TELECOM ADVISORY SERVICES

ASSESSMENT OF THE ECONOMIC IMPACT OF THE **AIRWAVES** ACT

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Authors

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

- Fernando Callorda (BA, MA, Economics, Universidad de San Andres-Argentina) is a project manager with Telecom Advisory Services, an Assistant Professor ESEADE (Argentina) and a Research Fellow with the Economics Department at the Universidad de San Andres. Before joining Telecom Advisory Services, he was a staff analyst in Argentina's Congress.

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This study was commissioned by the Competitive Carriers Association. The authors are solely responsible for the views and content of the study.

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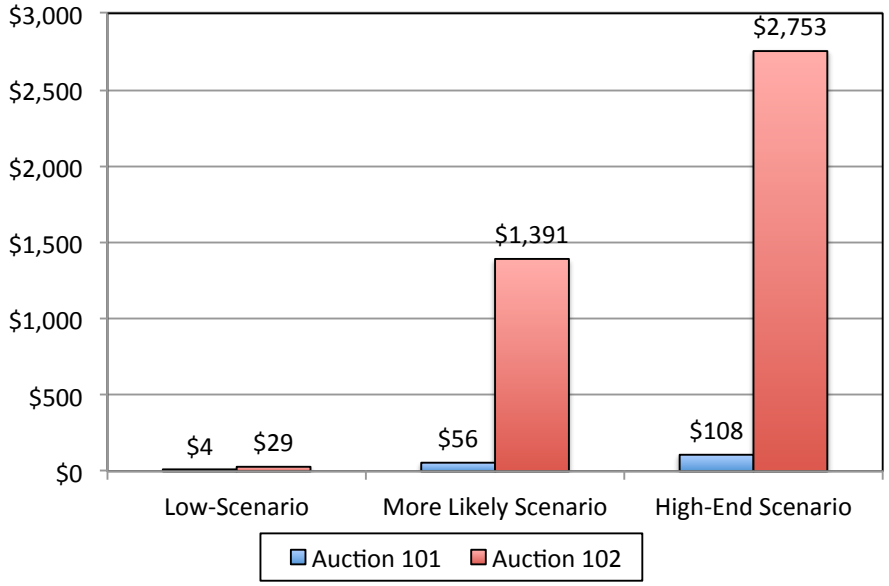
EXECUTIVE SUMMARY

The Advancing Innovation and Reinvigorating Widespread Access to Viable Electromagnetic Spectrum Act or the AIRWAVES Act was introduced in Congress with the purpose of encouraging the federal government to continue freeing up spectrum for licensed and unlicensed use, and use proceeds of spectrum auctions aimed at deploying wireless infrastructure to help close the urban-rural divide. According to the Act, the Federal Communications Commission ("FCC") should allocate 10% of proceeds from each of the upcoming spectrum band auctions specified in the bill to expand wireless infrastructure in rural areas that are underserved or unserved. The purpose of this study is to estimate the economic impact of AIRWAVES. While the bill refers to all 5G spectrum auctions, given the considerable uncertainty about auctions beyond the upcoming 28 GHz and 24 GHz, this study has estimated the economic impact of AIRWAVES resulting only from the proceeds of Auctions 101 and 102.

By relying on benchmarks from the acquisition of Straight Path ($ 0.017 MHz/Pop) and the 600 MHz reverse auction ($ 0.088 MHz/PoP) as well as the minimum opening bids of each auction, it is estimated that AIRWAVES could generate through auctions 101 and 102 up to $ 2,861 million, with a more likely estimate of $ 1,447 million to be invested in rural wireless broadband[1] (see graphic A).

