.S. While social media and content streaming account for the majority of mobile network traffic and generate billions in output, the impact of the wireless industry is far broader.

Search engines like Google and Bing have seen significant increases in usage owing to the availability of wireless services. Google estimates that 63% of its organic search traffic in 2023 originated from mobile devices, highlighting the key role that wireless networks play in enabling access to information and e-commerce. Today, over three-quarters of U.S. adults report buying things online using a smartphone.[43]

[40] Source: Bureau of Labor Statistics, 2024, EMPLOYMENT PROJECTIONS — 2023–2033, available at: https://www.bls.gov/news.release/pdf/ecopro.pdf

[41] Source: ITU, 2021, The economic impact of broadband and digitalization through the COVID-19 pandemic, available at: https://www.itu.int/dms_pub/itu-d/opb/pref/D-PREF-EF.COV_ECO_IMPACT_B-2021-PDF-E.pdf

[42] Crandall et al., 2007, The Effects of Broadband Deployment on Output and Employment: A Cross-sectional Analysis of U.S. Data, Issues in Economic Policy, The Brookings Institution.

[43] Pew Research Center, 2022, For shopping, phones are common and influencers have become a factor, available at: https://www.pewresearch.org/short-reads/2022/11/21/for-shopping-phones-are-common-and-influencers-have-become-a-factor-especially-for-young-adults/

The mobile gaming industry, too, generates vast amounts of output and leverages the fast connection speeds and low latencies available on modern wireless networks to allow users to play games on their mobile devices. The file-sharing industry, meanwhile, has taken advantage of wireless networks to allow secure, mobile access to files that would traditionally only have been accessible on a home or office fixed network. In doing so, the file sharing industry accounts for 7% of mobile network traffic.

In Table 10 below, we outline the output and mobile network traffic generated by the five key uses for mobile networks discussed above. We focus on these use cases as they account for most of mobile network traffic today and significantly contribute to the American economy. However, we note that these use cases do not account for all network traffic nor all of the economic activity attributable to wireless networks. Nor can they account for new uses of the network that could develop when innovators are assured of the capacities necessary to support those uses. Additionally, 5G and future wireless technologies are increasingly serving as the foundation for enterprise connectivity innovations, and the economic benefits of those should expand over time assuming sufficient spectrum is made available to account for those use cases. Therefore, the figures in this section should be interpreted as a conservative estimate of the total impact on downstream industries that an additional mobile allocation of 400 MHz of mid-band spectrum would have on the American economy.

Table 10: Output and network traffic generated by selected use cases for wireless connectivity

	Social media	**Video and audio streaming**	**Device and cloud gaming**	**General web apps**	**File sharing**
Share of total mobile network traffic	35%	32%	7%	5%	7%
Output generated in 2024 ($B)	139.0	73.0	55.4	287.5	7.3
Share of traffic taking place on mobile	18%	8%	10%	7%	8%
Industry output attributable to mobile ($B)	24.6	5.9	5.4	21.5	0.6
Output CAGR	16.7%	6.1%	3.4%	10.4%	0.4%

Source: Network usage data from Sandvine Global Internet Phenomena Report 2024[44]; industry output data from IbisWorld Market Research Reports[45]. Output attributable to mobile is equal to the produce of industry output share of traffic taking place on mobile networks. The output for general web apps is assumed to be from search only.

This economic activity generates an ever-increasing demand for data as it flows through wireless networks. However, the demand for data is not evenly distributed throughout the day, with peak usage generally occurring in the evening, when people consume the most data as they stream content, engage with social media, or browse the internet. Figure 10 displays the amount of video

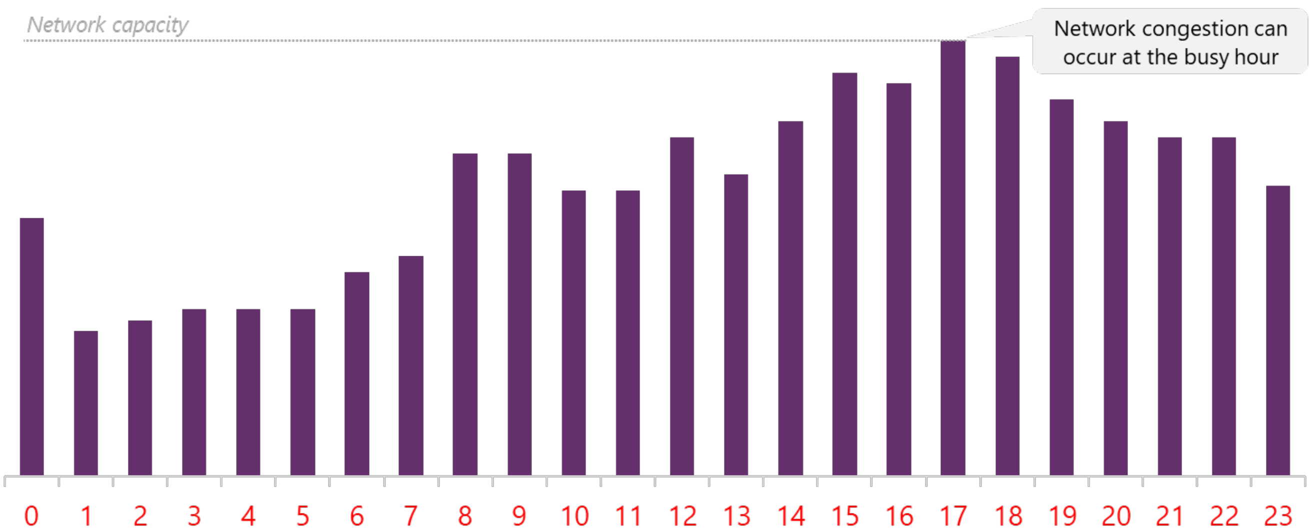
[44] Sandvine, 2024, The Global Internet Phenomena Report, available at: https://www.sandvine.com/phenomena

