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The Economic Impacts of Reallocating High-Band Spectrum to 5G in the United States

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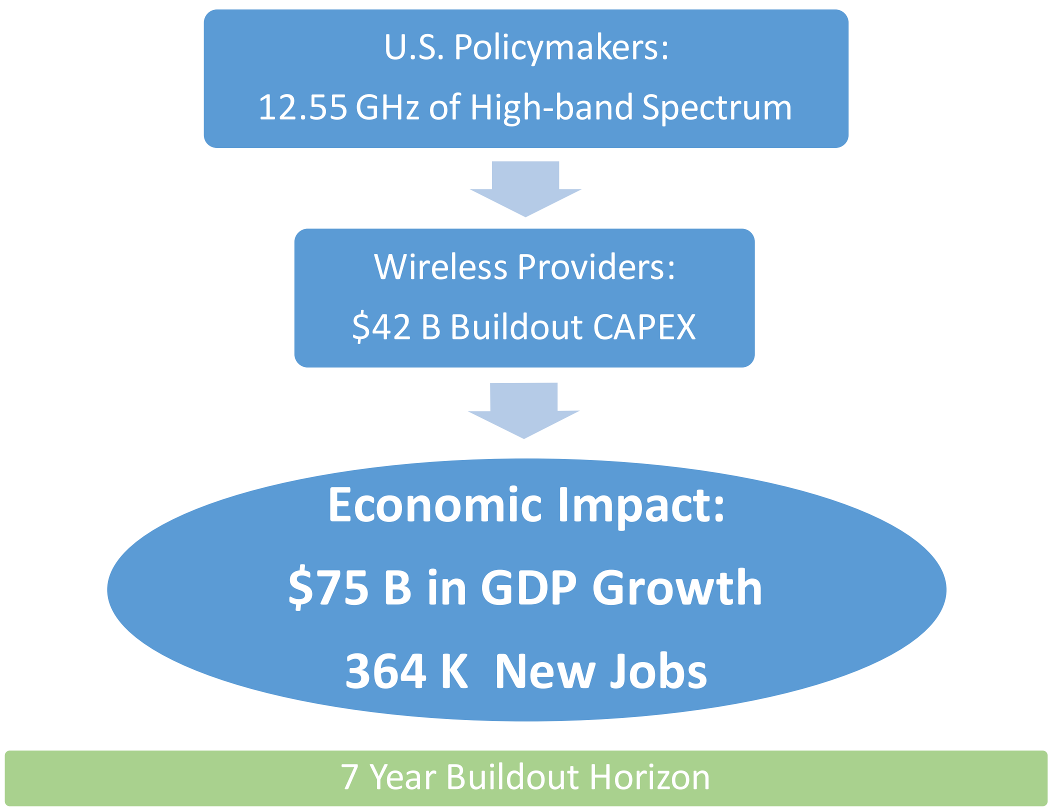
Summary of Key Findings

The next generation of wireless technology (5G) represents a significant leap forward in mobile communications, promising substantial increases in data speed, service quality, and network capacity. This new technology will rely on a much wider range of spectrum than current 4G LTE networks. To achieve this significant leap forward, two things need to happen: policymakers must reallocate spectrum for 5G uses and service providers will need to, as they have begun to do, invest hundreds of billions of dollars in new infrastructure.

This study examines the economic impacts of reallocating 12.55 GHz of licensed high-band spectrum for 5G networks. We conclude that wireless providers will invest in excess of $42 billion on infrastructure to deliver 5G services using this high-band spectrum over a seven-year buildout period. This high-band spectrum buildout will result in:

- $75 billion in additional GDP.
- 364,000 new jobs, accounting for both direct and spillover effects.



I. Background on 5G and High-Band Spectrum

Wireless communication services, such as voice, messaging, internet, and video, have become a critical component of most economic activity and indispensable in our personal and professional lives. This prominence has been achieved through considerable advances in mobile communications capabilities and service quality with each successive generation of network technology, from analog 1G service in the 1980s through the current 4G LTE generation of technology.

5G wireless networks promise substantial improvements in data speeds (up to 100 times faster than current LTE), single digit (millisecond) latency, and a significant increase in the number of wirelessly-connected devices (capacity), compared to current 4G LTE networks.[1] These improvements are expected to enable or enhance numerous use cases, including autonomous vehicles, the industrial Internet of Things, and telemedicine.