Graphic A. Potential AIRWAVES Scenarios from Auction 101 and 102



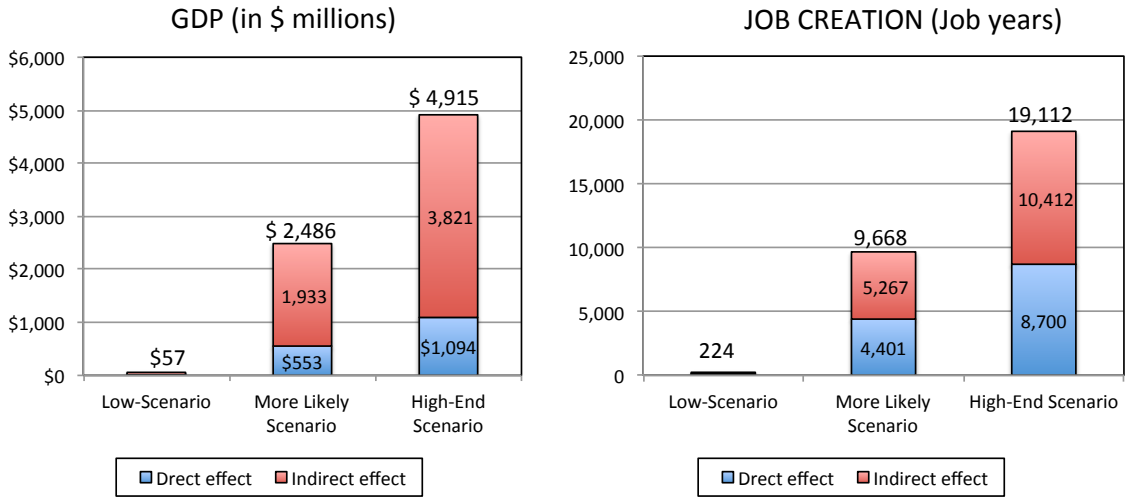
Source: Telecom Advisory Services analysis

[1] For reference, GSMA Intelligence estimates the annual wireless CAPEX in the United States to reach $ 32.33 billion.

Additional planned auctions in the 3.5 GHz band, and the 3.7 to 4.2 GHz bands could increase this amount significantly.

Using the 101 and 102 auctions as a starting point, it is estimated that, only in terms of the short-term network construction effect, an infusion of $ 2,861 million capital spending will generate an incremental GDP of $ 4,915 million and create 19,100 job years, of which 8,700 would be in construction and the remainder in industries supplying inputs to the telecommunications industry (e.g. towers, telecommunications equipment, electrical equipment, etc.). A more likely scenario of $ 1,447 million CAPEX could result in $ 2,486 billion in additional GDP and 9,700 job years[2] (see graphic B).

Graphic B. AIRWAVES: Short-term network construction economic effect



Source: Telecom Advisory Services analysis

Beyond this short-term network construction effect, the AIRWAVES generated capital should increase 4G coverage by up to 1.08 percentage points, with a more likely estimate of 0.55 percentage points (it is estimated based on OpenSignal crowdsourced data that current 4G population coverage currently reaches 95.78% of the population[3]). This increase represents a reduction of the rural coverage gap of between 24% and 12%[4]. The reduction in uncovered population will generate spillovers on the economy by increasing the circulation of goods and services (for example, through the enhancement of e-commerce flows, or by augmenting the efficiency of industrial production). This will be critical in terms of increasing output of industries that are important in rural areas. For example, the impact of broadband-enabled agricultural automation is based on its

[2] This contribution could be maximized if the AIRWAVES subsidy is not taxed as revenues for the rural carriers.

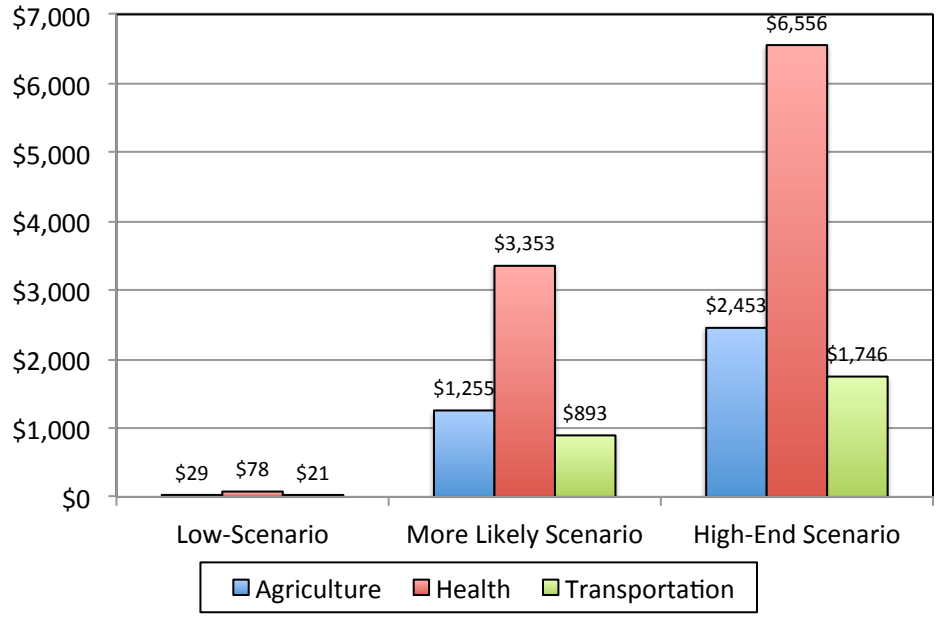
[3] Even if this is the best data available, there is still no reliable data set for standardized 4G coverage.