[45] IbisWorld, 2024, Market Research Reports, available at: https://www.ibisworld.com/

streaming traffic taking place over mobile networks by hour. Peak usage occurs between 5 and 6 p.m., whereas usage is significantly lower between 1 and 5 a.m., when most people are sleeping.

Data traffic demand during the busiest hours places wireless networks under significant strain, reducing customer service quality. The reduction in speeds, higher latencies, or interrupted connectivity affects wireless subscribers and hampers the ability of industries that rely on this connectivity to drive their businesses. For example, if a consumer is unable to watch a streaming video owing to buffering as a result of network strain, they will inevitably churn away from the streaming platform to do something else. Consequently, the streaming platform loses out on ad revenue that it would have otherwise obtained had the network enabled the user to stream content smoothly.

Figure 10: Video streaming usage on mobile networks by hour



Source: Adapted from Sandvine Mobile Internet Phenomena Report 2021

Today, network congestion only affects a relatively low proportion of total network traffic and only constrains economic activity at the busiest hours. However, the demand for data continues to grow as the quality of content streamed over the internet improves, online games require more bandwidth and more commerce takes place over the internet. As use cases continue to demand more data, the strain placed on networks will intensify, not just at the busiest hour but starting to affect more hours throughout the day. Without additional spectrum, mobile networks will become more congested across wider swathes of the day, a problem that may only be partially alleviated by expensive investments in densifying networks. This lost traffic will directly translate into lost sales and foregone revenue across the many industries that depend on reliable wireless communications.

To estimate the economic impact that an additional allocation of 400 MHz of spectrum to mobile would have, we estimate the value of the output that would be foregone between 2025 and 2040 if no additional spectrum was allocated to mobile.

Volume of mobile traffic that would be foregone without an additional 400 MHz of spectrum

We begin by projecting mobile data traffic from 2023 to 2040 by applying a 16% CAGR to the current mobile traffic volume. This is the rate at which Ericsson forecasts mobile data traffic will grow until the end of the decade.[46] We then forecast the unconstrained, desired network usage for each hour of the day using the estimated share of traffic occurring at each hour from Sandvine hourly network usage estimates.

Next, we estimate the volume of traffic that could be served at each hour under two spectrum allocation scenarios:

- no additional spectrum is allocated to mobile; and
- an additional 400 MHz of spectrum is allocated to mobile.

Under the first scenario, we assume that without additional spectrum, mobile data network capacity at a given hour cannot exceed present-day traffic at the busiest hour to forecast the volume of traffic that can be served in each hour given spectrum constraints. For the second scenario, we assume that the maximum hourly traffic capacity that can be carried is proportional to the quantity of spectrum that is allocated to mobile. An additional 400 MHz of spectrum would therefore increase the capacity of the network at the busy hour by 36% relative to the first scenario.[47] We assume that the pace of network densification is identical in each of the two scenarios. In reality, network operators are likely to build cell sites and densify their networks at a faster rate under the first scenario to minimally compensate for a shortage of spectrum. However, the rate in data growth exceeds the pace at which operators densify their networks to such a large degree that this simplifying assumption has little impact on results. Between 2013 and 2023, the number of cell sites deployed in the U.S. grew at an average of 3.6% a year.[48] Over that same period, wireless data grew at a rate of 42% per year, from 3 trillion MB in 2013 to over 100 trillion MB in 2023.[49]

The difference in traffic between these two scenarios allows us to identify the volume of traffic that would be foregone were no additional spectrum to be allocated to mobile. We note that because our model examines the difference between the two traffic-constrained scenarios, our estimated economic impact is robust to the baseline level of the total unconstrained traffic used and the growth rates assumed over the projected period. To see this, observe that in Figure 11, the rapid growth in the unconstrained traffic (in yellow) does not lead to unbound growth in traffic differences between the two constrained traffic scenarios (in blue and purple). Moreover, the more aggressive the traffic growth assumption, the smaller the estimated economic impact of an additional 400 MHz allocation because network congestion becomes severe early on, and the marginal spectrum alleviates a

46 Ericsson, Mobile data traffic outlook, available at: https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast

47 There is currently 1123 MHz of spectrum allocated to mobile in the U.S. An additional 400 MHz of spectrum represents an increase in the allocation of 36%.