5G will enable these improvements because it is designed to exploit not only low-band spectrum, which historically has been used for mobile voice and data services, but also mid- and high-band spectrum, capitalizing on the propagation characteristics of the different spectrum bands. By leveraging the bandwidth availability and propagation characteristics at higher frequencies (above 24 GHz), high-band spectrum will enable very high data speeds and capacity (i.e., the ability to accommodate a large number of connected devices), and is thus a vital component for 5G services. Due to the shorter wavelength, high-band spectrum is often referred to as “millimeter wave.” Although the properties of high-band waves will enable very fast data speeds, low latency, and considerable device-capacity, the propagation characteristics of millimeter waves will necessitate dense cell tower networks to provide coverage for a given area. For these reasons, the high-band will be most efficient in dense urban areas as well as in facilities where large groups of people frequently gather, such as in sports stadiums.[2]

Unlike prior generations of wireless networks such as 3G and 4G, the benefits of 5G will be achieved through complementary relationships between low-, mid-, and high-band spectrum. In particular, the United States’ large landmass and range of population densities will require leveraging the complementarity nature of the different bands to deliver a 5G experience. Constrained supply of spectrum in any of the three spectrum ranges could jeopardize U.S. 5G leadership.

In this white paper, we estimate the economic impacts associated with the deployment of 12.55 GHz of high-band spectrum, specifically in bands in the 24 to 50 GHz bands that policymakers are considering for commercial wireless use. (See Table 1 below.) These economic impacts derive from the infrastructure that will be deployed when high-band spectrum is made available.[3]

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1 ITU-R, “Minimum requirements related to technical performance for IMT-2020 radio interface(s),” November 2017, available at https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf.

2 Behar, Rose, “Millimeter wave to low-band: The different types of 5G and how they work,” January 6, 2019, available at https://www.digitaltrends.com/mobile/5g-spectrum-variants/, accessed on February 26, 2019.

3 5G will also deliver substantial benefits supporting new and innovative services and industries.

Table 1
High-Band Spectrum Bands under Consideration for 5G

Band		Total MHz
24 GHz	24.25 - 24.45	200 MHz
24 GHz	24.75 - 25.25	500 MHz
26 GHz	25.25 - 27.50	2,250 MHz
28 GHz	27.50 - 28.35	850 MHz
29 GHz	29.10 - 29.25	150 MHz
31 GHz	31.00 - 31.30	300 MHz
32 GHz	31.80 - 33.40	1,600 MHz
37 GHz	37.00 - 38.60	1,600 MHz
39 GHz	38.60 - 40.00	1,400 MHz
42 GHz	42.00 - 42.50	500 MHz
47 GHz	47.20 - 48.20	1,000 MHz
50 GHz	50.40 - 52.60	2,200 MHz
Total		12,550 MHz

II. Estimating the Economic Impacts of the Buildout of 5G

To estimate the economic impacts of infrastructure spending to buildout high-band spectrum for 5G, we take the following steps. First, assuming that 12.55 GHz of spectrum is made available, we forecast the expected seven-year capital expenses for building out a 5G network for U.S. wireless providers.[4] We validate these estimates in comparison to historical capital spending on deployment of 4G LTE and to other industry analyst projections regarding the cost of 5G deployment. Second, to estimate the spending attributable to the deployment of high-band spectrum for 5G, we scale total capital expenditures using a two-factor base station density model which accounts for the coverage and capacity of low-, mid-, and high-band cells. Third, we use an input-output model and data from the Bureau of Economic Analysis to estimate the economic

[4] A seven-year window was chosen to correspond with recent historical trends in the communication industry; recent generations of wireless networks (i.e., 3G and 4G) were implemented over approximately seven years (2003-2010 for 3G, 2010-2017 for 4G). Deutsche Bank, "Charting The 5G Revolution Spending Mix Shift Favors Infrastructure" February 4, 2018, p. 4. *See also* CHR Solutions, "5G Legerdemain," available at https://www.chrsolutions.com/blog/5g-legerdemain/, accessed on January 29, 2019. The selected providers are Verizon Wireless, AT&T, T-Mobile USA, Sprint, and U.S. Cellular.

impacts associated with forecasted capital expenditures for the buildout of high-band spectrum. For a detailed discussion of our methodology, please refer to the report Appendix.