[4] While this increase in population coverage is relatively small in percentage points, it represents large swaths of territory.

contribution to the increase in total factor productivity through more efficient use of labor, timeliness of operations (optimization of agronomic windows, reduction of spoilage and harvest losses), and efficient use of inputs (water, seeds, fertilizers).

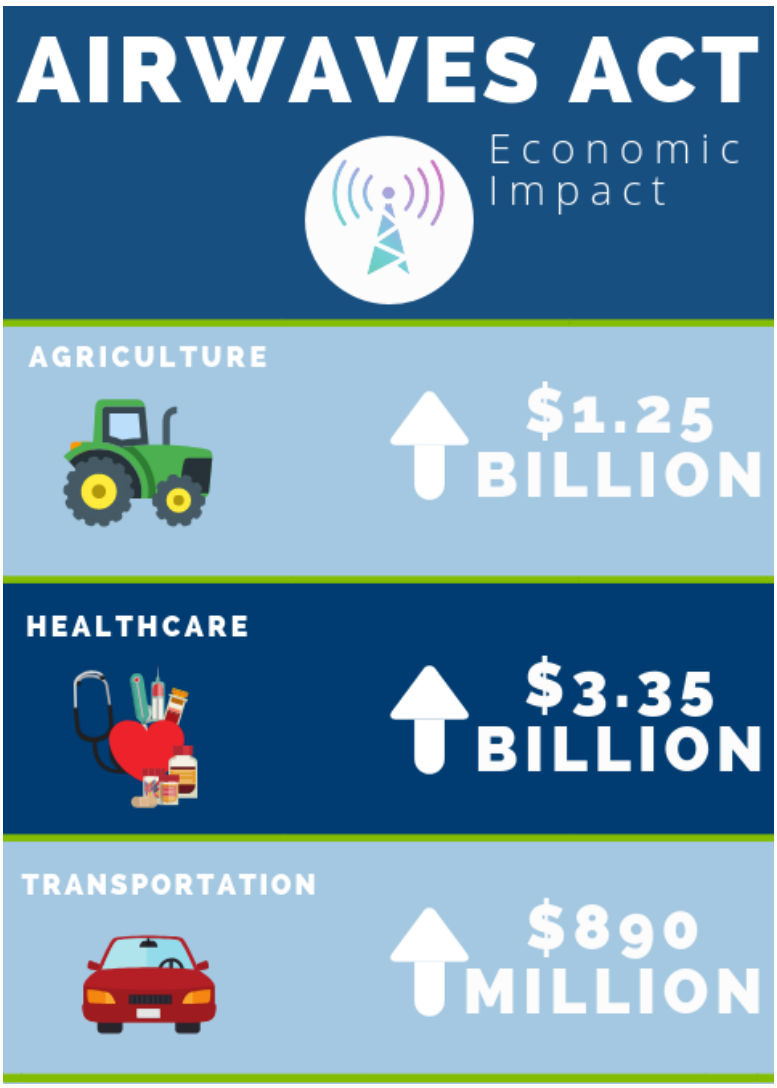
In consequence, additional 4G coverage derived from AIRWAVES investment will grow output by up to $2.45 billion in agriculture, $ 6.56 billion in health care, and $ 1.75 billion in transportation. Within a more likely scenario, the impact would be $ 1.25 billion in agriculture, $ 3.35 billion in health care, and $ 0.89 billion in transportation (see graphic C).

Graphic C. AIRWAVES: Long-term economic effects



Source: Telecom Advisory Services analysis

These figures underline the importance of AIRWAVES in terms of its economic effect in rural America.