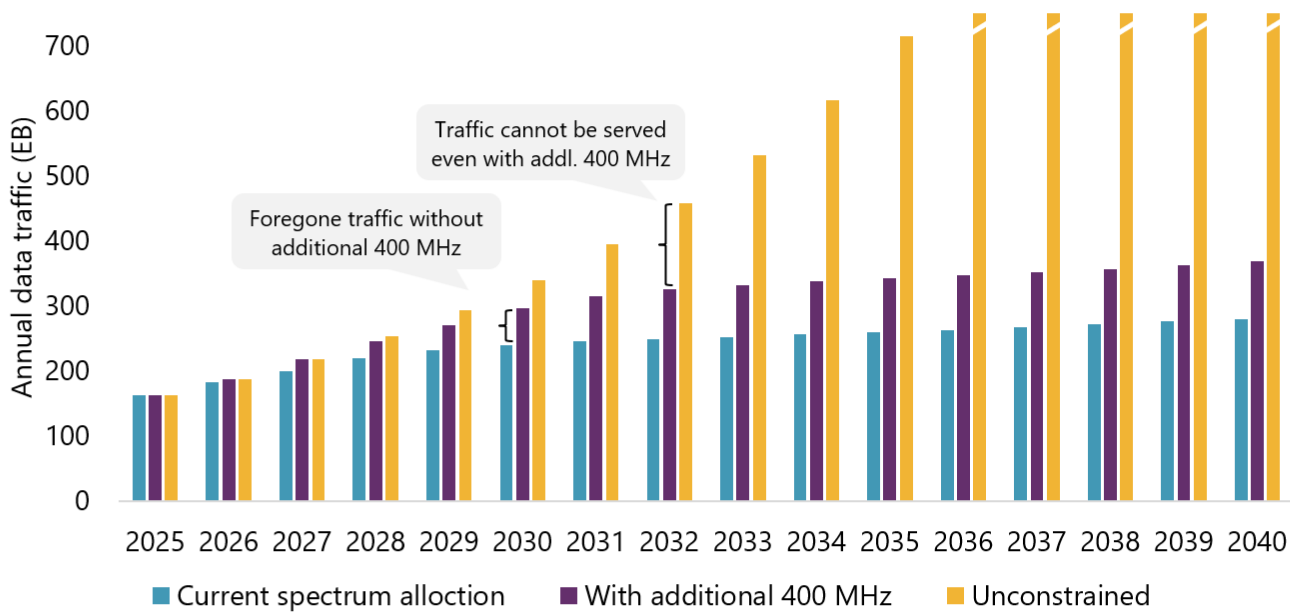
48 CTIA, 2022, Summary of CTIA's Annual Wireless Industry Survey, available at: https://api.ctia.org/wp-content/uploads/2022/09/Summary-of-CTIAs-Wireless-Industry-Survey-2022.pdf; and

CTIA, 2024, 2024 Annual Survey Highlights, available at: https://www.ctia.org/news/2024-annual-survey-highlights#:~:text=By%20the%20end%20of%202023,reforms%20were%20enacted%20in%202018.

49 *Ibid.*

relatively small proportion of the lost traffic. This counsels for a pipeline of additional spectrum with longer foresight, accounting for spectrum needs beyond these initial 400 MHz benefits.

Figure 11: Mobile data traffic with and without additional 400 MHz of spectrum



Source: NERA analysis based on Ericsson Mobility Visualizer traffic data for North America

Traffic associated with mobile network use cases

To attribute total mobile traffic across the five use cases identified in Table 10 we multiply total network traffic forecasts by the share of mobile traffic accounted for by each application. We assume that the relative proportion of mobile traffic generated by each application remains constant through to 2040.

Output associated with mobile network use cases

We forecast the output of each of the five use cases listed in Table 10 until 2040 using CAGRs obtained from IbisWorld Market Research Reports. We then estimate the share of this output that is attributable to mobile under the assumption that output is proportional to traffic. We multiply total output by the share of traffic associated with that application that takes place over mobile. For many applications, output is closely related to the volume of traffic. For example, the advertising revenue of a social media platform is closely linked to the traffic that platform serves.

Value of additional traffic served with additional 400 MHz

We recognize that an application's output will not necessarily have a linear relationship with the traffic it generates. For instance, some of the additional bandwidth consumed by say, Instagram, will be associated with serving higher quality video content rather than being generated by new users. And while higher definition content will attract more users and improve user retention, this effect will likely exhibit diminishing marginal returns. To account for this, we estimate each application's marginal output that is generated with each additional exabyte (EB) of data per year. This means for social media applications, for example, each additional EB of data generates about 30% less revenue in 2030 than it does in 2025.

We then obtain the marginal output that would be generated by each application with an additional 400 MHz allocation to mobile by multiplying the extra traffic generated by that application with additional spectrum by the marginal output generated by each incremental EB of data.