1. Estimated Capital Requirements for 5G Infrastructure Deployment

Using wireless providers' historical investments in 4G LTE infrastructure, we forecast that capital expenditures on 5G infrastructure over the seven-year buildout period will be approximately $298 billion in 2018 dollars.[5]

We considered existing estimates of spending on prior wireless generations to ensure our estimate of 5G capital expenditures was within the range of past spending estimates. We find that estimates for 4G range from $175 billion to $371 billion.[6] We next reviewed estimates for 5G capital spending, including some estimates for other regions of comparable size. These estimates ranged from $225 billion to over $400 billion, with many estimates falling between $250 billion and $300 billion.[7] In the process of researching these estimates, we also identified corroborating estimates for components of 5G infrastructure. For example, one study estimated the cost of backhaul infrastructure for 5G, only one component of overall 5G infrastructure spending, at $130 billion.[8]

2. Estimated Capital Requirements for 5G Infrastructure for High-Band Spectrum

To isolate the spending attributable to high-band spectrum from the overall $298 billion of investment, we created a two-factor base station density model that considers the propagation and capacity characteristics of base stations in the low-, mid-, and high-bands. The model utilizes a classification scheme of U.S. counties by population density and proximity to urban clusters, parameters that determine the coverage of low-, mid-, and high-band cell base stations, and projections for the number of network-enabled devices and data usage per capita during the timeframe of the 5G buildout, which determine the capacity requirements of the networks. We assume that the high-band will be more selectively deployed to provide data capacity in areas

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5 Although some analysts caution that the time to a full 5G buildout may be longer than seven years (because novel uses may develop slower than expected), we are confident that rapid technological change and competition (among wireless provider and firms developing 5G-based products and services) will drive the rapid deployment of 5G in the U.S.

6 Morgan Stanley estimates total 4G infrastructure spending of $275 billion. (Morgan Stanley, "Telecoms Send Mixed Signals on 5G Wireless" November 9, 2017). Based on grossing up Deloitte's projected annual capital investment figures ($25 to $53 billion) to a seven-year roll-out, we derived a total average projected 4G investment of approximately $273 billion (with a range of $175 to $371 billion). Deloitte, "The impact of 4G technology on commercial interactions, economic growth, and U.S. competitiveness," August 2011.

7 Morgan Stanley estimates that 5G infrastructure deployment costs in the U.S. will total $225 billion between 2019 and 2025. Morgan Stanley, "Telecoms Send Mixed Signals on 5G Wireless," November 9, 2017. The Mobile World Congress in 2017 estimated that 300 to 500 billion euros (approx. $330 to $550 billion dollars) would be needed to build a 5G network in Europe. GSMA Intelligence, "Mobile World Congress 2017 wrap-up," March 2017. The population of Europe, in its entirety, is considerably larger than United States, which would suggest a higher 5G buildout cost relative to the United States.

8 Deloitte, "Communication infrastructure upgrade" July 2017, p. 13.

expected to have high device density. Therefore, we focus on the projected data needs of urban regions to estimate the number of high-band cell sites that will be built during the 5G build-out.

Given that data capacity increases with spectrum frequency, we assume that areas with higher population density (and, as a result, more devices) will be better served by complementary use of low-, mid-, and high-band spectrum. In contrast, the relatively light device-load in more sparsely-populated areas implies that these areas can be served in an economically efficient manner based on the coverage and capacity characteristics of low- and mid-band spectrum.

At the same time, we derive the expected capital investment in each spectrum band based upon the proportion of future cell sites and base stations that will be built in counties best suited for that spectrum. For example, we expect that high-density areas (such as sports stadiums, malls, airports, and universities) in otherwise sparsely-populated areas will be served by base stations utilizing all three bands, including high-band.[9]

We assume that total U.S. network buildout will be largely complete at the end of our seven-year horizon, as was on average the case with prior wireless generations. We believe network expansion and densification will continue after seven years, in response to the continued growth in the number of data-demanding devices, especially in more densely populated areas.

Our model estimates that 14 percent of 5G base stations deployed over the next seven years will be attributable to high-band spectrum. We therefore assign that share of capital spending to the high-band and arrive at our capital spending estimate attributable to high-band spectrum of approximately $42 billion.

3. Economic Impacts of Infrastructure Capital Expenditures

Total Economic Impacts of High-Band 5G Buildout: $75 billion

We find that the total economic impacts attributable to the 5G high-band spectrum are approximately $75 billion over the next seven years, or $10.7 billion annually. We also estimate the impact of high-band driven 5G infrastructure spending on employment, and find that approximately 364,000 U.S. job-years will be created, or 52,000 jobs annually.