I. BACKGROUND

In August, 2017, Senators Gardner (R-CO) and Hassan (D-NH) introduced S. 1682, the Advancing Innovation and Reinvigorating Widespread Access to Viable Electromagnetic Spectrum Act or the AIRWAVES Act, aimed at encouraging the federal government to continue freeing up spectrum for licensed and unlicensed use, and use proceeds of spectrum auctions to help close the urban-rural divide. More specifically, according to the Act, the FCC should allocate 10% of proceeds from each of the upcoming spectrum band auctions specified in the bill to expand wireless infrastructure in rural areas that are underserved or unserved[5]. In February 2018, Congressmen Lance and Doyle introduced

[5] As stated in the bill, "Notwithstanding section 309(j)(8) of the Communications Act of 1934 (47 U.S.C. 309(j)(8)), the Commission shall allocate 10 percent of the proceeds from each system of competitive bidding conducted under this Act for the deployment of wireless infrastructure in areas that the Commission has determined are underserved or unserved with respect to wireless broadband Internet access service."

H.R. 4953 as a companion bill in the House of Representatives. AIRWAVES is supported by Competitive Carriers Association ("CCA")[6], AT&T[7], CTIA[8] and the Wi-Fi Alliance[9], among others.

In this context, Competitive Carriers Association (CCA) requested a study quantifying the economic benefit of the Act in extending wireless coverage to rural areas. Along those lines, the CTIA, for example, pointed out that, had the legislation been in effect for the last two AWS-3 and broadcast incentive auctions (which together raised approximately $65 billion), it would have meant over $6 billion assigned for deploying rural wireless broadband.

According to this objective, the goals of this study are:

- To quantify the investment amount that could be assigned to rural wireless broadband deployment in light of the proposed bill in the context of upcoming 5G auctions;
- To estimate the impact of this investment on extending wireless broadband coverage in rural areas; and
- On the basis of the extended coverage, estimate the economic contribution in terms of GDP growth and job creation.

The following document begins by outlining the methodology used for conducting such an assessment (section II). It then follows by presenting an estimate of the auction proceeds to be collected for rural wireless deployment as a result of AIRWAVES (section III). Once this amount has been estimated, it calculates its aggregate short-term economic contribution as a result of network construction (section IV). The investment amount is also relied upon to calculate the impact on wireless broadband coverage (section V). The increase in coverage will yield a contribution to the GDP and job creation of three economic sectors that are of critical importance to rural areas of the country: agriculture, health care, and transportation (section VI).

II. METHODOLOGY

AIRWAVES triggered investment in 4G network deployment will have two types of economic effects. First, the deployment of 4G networks will contribute to a short-term increase in output and employment. This contribution is called the "network construction

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[6] CCA Commends Bipartisan Introduction of the AIRWAVES Act, August 1, 2017.

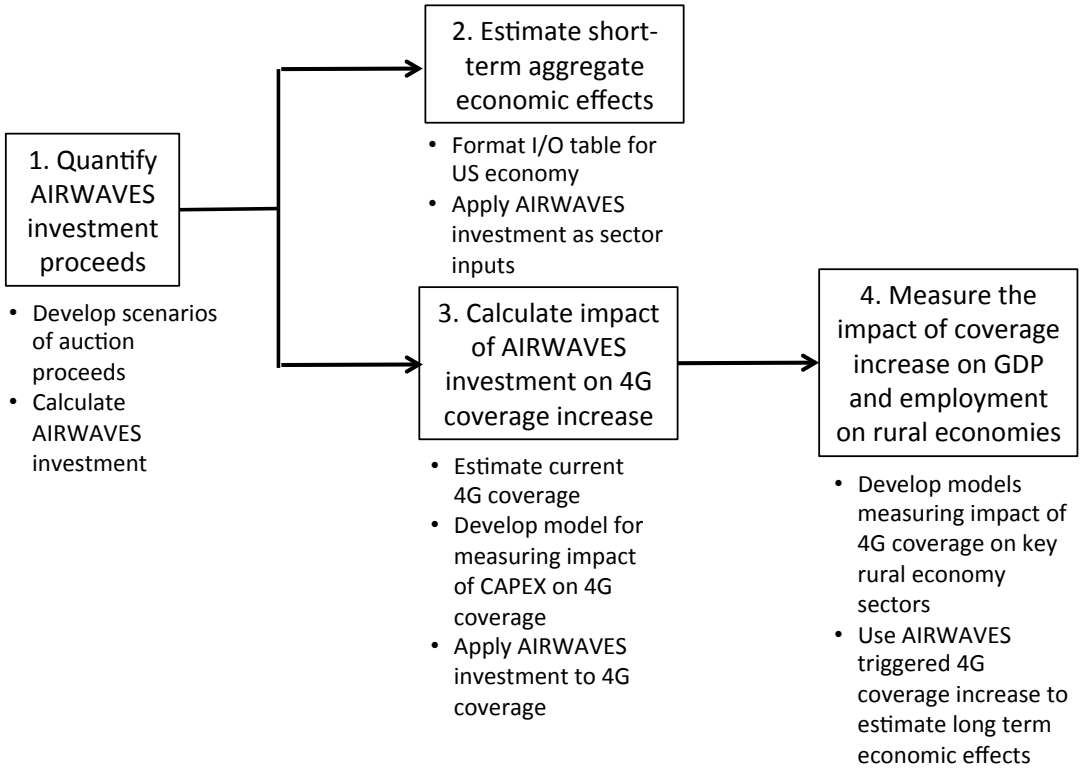
[7] AT&T Statement on Introduction of AIRWAVES, February 8, 2018 Act in U.S. House.