Obtaining estimated GDP and employment impacts

We use input-output multipliers to estimate the total impact of the additional direct output generated by each application on GDP and employment. We use type II multipliers to account for the direct, indirect, and induced effects of the additional direct output. We identify the input-output multipliers for each application based on previous research by Compass Lexecon as described in the table below.[50] We use the latest data from the Compass Lexecon report, which examines the period 2011-2020.

To obtain the GDP multiplier we divide total GDP generated by the application by its direct output. We benchmark the implied GDP multipliers against those in the Regional Input-Output Modeling System (RIMS) dataset produced by the Bureau of Economic Analysis (BEA). We observe that the multipliers in Table 11 are slightly higher than the RIMS multipliers for industries in the Information sector. However, we note that this is to be expected given these industries' deep integration within the economy and substantial spillover effects, which are not captured in RIMS multipliers owing to their regional nature.

To obtain the employment multiplier we divide total jobs enabled by the application by its direct output. We benchmark the implied employment multipliers against those in the RIMS dataset as well as employment multipliers produced by the Economic Policy Institute. We observe that the multipliers in Table 11 for device and cloud gaming, general web apps and file sharing are consistent with the multipliers published by BEA and the Economic Policy Institute. However, the employment multiplier we obtain from the Compass Lexecon paper for social media is 18.7. The figure is higher than expected, and we therefore use a more conservative multiplier of 9.3 from the Economic Policy Institute.[51]

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50 Compass Lexecon, 2022

51 Economic Policy Institute, 2019, Updated employment multipliers for the U.S. economy, available at: https://www.epi.org/publication/updated-employment-multipliers-for-the-u-s-economy/. The value of 9.3 is the total employment multiplier associated with the software publisher's industry.

Table 11: Input-output multipliers associated with each application

Application	GDP multiplier	Employment multiplier
Social media	1.82	9.3
Video and audio streaming	1.82	9.3
Device and cloud gaming	0.51	8.5
General web apps	2.00	8.2
File sharing	2.00	8.2

Source: Compass Lexecon (2022) and Economic Policy Institute (2019). For video and audio streaming, we use the same multipliers as for the social media industry. For general web apps and file sharing, we use the same multipliers as for search engines. The employment multiplier is scaled to produce jobs per $1M in direct output.

Economic impact

Table 12 shows the total impact on U.S. GDP and employment of an additional 400 MHz by selected applications between 2025 and 2040. Over this period, we estimate that the social media, video and audio streaming, mobile gaming, general web apps and file sharing industries will generate around 750 billion dollars in GDP. At the same time, these industries will generate close to 4 million jobs.

The allocation of additional mid-band spectrum for mobile may give rise to new applications and business models that are not feasible today owing to network constraints. In our calculation, we only estimate the impact of network constraints on foregone revenue from existing applications and businesses. With more bandwidth and faster speeds, new applications like VR gaming or improved telehealth services may emerge, driving the creation of further output, GDP, and jobs. In particular, AI is expected to greatly accelerate data growth. AI mobile data is expected to grow at a 55% CAGR between 2023 and 2033, increasing the need and value of the spectrum. AI traffic is expected to be bursty and unpredictable, require low latency, and increase the demand for the uplink (for applications using cloud computing).[52]

Table 12: Total economic impact generated by an additional 400 MHz for selected applications, 2025-2040

Application	GDP ($B)	Employment (M)
Social media	342	1.7
Video and audio streaming	74	0.4
Device and cloud gaming	18	0.3
General web apps*	311	1.3
File sharing	8	0.0**
Total	**753**	**3.7**

*Source: NERA Economic Consulting. *General web apps includes 5% traffic share plus residual traffic share of 14%*
***0.031*

[52] Harri Holma, The AI revolution: Preparing for a surge in 5G uplink traffic

3.4. Supporting industries that serve the wireless industry

The wireless industry will spend billions of dollars deploying and operating 400 MHz of additional mid-band spectrum – increasing the demand for equipment, construction, power, and other industries that serve the wireless industry.

To estimate the economic impact of the additional capex and opex associated with the deployment and operation of the spectrum, we follow two steps:

1. We estimate the additional capex and opex required to deploy and operate 400 MHz of mid-band spectrum nationwide.
2. We use an input-output model and data from the Bureau of Economic Analysis to estimate the economic impact of the marginal capex and opex on GDP and employment.

Capex and opex required to deploy and operate 400 MHz of mid-band

We estimate that the capex required to deploy 400 MHz of mid-band spectrum is approximately $35 billion over seven years. The capex will be used to install new equipment and infrastructure, requiring additional expenses to operate and maintain. We estimate the associated additional operating expenses will be around $9 billion annually.