To arrive at these estimates, we utilize an input-output model to determine the total economic impacts of spending on high-band infrastructure. A widely-used method, input-output modeling provides an estimate of how spending in one industry affects other industries in the economy.

5G high-band spectrum buildout will create 364,000 new jobs

Based on previous research, we decompose 5G infrastructure-related capital spending into four industry groupings: 47 percent wireless communications equipment, 29 percent

9 U.S. Cellular has discussed targeting high-density areas for early development, including universities and university sporting arenas. TDS and U.S. Cellular, "Fourth Quarter 2018 Results," February 22, 2019, available at https://www.fool.com/earnings/call-transcripts/2019/02/22/united-states-cellular-corporation-usm-q4-2018-ear.aspx, accessed on March 18, 2019.

construction, 15 percent wireline communications equipment, and 10 percent wire and cable.[10] These ratios reflect the expectation that the 5G deployment will require substantial investment in backhaul fiber as well as additional small cells and towers.[11]

Having estimated the total capital spending attributable to high-band spectrum and the share of spending by industry, we then apply industry-specific RIMS multipliers published by the BEA to determine the overall economic impact of these capital spending dollars.[12]

We further disaggregate our figures into direct, indirect, and induced economic activity, as shown in Figures 1 and 2 below. Economic studies investigating the impact of new capital spending will often distinguish between these three types of economic activity to provide clarity on the type of change spurred. Direct effects are the increased GDP and employment directly resulting from the new spending on goods and services to deploy the 5G infrastructure itself. Indirect effects are changes to sales and employment in sectors supplying goods to the industries which create that infrastructure. Induced effects are increased sales and employment driven by greater household spending due to higher incomes driven by the initial spending.[13]

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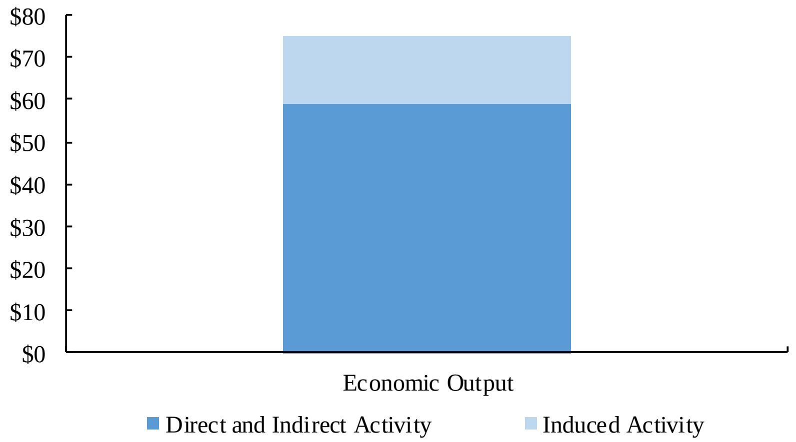
10 Jeffrey A. Eisenach, Hal J. Singer, and Jeffrey D. West. "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," January 5, 2009, p. 8. These methods are also similar to but slightly modified from David W. Sosa and Mark Van Audenrode, "Private Sector Investment and Employment Impacts of Reassigning Spectrum to Mobile Broadband in the United States," August 2011, but we believe the greater emphasis on backhaul in 5G deployment justifies this approach. We averaged together the two weightings proposed by these papers to obtain the weights reported above.

11 Our estimates are consistent with other research. For example, Deloitte projects that there will need to be between $130-150 billion spent on fiber deployment in the next five to seven years. Deloitte, "Communications infrastructure upgrade: The need for deep fiber," July 2017, p. 13. This is 44 to 50 percent of our expected network capex in the next seven years.