[8] CTIA Applauds Representatives Lance and Doyle on Bipartisan Airwaves Act Introduction, February 7, 2018.

[9] Wi-Fi Alliance® welcomes AIRWAVES Act, August 3, 2017.

effect"[10]. The second effect comprises the spillovers broadband networks generate on the economy by increasing the circulation of goods and services (for example, through the enhancement of e-commerce flows, or by augmenting the efficiency of production). This study calculates both effects. To tackle their estimation, the research is structured around four steps, each one based on a specific methodology (see figure 1).

Figure 1. Study Methodologies



As presented in figure 1, Step 1 calculates the investment to be triggered by the upcoming 5G wireless investment. On this basis, short-term aggregate economic effects (Step 2) and long term spillovers (Steps 3 and 4) can be calculated. The methodologies used in each step are reviewed in turn.

II.1. Step 1: Quantify the AIRWAVES investment

The first step followed to estimate the amount of investment to be assigned to rural wireless broadband is to determine the potential AIRWAVES triggered investment to be generated in the upcoming 5G wireless auctions. This amount is directly dependent on the proceeds of the auctions specified in the bill (above 24 GHz). Of all the bands mentioned in the Act, the FCC has so far announced plans to start auctioning millimeter wave ("mmW") licenses in the 28 GHz spectrum bands in November 14, 2018 (Auction 101), followed as soon as this is completed with an auction of spectrum in the 24 GHz

[10] Katz, R. (2012). The impact of broadband on the economy: research to date and policy issues. Geneva: International Telecommunications Union.

band (Auction 102). Beyond that, the FCC will take the steps needed to make the 3.5 GHz band and the 3.7 to 4.2 GHz band available for commercial terrestrial use. Given the considerable uncertainty about the auctions beyond 28 GHz and 24 GHz, this study focuses only on auctions 101 and 102.

Since auctions 101 and 102 represent the first time mmW spectrum will be publicly auctioned, the estimation of proceeds entails a valuation uncertainty given the lack of benchmarks[11]. In this context, two factors intrinsic to the value of mmW spectrum need to be considered. On the one hand, the value of mmW spectrum is driven by its importance within 5G deployment plans; this should drive high value. On the other hand, mmW bands typically can only transmit signals at relatively short distances—like several hundred meters—whereas traditional mid-band or low-band cellular spectrum can transmit signals several miles or more, depending on operators' technologies and spectrum configurations. This could potentially reduce their value, although part of it could be compensated by higher transmission bandwidth and speed[12]. In addition, auction proceeds could be influenced by factors such as current spectrum ownership by national carriers, location of licenses being offered, as well as industry dynamics.