We estimate the required capex to deploy 400 MHz of mid-band spectrum based on the capex spent deploying 280 MHz of C-Band spectrum (3.7 GHz). We estimate the relevant opex based on previous studies establishing that wireless operators typically spend 25% of the capex as yearly opex.[53] Based on previous studies, we project that deployment would take about seven years and that equipment would be operated for ten years.[54] [55]

Based on company filings, we estimate that deploying 280 MHz of C-band required about $20 billion between 2021 and 2024. AT&T has reported spending $7 billion in deploying C-Band and Verizon has reported $10 billion.[56] [57] Based on these figures, we estimate that the total capital expenditure required to deploy 280 MHz of C-Band was about $20 billion. Table 13 shows the MHz-Pop weighted holdings for each operator and its associated capex.

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[53] GSMA and Coleago Consulting, 2021. Estimating the mid-band spectrum needs in the 2025-2030 time frame (Global Outlook), available at: Estimating-Mid-Band-Spectrum-Needs.pdf

[54] Prieger, 2020. An Economic Analysis of 5G Wireless Deployment: Impact on the U.S. And Local Economies, available at: Microsoft Word - ACT Report -- An Economic Analysis of 5G (Feb 2020).docx

[55] Sosa and Rafert, 2019. The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States, available at: The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States

[56] Telecoms.com, 2021, AT&T to spend less than Verizon on C-band 5G rollout, available at: https://www.telecoms.com/5g-6g/at-t-to-spend-less-than-verizon-on-c-band-5g-rollout

[57] Telecoms.com, 2023. Verizon confirms climb-down from C-band capex peak, available at: Verizon confirms climb-down from C-band capex peak

Table 13: Implied capex associated with deploying 280 MHz of C-Band

Operator	MHz	Disclosed Capex ($B)	Average Capex per 100 MHz	Implied CAPEX
AT&T	79.8	7	8.77	7.00
T-Mobile	27.4			1.94
UScellular	4.9			0.35
VZW	160.7	10	6.22	10.00
Other	7.1			0.50
Total	**280**		**7.07**	**19.79**

Source: NERA Economic Consulting based on public filings

Based on the C-Band capital expenditures and previous studies that have established the timeline and capex, we estimate the marginal opex and capex associated with deploying the spectrum. Table 14 shows the deployment schedule. For purposes of our analysis, we have assumed that spectrum becomes available in four tranches of 100 MHz and that total deployment will take seven years. We believe this is a reasonable assumption given past trends, but different bands have different timelines, and buildout would vary depending on how much spectrum is made available at what time. We assume ten years of opex are triggered any time capex is spent. We adjust the 2021 C-Band reference numbers by inflation with respect to their initial deployment years but make no additional adjustments on projected capex or opex.

Table 14: Estimated capex and opex associated with four tranches of 100 MHz of mid-band spectrum

Year of initial deployment	Total capex ($B)	Yearly opex ($B)
2025	8.57	2.142
2026	8.73	2.182
2027	8.91	2.228
2028	9.10	2.275
Total	**35.31**	**8.83**

Source: NERA Economic Consulting

There is uncertainty regarding the quantity and availability dates for mid-band spectrum, and the scenario presented here is a hypothetical. If quantities change, our calculations will scale down proportionally for blocks of 100 MHz up to 400 MHz. Spectrum capex and opex depend more on the number of carriers than the bandwidth. In mid-band spectrum, the maximum current carrier is 100 MHz – which means that our calculations are proportional in blocks of 100 MHz but would not be proportional for smaller increments. If dates change, inflation-adjusted figures will change in proportion to the delay or acceleration with respect to the base schedule. However, inflation has a minor impact on these calculations, provided that projected inflation for the relevant period is about 2.1% per year.[58]

I-O GDP and employment multipliers

We use input-output multipliers to estimate the impact of the marginal capex and opex on industries that serve the wireless industry. First, we identify the industries where the marginal capex and opex are spent. Second, we distribute the total annual expenditure to each industry. Finally, we identify the multipliers associated with those industries to compute the effect of the marginal expenditure.

We identify the industries and their corresponding weights based on previous research. For capex, we use the industries and weights identified by Sosa and Rafert (2019).[59] For opex, we obtained the weights from an Analysis Mason paper identifying the destination of opex, and we matched their categories with NAICS industries.[60] We obtained the multipliers for each industry from the Bureau of Economic Analysis.[61] We use type II multipliers to account for the direct, indirect, and induced effects of the expenditures on GDP and employment. Table 15 shows the industries affected by the marginal capex and opex, their GDP and employment multipliers, and their weight in each category.