12 U.S. Bureau of Economic Analysis Regional Input-Output Modeling System Multipliers (RIMS II Multipliers (2007/2016)).

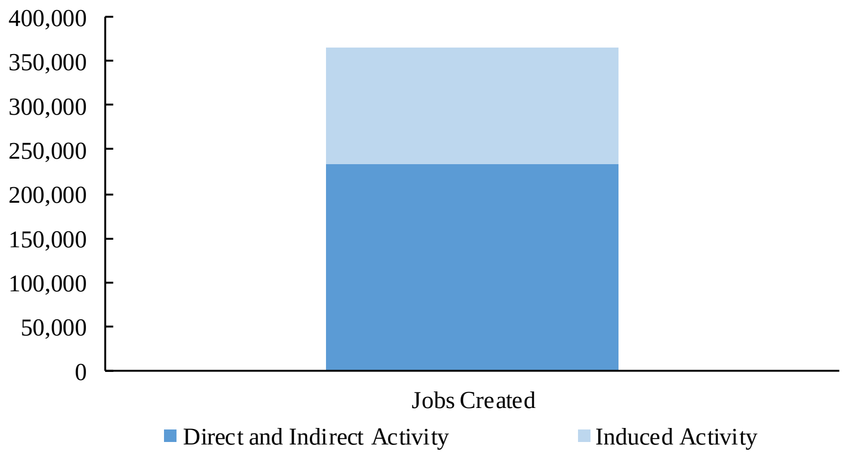
13 David Sosa and Marc Van Audenrode, "Private Sector Investment and Employment Impacts of Reassigning Spectrum to Mobile Broadband in the United States," August 2011.

Figure 1
Economic Impacts (in Billions) from High-Band Infrastructure Spending



Notes:
[1] See Appendix for sources.

Figure 2
Jobs Created from High-Band Infrastructure Spending



Notes:
[1] See Appendix for sources.

Appendix: Study Methodology

To estimate the economic impacts associated with the development of 5G high-band infrastructure over seven years, we:

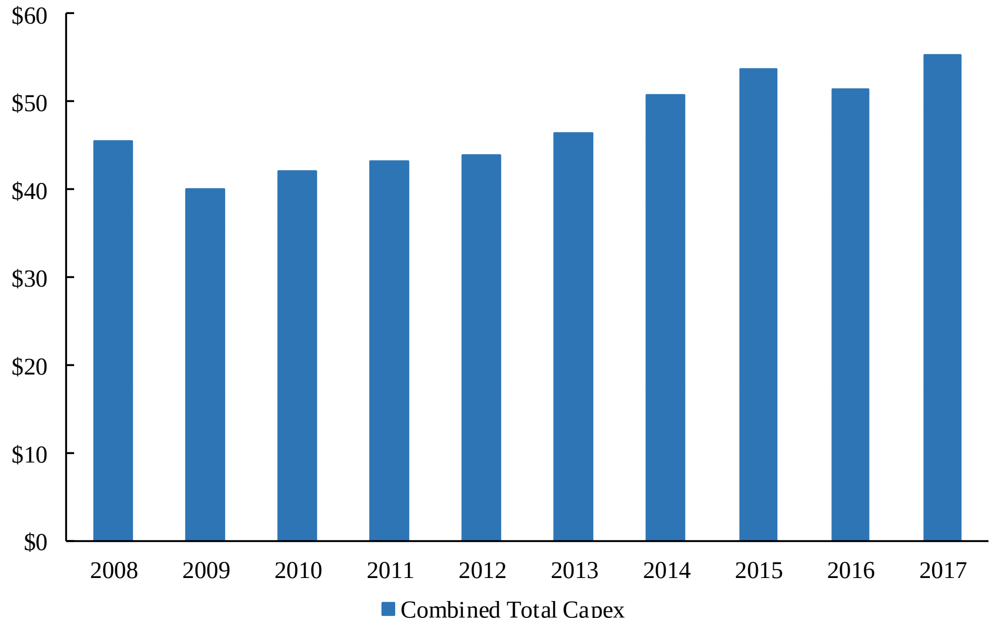
- Assess historical capital spending across five wireless providers to project spending for the deployment of 5G infrastructure and validate against other publicly available estimates.
- Construct a two-factor model incorporating wavelength propagation characteristics and device density to estimate the best use applications across low-, mid-, and high-band frequencies.
- Construct an input-output model using different types of economic activity (NAICS codes) to extrapolate the economic impact of capital spending for high-band infrastructure.

1. Estimation of the Capital Requirements for Nationwide 5G Infrastructure

To forecast the future spending on 5G infrastructure attributable to five large U.S. providers, we first reviewed company public statements from these providers and gathered data on capital expenditure spending from 2008 to 2017.[14] Informed by providers' recent capital expenditures, as shown in Figure A-1 below, we modeled future capital expenditures.

[14] Forms 10-K, Annual Reports, Investor Presentations, and Earnings Call Transcripts. We applied a six percent discount to total capital expenditures based on the detail available which suggested that six percent of capital expenditure was not directed towards the network but, rather, to other corporate needs. This estimate is based on the Verizon Wireless average "Network Capex" over "Total Capex" from 2008 to 2017, which is equal to 94%.