Considering the high level of uncertainty of what total auction proceeds will be, three scenarios (high, medium and low) were developed as part of this study:

- Low scenario: this assumes auction proceeds to be based on the minimum opening bids. Since the licenses available in Auction 101 pertain mostly to low density rural areas, carrier interest for acquiring them could be low. In fact, some analysts expect low bids to be prevalent in Auction 101[13].
- High scenario: spectrum bands, considered to be critical to build 5G service offering, have already been driving an arms race between Verizon, ATT and T-Mobile to acquire licenses[14]. This could result in high auction proceeds. For this

[11] Use of comparable results (commonly referred to as benchmarking) is the most commonly used spectrum valuation methodology. Comparable results can be analyzed in two ways:

- By collating and normalizing auction prices obtained in similar cases for which the results will be used (for example, neighboring countries);
- By relying on econometric analysis, which allows different cases to be included taking account of socio-economic or topographic differences.

This methodology involves the collation of data on prices paid in other spectrum auctions or transactions, which is possible in the case of spectrum for cellular telecommunications with comparable data.

[12] Verizon, for example, has announced that it can offer 1 Gbps connections in 28 GHz beyond 2,000 feet.

[13] Dano, M. "Why the 28 GHz spectrum auction only covers 23.7% of the U.S. population". Fierce Wireless. April, 20, 2018.

[14] Chamberlain, K. "Verizon, Straight Path pay record $600 M in spectrum settlement", Fierce Wireless, March 1, 2018.

purpose, this scenario will be based on the price per MHz-PoP implied in Verizon's Straight Path acquisition and the 600 MHz incentive spectrum auction.

- More likely scenario: defined as a mid-point of the prior two.

II.2. Step 2: Measure the short-term economic impact of AIRWAVES investment

Once the investment input has been calculated in Step 1, short-term employment and output effects were estimated for the US economy. The AIRWAVES investment will generate a short-term effect as a result of the increase in spending in network deployment in rural areas. Broadband network construction drives an increase in output and job creation in three ways. First, network construction drives spending to purchase equipment and construction services, and requires the creation of direct jobs (such as telecommunications technicians, and construction workers) to build the facility. Secondly, the direct spending on network construction has an impact on indirect output and employment in industries related to inputs to network deployment (such as electronic equipment, towers, etc.). Finally, the household spending driven by the income generated from the direct and indirect jobs should create induced employment. However, following the assumption of conventional economic impact analysis conducted in contexts of full employment such as the one undergoing in the United States at this time, the induced effects were not considered in this study.

To calculate output and employment effects resulting from rural wireless broadband deployment, we relied on input-output analysis. In order to be utilized in this analysis, the input-output matrices needed to be formatted to calculate the output and employment multipliers. From the I/O-table, it is possible to obtain multipliers for total industry supply and additional variables as value added and employment. The calculation of the multipliers for the total industry supply uses the direct requirement table, also called the Leontief-Inverse. The direct requirement table (DR) is calculated by the following formula:

$$DR = (I - A)^{-1}$$

with A = I/O-table / total industry supply
(division of each cell of intermediate domestic supply by total industry supply)
I = Identity matrix

The sum of the columns per industry reflects the increase of the total industry supply by one additional unit of demand in this specific sector. An adjustment for the share of imports on total industry supply results in the total domestic production of US industries. The multiplication of the share of value added of total domestic industry production yields the value added multiplier. By relying on labor productivities it is then possible to calculate the output and job effects.

To construct the I/O tables, we relied on input-output matrices published by the Bureau of Economic Analysis (BEA). For this study, we relied on the BEA make and use tables

from the 2015 Benchmark Input-Output Accounts and the Bureau of Labor Statistics: Employment by Industry ("Employment and Earnings Online," First Quarter 2017 issue). The I/O matrix was built using a methodology from Chamberlain Economics LLC. To construct an I/O-table that can be used to calculate multipliers that reflect domestic production only it was necessary to exclude imports from the make table. The resulting I/O-table from BEA data has the dimension of 71*71 industries. Due to the fact that the employment data used for productivity calculations is provided for 262 industries, the statistics were consolidated in 71 sectors.

Once the I/O tables were constructed, the total AIRWAVES generated investment in network deployment (calculated in Step 1) was split by inputs (equipment, construction, and towers) following industry benchmarks, and entered in the input side of the matrix to calculate its contribution to GDP and job creation.

II.3. Step 3: Estimate the impact of increased wireless broadband coverage as a result of AIRWAVES investment

Beyond the short term economic impact calculated in Step 2, by increasing wireless broadband coverage, AIRWAVES triggered investment yields a reduction of the rural-urban digital divide. To calculate the increase in coverage, two values needed to be estimated: a) current 4G coverage, and b) the impact on coverage of the resulting capital spent in network deployment (this last variable coming from Step 1).