Table 15: Multipliers associated with the additional capex and opex

Industry	Gross Domestic Product[1]	Employment[1]	CAPEX weight[2]	Opex weight[3]
334210 Telephone apparatus manufacturing	1.03	7.1	15%	
334220 Broadcast and wireless communications equipment	1.11	7.4	47%	10%
335920 Communication and energy wire and cable manufacturing	0.80	6.3	10%	
233240 Power and communication structures	1.17	9.8	29%	44%
221100 Electric power generation, transmission, and distribution	1.02	4.7		8%
811200 Electronic and precision equipment repair and maintenance	1.31	14.9		38%
Total Capex	**1.10**	**8.03**		
Total Opex	**1.21**	**11.12**		

58 IMF, 2024, World Economic Outlook, October 2024

59 Sosa and Rafert, 2019. The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States, available at: The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States

60 Anil Rao, 2020. Network automation is key to delivering significant opex reduction and increasing agility in the 5G era

61 RIMS II multipliers, Bureau of Economic Analysis (BEA), see: RIMS II multipliers | U.S. Bureau of Economic Analysis (BEA)

Source: (1) RIMS II multipliers, Bureau of Economic Analysis (BEA)
(2) Sosa and Rafert, 2019. The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States
(3) Anil Rao, 2020. Network automation is key to delivering significant opex reduction and increasing agility in the 5G era

Economic impact

We use the total capex over seven years and the total opex over ten years to estimate the total effect on the economy on GDP and employment. Table 16 shows the total capex and opex we estimate are needed to deploy 400 MHz of mid-band spectrum. The table also shows the total years we are considering in our economic impact. Our opex estimation is likely conservative as operators may maintain the equipment longer than 10 years.

Table 16: Incremental capex and opex required to deploy and operate 400 MHz of mid-band spectrum

	Total ($B)	Annualized ($B)	Years
Capex	35.3	5.0	7
Opex	88.3	8.8	10
Total	123.6	13.9	

Source: NERA Economic Consulting

Table 17 shows our economic impact estimation in terms of GDP and jobs. As with other estimations in this paper, we report the marginal impact of 400 MHz, and the average impact of each 100 MHz.

Table 17: Economic impact of deploying and maintaining 400 MHz of mid-band spectrum

	400 MHz		100 MHz	
	GDP (B)	**New Jobs**	**GDP (B)**	**New Jobs**
Capex	38.8	283,626	9.7	70,906
Opex	106.5	981,520	26.6	245,380
Total	**145.3**	**1,265,146**	**36.3**	**316,287**
Annualized				
Capex	5.5	40,518	1.4	10,129
Opex	5.3	49,076	1.3	12,269
Total Annualized	**10.9**	**89,594**	**2.7**	**22,399**

Source: NERA Economic Consulting

4. Allocating additional spectrum to Mobile vs Wi-Fi

Spectrum is a scarce natural resource with many competing uses. Two key conflicting uses for spectrum are mobile telecommunications, which benefits most from high-power exclusive-use licenses, and unlicensed use, which includes Wi-Fi, where users share spectrum. To ensure the U.S. remains a leader in wireless telecommunications, and for spectrum to deliver maximum economic value, both use cases require access to sufficient spectrum bandwidths. Figure 12 shows that while the U.S. has ensured Wi-Fi's spectrum needs are met by allocating more mid-band frequencies to unlicensed use than any other country, its spectrum policy has not delivered the mid-band spectrum mobile operators need. As a result, the U.S. has fallen behind the likes of China, Japan, and the UK, all of which have allocated more mid-band spectrum to commercial wireless use than the U.S. Of course, wireless operators can, to a degree, substitute between spectrum bands to compensate for a shortfall of a particular type of spectrum. However, even when looking at total spectrum allocations across all bands, the U.S., which has allocated 1,123 MHz of spectrum below 6 GHz to mobile[62], still lags well behind China, which has allocated over 1,800 MHz to mobile.[63]

Spectrum requirements

As Wi-Fi technology and applications evolved, so too have their bandwidth requirements. In 2020, the FCC addressed this by opening 1200 MHz of spectrum in the 6 GHz band for Wi-Fi and other unlicensed applications. This allocation was in addition to the spectrum already allocated in the 2.4 and 5 GHz bands. In a white paper published by Intel, Akhmetov et al. estimate that Wi-Fi 7, the latest iteration beginning deployment in the U.S., would need three non-overlapping channels of 320 MHz to ensure optimal long-term Wi-Fi performance for bandwidth-demanding future applications.[64] Even ignoring the constraints on allocations imposed in the context of competing uses for spectrum, Wi-Fi's spectrum needs appear to be met. Moreover, the U.S. already leads its peers in terms of unlicensed spectrum allocations, as shown in Figure 12.

American wireless operators, meanwhile, currently only have access to 380 MHz of full-power mid-band spectrum – five times less than that allocated to Wi-Fi. And while the U.S. may lead in terms of unlicensed allocations, it has already fallen behind several of its peers, both in terms of mid-band and total spectrum allocations for commercial wireless use. The last auctions of spectrum for commercial wireless use in the U.S. took place in 2022, when 100 MHz of spectrum in the 3.45 GHz band was assigned, followed by an auction for 2.5 GHz overlay licenses which amounted to approximately 68 MHz of spectrum nationwide. Since then, wireless operators have had to cope with the exponential

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62 FCC, 2024, 2024 Communications Marketplace Report, Fig. II.B.11, available at: https://docs.fcc.gov/public/attachments/FCC-24-136A1.pdf

63 Analysys Mason, 2022, Comparison of total mobile spectrum in different markets, available at: https://api.ctia.org/wp-content/uploads/2022/09/Comparison-of-total-mobile-spectrum-28-09-22.pdf. To compute the current holdings for China, we sum the 682 MHz of spectrum below 3.0 GHz, the 460 MHz of mid-band spectrum already released, and the 700 MHz of spectrum in the 6 GHz band that was allocated after the Analysys Mason report was published. The total is 1842 MHz.