Figure A-1
Total Wireless Provider Capital Expenditures (in Billions)



Source:
Capex figures are from the five selected wireless providers' financial filings (the five providers are Verizon, AT&T, Sprint, T-Mobile, and U.S. Cellular).

In particular, we averaged capital spending over the past ten years (2008 to 2017) to account for investment patterns across an economic cycle, as well as investment patterns through the wireless technology cycle (i.e., the end of 3G to late 4G development). We then projected the firms' aggregate average annual spending over the next seven years to estimate how much the industry would invest in the buildout of 5G networks. (See Table A-1 below.)

Table A-1
Historical Network Capital Expenditures (in Billions) for Selected U.S. Providers

		Total
Network Capex (2008 - 2017)	$	444.09 B
Network Capex, Inflation Adjusted (2008 - 2017)	$	456.73 B
Annualized Network Capex (Inflation Adjusted)	$	45.67 B
7-Year Projected Network Capex	$	297.92 B

Notes:
[1] *Network Capex* excludes capital spending on corporate overhead, spectrum acquisition, and acquisitions.
[2] *Network Capex* is adjusted for inflation using the same composite producer price index applied in our multiplier analysis.
[3] *7-Year Projected Network Capex* is deflated to 2018 dollars using a CPI inflation forecast of 2.2% from the Philadelphia Federal Reserve less anticipated PPI inflation.
Sources:
[A] Capex figures are from the five selected wireless providers' financial filings.
[B] Historical inflation data are from the Bureau of Labor Statistics.

2. Estimation of the Capital Requirements for 5G Infrastructure for the High-Band

The above estimate of $298 billion, as noted, is our estimate of what selected providers will spend on capital for the seven-year buildout of the overall 5G network, and thus includes capital expenditures for the low-, mid-, and high-bands. To isolate capital expenditures attributable to high-band spectrum from the overall $298 billion, we created a two-factor base station density model that considers the propagation and capacity characteristics of base stations in the low-, mid-, and high-bands. We focus on these two factors because the spectrum propagation characteristics and capacity of base stations to handle requests from devices are important constraints. Because we assume high-band will be selectively deployed to provide data capacity in areas expected to have high device density, we focus on the projected data needs of urban regions to estimate the number of high-band cell sites that will be built during the 5G era.

The deployment of low-, mid-, and high-band is expected to be affected by population density.[15] We therefore based our model on density classifications of the U.S. as provided by the National Center for Health Statistics ("NCHS"), which categorizes each county by its density and proximity to urban clusters.[16] There are six categories: large central metro, large fringe metro, medium metro, small metro, micropolitan, and noncore (rural).

15 Ericsson Mobility Report, November 2016, p.17.

16 Data from CDC, "2013 NCHS Urban-Rural Classification Scheme for Counties," available at https://www.cdc.gov/nchs/data_access/urban_rural.htm. A description of the data and the classifications is CDC, "NCHS Urban-Rural Classification Scheme for Counties Data File Documentation," 2013, available at https://www.cdc.gov/nchs/data/data_acces_files/NCHSUrbruralFileDocumentationInternet2.pdf, accessed on January 29, 2019.

Table A-2
National Center for Health Statistics (NCHS) Urban-Rural Classification Scheme for Counties

Classification	Description
Large Central Metro	Counties in metropolitan statistical areas (MSAs) of 1 million or more population that: 1. Contain the entire population of the largest principal city of the MSA, or 2. Have their entire population contained in the largest principal city of the MSA, or 3. Contain at least 250,000 inhabitants of any principal city of the MSA.
Large Fringe Metro	Counties in MSAs of 1 million or more in population that do not qualify as large central metro counties.
Medium Metro	Counties within MSAs of populations of 250,000-999,999.
Small Metro	Counties in MSAS of populations less than 250,000.
Micropolitan	Counties in micropolitan statistical areas.
Noncore	Nonmetropolitan counties that did not qualify as micropolitan.

Source:
[A] 2013 NCHS Urban-Rural Classification Scheme for Counties, available at https://www.cdc.gov/nchs/data/series/sr_02/sr02_166.pdf.

Having organized the U.S. geographically into these six categories, we then modeled our two constraints. The first constraint is the geographic reach of a base station based on the frequency it uses. We relied on estimates regarding the propagation characteristics of each type of frequency, as a function of its wavelength, based on industry studies.[17] These propagation characteristics are adjusted by the geographical characteristics of the surrounding area. For example, base stations in dense urban areas will have shorter effective ranges due to building interference.