The estimates of current wireless broadband in the United States, assumed to be LTE service, are not very reliable. While the FCC publishes reports of LTE coverage by non-rural and rural areas, they are based on service provider data[15]. As stated by the FCC, the fact that a service provider reports coverage in a particular census block does not necessarily mean that it provides coverage everywhere in that block. This means that the coverage numbers reported by the FCC could be overestimated. To correct for this, we relied on OpenSignal, a company that crowdsources data on carrier signal quality from wireless users. OpenSignal publishes annual coverage reports for corridors in 29 states. This data allows downward adjusting the FCC data for coverage[16].

Following the estimation of current coverage, a model needed to be developed to quantify the impact of capital spending on 4G coverage. Unfortunately, US wireless CAPEX time series are not disaggregated and extensive enough to generate a sufficient number of observations to yield a statistically significant analysis. Thus, we opted to build

[15] FCC. Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services, FCC-CIRC1709-08, Twentieth Report, Page 59.

[16] It should also be mentioned that OpenSignal data tracks coverage only by geographic corridors or metropolitan areas; therefore, this estimate could also be overestimated. That said, given the lack of more reliable data, we were obliged to rely on OpenSignal statistics.

a model that estimates the relationship between capital spending and 4G coverage based on cross-sectional data for 160 countries from GSMA Intelligence.

Once we had a starting point (current adjusted wireless broadband coverage), the amount of AIRWAVES generated capital spending (from Step 1), and a model estimating coverage as a result of CAPEX, we could project the impact of the proposed bill on a reduction of the unserved population.

II.4. Step 4: Quantify the economic impact of AIRWAVES caused coverage increase

As mentioned in the introduction to this section, beyond the short-term economic effects calculated in Step 2, the newly developed wireless broadband generates spillovers. We chose to estimate these externalities on specific industries that are critical to the development and social well-being of rural areas: agriculture, transportation, and health care. For each of them, an econometric model was built relying on 4G coverage as independent variable by state (calculated as part of Step 3), and sector GDP by state as a dependent variable, complemented with several control variables. The assumptions underlying such models would be that AIRWAVES triggered network roll-out in rural areas would augment 4G network coverage with a resulting benefit in each of the three industries under study (agriculture, health care, and transportation).

* * * * *

Having presented the methodology used to assess the economic effects of AIRWAVES, we will now turn to presenting the results of the analyses.

III. AIRWAVE INVESTMENT AS RELATED TO RURAL WIRELESS BROADBAND DEPLOYMENT

As described in the methodology section, the first step in estimating the amount of investment to be assigned to rural wireless broadband is to determine the potential proceeds to be generated by upcoming spectrum auctions. The FCC plans to start auctioning mm-Wave licenses in the 28 GHz spectrum bands in November 14, 2018 (Auction 101), followed as soon as this is completed with an auction of spectrum in the 24 GHz band (Auction 102). Given the uncertainties of the proceeds to be generated by each auction, we have built three scenarios (low investment, medium, and high investment).

III.1. Low AIRWAVES investment scenario

Auction 101 will comprise 425 MHz blocks[17] in 1,537 counties, comprising around 23.7%

[17] These blocks are substantially wider than those that have been offered in previous spectrum auctions and should be able to support high bandwidth services, albeit over relatively short distances.

of the population and 61.7% of the territory (the coverage difference is due to the fact that they tend to be larger, primarily rural counties with low population density)[18]. Beyond the potential low interest by carriers on these licenses, a national wireless market consolidation scenario could further reduce the number of players in the auction game. Furthermore, the 5G barriers to entry are high for non-traditional players, such as Dish. The demand for data requires wide channel allocations, which is available in high frequency bands where the cost of infrastructure is high[19]. All these factors could combine to depress the price of spectrum. On the other hand, Auction 102 will auction seven 100 MHz blocks in each of 416 Partial Economic Areas[20]. Average minimum opening bids at auction 101 is set at $0.00065 MHz-PoP, while the value at auction 102 is 0.00938[21].