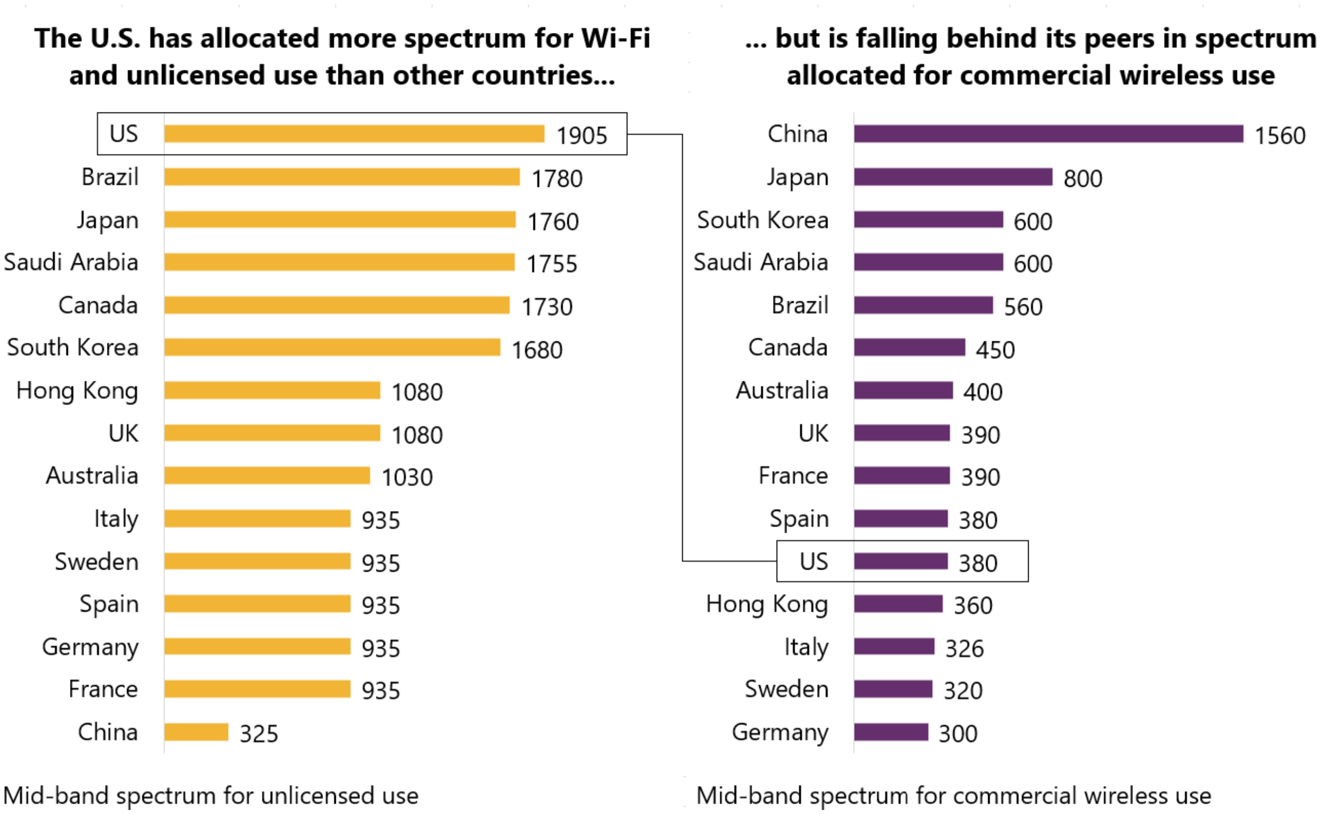
64 Akhmet et al., 2022, 6 GHz Spectrum Needs for Wi-Fi 7, available at: https://www.intel.com/content/www/us/en/products/docs/wireless/wi-fi-7/spectrum-needs-of-wi-fi-7.html

rise in demand for data using their existing spectrum allocations. Of greater concern, however, is the absence of a clear pipeline of future spectrum allocations for commercial wireless use in the U.S. (and even the authority for the FCC to auction that spectrum), especially in light of the continuing increase in demand for wireless data. Figure 12 shows that by 2027, the U.S.'s mid-band spectrum allocation will fall behind all but one of its G7 peers. By then, it is estimated that the U.S. could face a mobile spectrum deficit of 400 MHz, which could more than triple to over 1400 MHz by 2032.[65] Given the long lead times required before spectrum that has been designated for study for a particular use can be deployed, it is imperative that federal policymakers prioritize identifying additional spectrum for commercial wireless services.