The second constraint is based on the technical limitations of a base station's ability to handle a set number of devices at a given time. We modeled this based on a set of assumptions about a base station's data capacity. In particular, using data from Cisco on anticipated device count per capita in 2022 (roughly the middle of our forecasted timeframe), we estimated the number of devices that would occupy each square mile of each density category.[18] We next estimated the capacity of the base station itself using the peak 5G standard of 20 Gbps and an average 5G data speed.

We assume that low- and mid-band spectrum will be deployed throughout the country to achieve national 5G coverage, with a focus on populated areas in the least dense regions. It is likely that newly reallocated low-band spectrum would provide primary coverage in the more rural and less densely populated areas. We assume high-band deployment will initially focus on the highest density portions of large central metro counties, transportation centers (e.g., airports), and event locations (e.g., stadiums). However, given the short propagation characteristics of millimeter wave frequencies, we do not project that high-band will cover the total landmass of large central metro

[17] Note that we have refined our propagation characteristics from our previous paper, "The Economic Impacts of Reallocating Mid-Band Spectrum to 5G in the United States," released in February 2019. In particular, we adjust a base station's projected radius by its geographic region to model for interference from buildings and other structures. This refinement does not adjust the mid-band estimates provided in our previous paper.

[18] We utilize Cisco's projections for smartphones, tablets, and machine-to-machine modules in our device estimate. See Cisco, "VNI Complete Forecast Highlights," available at https://www.cisco.com/c/dam/m/en_us/solutions/service-provider/vni-forecast-highlights/pdf/United_States_Device_Growth_Traffic_Profiles.pdf, accessed on January 29, 2019.

counties in the U.S. Instead, we believe that wireless providers will selectively deploy high-band in densely populated areas to provide adequate data capacity.

High-band will provide the capacity critical for the 5G experience in the densest regions of the country. Large central metro MSAs supported average populations in 2012 of 3.33 million. An example of a typical large central metro MSA is Pittsburgh, Pennsylvania, with a 2012 population of 2,360,733. The expected density of 5G-connected devices in places like Pittsburgh will necessitate a dense network of high-band small cells to support the data needs of anticipated "smart city" applications and automated vehicles.

Based on our two-factor model, we estimate that 14 percent of base stations deployed over the next seven years will be attributable to high-band spectrum. We therefore assign that share of capital spending to the high-band and arrive at our capital spending estimate attributable to high-band spectrum of $75 billion.

3. Economic Impacts of Infrastructure Capital Expenditures

To estimate the economic impacts of infrastructure spending, we use an input-output model. A widely-used method, input-output modeling provides an estimate of how spending in one industry affects other industries in the economy. The first step in developing an input-output model is to identify where spending in one industry is directed. Specifically, here, we first identified the industries into which telecommunications infrastructure capital spending flows. Once we determined what those industries are and the proportion of spending they will receive, we used our capital spending estimates as inputs to the input-output model and estimated the impacts of this spending on both economic output and employment.

i. Industry Identification and Input-Output Multipliers

To model the economic impacts of this capital spending, we used industry data and prior research to identify the industries that will receive spending as the high-band of 5G is built-out over the next seven years. Based on this research, we identified the construction, manufacturing, and telecoms equipment industries as those that will receive 5G infrastructure-related capital spending.[19] We decomposed 5G infrastructure-related capital spending into four industry groupings: 47 percent wireless communications equipment, 29 percent construction, 15 percent wireline communications equipment, and 10 percent wire and cable.[20] These ratios reflect the

[19] Four North American Industry Classification System ("NAICS") codes are used: 230000 (Construction); 335920 (Communication and energy wire and cable manufacturing); 334210 (Telephone apparatus manufacturing); and 334220 (Broadcast and wireless communications equipment).

[20] Jeffrey A. Eisenach, Hal J. Singer, and Jeffrey D. West. "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," January 5, 2009, p. 8. These methods are also similar to but slightly modified from David W. Sosa and Mark Van Audenrode, "Private Sector Investment and Employment Impacts of Reassigning Spectrum to Mobile Broadband in the United States," August 2011, but we believe the greater emphasis on backhaul in 5G deployment justifies this approach. We averaged together the two weightings proposed by these papers to obtain the weights reported above.

expectation that 5G deployment will require substantial investment in backhaul fiber as well as additional small cells and towers.[21]

Having estimated the spending to each of these four industries and the total capital spending attributable to high-band spectrum, we then applied industry-specific RIMS multipliers as provided by the BEA to determine the overall economic impacts of these capital spending dollars. See Table A-3 below for the multipliers by industry.