The discrepancy in mid-band spectrum allocations to unlicensed use and commercial wireless use does not align with how these technologies use the spectrum. Wi-Fi and other unlicensed users operate at low power in localized environments, like homes and offices, where spectrum is readily available for re-use, even in close proximity. With Wi-Fi, a relatively small amount of bandwidth is capable of serving high volumes of traffic in a given geographic area. In contrast, mobile networks must serve users spread across wide geographic areas, travelling at differing speeds, and often outdoors. The wide coverage areas that need to be served mean that wireless operators need access to full-power, dedicated spectrum licenses to avoid interference and maintain network quality. Therefore, the scope for frequency re-use is far more limited than with unlicensed use, leading to wireless operators needing much more spectrum per GB of traffic served than unlicensed users.

65 The Brattle Group, 2023, How Much Licensed Spectrum is Needed to Meet Future Demands for Network Capacity?, available at: https://api.ctia.org/wp-content/uploads/2023/04/Network-Capacity-Constraints-and-the-Need-for-Spectrum-Brattle.pdf

Figure 12: Mid-band spectrum allocations for unlicensed use and commercial wireless use in selected countries by 2027



Source: Adapted from Analysys Mason, 2022, Comparison of total mobile spectrum in different markets.
Notes: We have removed any spectrum that is not available on an exclusive use, full-power basis.

Economic impact

In assessing how to allocate spectrum, policymakers should consider the economic impact of allocations alongside the technical needs of different use cases. In 2024, the WiFiForward coalition commissioned a paper to establish the economic benefits of Wi-Fi and an additional allocation of 125 MHz of mid-band spectrum for unlicensed use.[66] This study identified eight sources of GDP and consumer benefit that would derive from an additional 125 MHz of spectrum in the 7 GHz band. In Table 18, we summarize the economic value generated by source. Although Wi-Fi as a whole generates tremendous value, the results in Table 18 suggest that given how much spectrum Wi-Fi already has, an additional 125 MHz allocation would produce relatively little incremental economic value.

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66 Telecom Advisory Services, 2024, Assessing the economic value of Wi-Fi in the United States, available at: https://wififorward.org/wp-content/uploads/2024/09/Assessing-the-Economic-Value-of-Wi-Fi.pdf

Table 18: Economic value of an additional 125 MHz allocation to Wi-Fi

Source	Metric	2025	2026	2027
Benefit to consumers of free Wi-Fi traffic offered in public sites	GDP ($B)			0.36
Deployment of free Wi-Fi in public sites	CS ($B)			0.35
Benefit to consumers of faster free Wi-Fi under Wi-Fi 6E & above	CS ($B)	0.01	0.01	0.01
Closing the digital divide: use of Wi-Fi to increase coverage in rural & isolated areas	GDP ($B)	0.36	0.84	1.72
Wide deployment of IoT	GDP ($B)	2.05	4.90	11.20
Capex & Opex savings Cellular offloading	PS ($B)	0.08	0.17	0.31
Revenues of service providers offering paid Wi-Fi access in public places	GDP ($B)	0.02	0.04	0.05
Aggregated revenues of WISPs	GDP ($B)	0.01	0.02	0.04

Source: Telecom Advisory Services, 2024, Assessing the economic value of Wi-Fi in the United States
Note: CS: consumer surplus, PS: producer surplus

In contrast to unlicensed users, commercial wireless operators face a looming spectrum shortage. As we highlight in Table 19, the impact on GDP, employment and consumer surplus of allocating additional spectrum to mobile is substantial.

Direct comparisons between the two studies are challenging owing to the Wi-Fi study's limited forecast horizon to 2027. However, we note that Wi-Fi has already been allocated an additional 1200 MHz in the 6 GHz band, which is only just recently seeing equipment for. There is a less immediate need for additional unlicensed spectrum than commercial wireless users, who only have access to 380 MHz of full-power mid-band spectrum. Furthermore, some use cases can be equally or better served by mobile than Wi-Fi, for example, the wide deployment of IoT. Consequently, the economic impact of adding 100 MHz to a base of 380 MHz for mobile can reasonably be expected to have a larger impact than adding 100 MHz to a base of 1900+ MHz already allocated for unlicensed use.

Table 19: Summary of the economic impact of allocating each additional 100 MHz of mid-band spectrum to mobile

	GDP ($B)	Employment (M)	Consumer Surplus ($B)
Better mobile service at no additional cost			385
Improving broadband with FWA	40	0.30	3
Supporting industries that rely on mobile connectivity	188	0.93	
Supporting industries that serve the wireless industry	36	0.32	
Total	**264**	**1.55**	**388**

Note: Effect of each 100 MHz up to 400 MHz

5. Conclusion

The wireless industry serves as a vital pillar of the American economy, significantly contributing to innovation, economic growth, and job creation. Its extensive investments in infrastructure and technology not only enhance communication capabilities but also support a wide range of industries that rely on wireless connectivity for their operations.

As the demand for data continues to escalate, additional mid-band spectrum will be more needed than ever to continuing fueling the American economy.

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NERA
2112 Pennsylvania Avenue NW
4th Floor
Washington, DC 20037
www.nera.com