Table A-3
Weighted Average Multiplier

	Final Demand: Output (per $ Invested)	Final Demand: Employment (per Mn $ Invested)	Weights for 5G [1]
334210 Telephone apparatus manufacturing	1.75	7.25	15%
334220 Broadcast and wireless communications equipment	1.64	6.31	47%
335920 Communication and energy wire and cable manufacturing	1.95	7.96	10%
230000 Construction	1.99	13.49	29%
Combined Multipliers	**1.78**	**8.66**	

Note:
[1] Industry weights were determined by combining Fiber to the Home ("FTTH") and Wireless Industry estimates.
Sources:
[A] BEA RIMS II Multipliers.
[B] Eisenach, Singer, and West, "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," January 5, 2009.

ii. Economic Output and Employment Impacts

Applying these multipliers, we estimated that the total economic impacts attributable to 5G high-band spectrum are $75 billion over the next seven years, or $10.7 billion annually. Our estimates are provided in Table A-4. We assume that 12.55 GHz of high-band spectrum between 24 and 53 GHz will be licensed to U.S. wireless providers and that the vast majority of U.S. network buildout will be completed in seven years. We disaggregate total economic impacts into direct, indirect, and induced economic activity. Economic studies investigating the impact of new capital spending will often distinguish between these three types of economic activity to provide clarity on the type of change spurred. Direct effects are the increased GDP and employment directly resulting from the new spending on goods and services to deploy the 5G infrastructure itself. Indirect effects are changes to sales and employment in sectors supplying goods to the industries which create that infrastructure. Induced effects are increased sales and employment driven by greater household spending due to higher incomes driven by the initial spending.

We also estimated the impact of infrastructure spending for the 5G high-band spectrum on employment, and found that approximately 364,000 U.S. job-years will be created, or 52,000 jobs annually.

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21 Our estimates are generally consistent with another study, which predicts that between $130-150 billion will be invested in fiber deployment in the next five to seven years. Deloitte, "Communications infrastructure upgrade: The need for deep fiber," July 2017, p. 13. This is roughly 50 percent of the expected network capex in the next seven years.

Table A-4
Economic Impact Estimates for High-Band: 2019 - 2025

	7-Year Total	Annualized
Total Capex	$297.92 B	$42.56 B
High-Band Capex	$42.04 B	$6.01 B
Total Jobs Supported	364,230	52,033
Direct and Indirect Activity	*233,694*	*33,385*
Induced Activity	*130,536*	*18,648*
Total Impact on Output	$75.01 B	$10.72 B
Direct and Indirect Activity	*$59.15 B*	*$8.45 B*
Induced Activity	*$15.86 B*	*$2.27 B*

Notes:

[1] These figures represent the total estimated economic impact between 2019-2025.

[2] Direct Activity is defined as impacts on employment and output as a result of the investments made by US wireless providers.

[3] Indirect Activity includes the employment and output impacts on other firms, such as vendors, from purchases made by the investing wireless providers.

[4] Induced Activity is generated by expenditures made by employees of the firms that benefit from direct and indirect activity.

Sources:

[A] Wireless Providers' Financial Filings.

[B] 2010 United States Census.

[C] Zhang, Ryu, Subramanian, and Sampath, "Coverage and Channel Characteristics of Millimeter Wave Band Using Ray Tracing," June 2015.

[D] Eisenach, Singer, and West, "Economic Effects of Tax Incentives for Broadband Infrastructure Deployment," January 5, 2009.

[E] BEA RIMS II Multipliers.

[F] NCHS Urban-Rural Classification Scheme for Counties, available at https://www.cdc.gov/nchs/data_access/urban_rural.htm.

[G] Bureau of Labor Statistics, "Producer Price Index Databases," available at https://www.bls.gov/ppi/#data.

[H] Cisco, "VNI Complete Forecast Highlights," available at https://www.cisco.com/c/dam/m/en_us/solutions/service-provider/vni-forecast-highlights/pdf/United_States_Device_Growth_Traffic_Profiles.pdf.

[I] MyBroadband, "How much data watching a 4K Netflix series uses," April 9, 2018, available at https://mybroadband.co.za/news/technology/255147-how-much-data-watching-a-4k-netflix-series-uses.html.

[J] ITU-R, "Minimum requirements related to technical performance for IMT-2020 radio interface(s)," November 2017, available at https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf.

[K] ITU-R, "Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses," December 2013.