These values are higher than the price per paid by AT&T for the acquisition of FiberTower. AT&T paid $207 million to acquire this company, which owned a significant footprint of millimeter wave spectrum in the 39 GHz band[22], with 475 licenses of 360 MHz in the top 100 US markets[23]. There is a consensus among analysts and policymakers[24] that AT&T paid an extremely low price for these holdings, which invalidates it as a benchmark for a low AIRWAVES investment scenario[25]. Assuming that the transaction resulted in the acquisition by AT&T of approximately 116,000,000,000 MHz/PoP, the price per MHz/PoP would have been approximately $ 0.0000049, well below the minimum price set by the FCC for the upcoming auctions. In consequence, we chose to retain the minimum bid values as the benchmark for the AIRWAVES low

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[18] Dano, M. "Why the 28 GHz spectrum auction only covers 23.7% of the U.S. population". Fierce Wireless. April, 20, 2018.

[19] Rayal, F. 600 MHz Incentive Auction: Beating Disappointment, March 27, 2017.

[20] Wiley Rein. Summary of Competitive Bidding Procedures for Auctions 101 (28 GHz) and 102 (24 GHz) April 23, 2018.

[21] See FCC. Auction 101 (28GHz) Bidding Units, Upfront Payments, and Minimum Opening Bids and Auction 102 (24 GHz) Bidding Units, Upfront Payments, and Minimum Opening Bids.

[22] AT&T completes acquisition of FiberTower Corporation. February 9, 2018.

[23] In January 2018 the Federal Communications Commission (FCC) forced FiberTower to relinquish all of its 24GHz concessions (around 121) and roughly the same number of 39GHz permits, as part of a settlement dating back to July 2012. The settlement means that AT&T has only received around 479 of FiberTower's 39GHz licenses and none of its 24GHz licenses.

[24] Letter from Rep. Anna Eshoo to Ajit Pai, March 14, 2018.

[25] Dano, M. "AT&T's FiberTower deal raises questions about the value of 5G spectrum", Fierce Wireless, March 15, 2018.

investment scenario.

III.2. High AIRWAVES investment scenario

Probably the best benchmark for estimating the high value of Auction 101 spectrum value is Verizon's $3.1 billion acquisition of Straight Path and its $1.8 billion purchase of XO, which gave the carrier a dominant position in the 28 GHz spectrum. Straight Path held 735 millimeter wave licenses, which amounted to 620 MHz in the top 30 US markets. In addition to the 28 GHz spectrum in key markets such as New York and San Francisco, Straight Path held a position in the LMDS 39 GHz band, representing 95% of the commercially available licenses[26]. While XO combined several assets beyond 28 GHz (e.g. national fiber optic network), Verizon stated that XO spectrum licenses would assist the carrier in the deployment of the 5G network[27]. Thus, both acquisitions were complementary in terms of Verizon's 5G strategy[28].

The Straight Path acquisition was completed after a bidding war with AT&T. Verizon's all stock offer was valued at $184 per share, outbidding AT$T's bid of $ 95.63 per share. Moffett Nathanson, a wireless analyst, stated that the bidding war caused the value of Straight Path millimeter wave spectrum to rise from about $0.009 per MHz-PoP, to $0.0172 per MHz-PoP[29].

When it comes to Auction 102, given its nationwide scope, a reasonable benchmark could be the 600 MHz incentive spectrum auction. In this case, wireless service providers paid $19.632 billion for 70 MHz of spectrum[30], or an average of $0.88/MHz-PoP[31]. On the one hand, these values are seen to be fairly rational and aligned with prior 700 MHz auctions (AWS-3 being an outlier). On the other hand, there is some uncertainty as to whether mm-Wave spectrum will be valued as much as the 600 MHz band. As mentioned above, the FCC plans to begin bidding at $293 million, which is substantially less than the

[26] "Verizon is buying Straight Path for more than $ 3 billion". Fortune, May 11, 2017.

[27] In addition to the fiber transaction, Verizon entered into an agreement to lease 28 GHz wireless spectrum from former XO affiliate NextLink Wireless. Additionally, Verizon has an option, exercisable under certain circumstances, to buy NextLink. Verizon. Verizon completes purchase of XO Communications' fiber business. Feb 01, 2017.

[28] Goovaerts, D. "Verizon snatches Straight Path from AT&T's Grasp with $3.1 billion offer". CED, 5/11/2017.

[29] Baumgartner, J. "Verizon outbids AT&T for Straight Path". Multichannel News. May, 11, 2017.

[30] The auction left 14 MHz for guard bands that could be used for whitespace [unlicensed with geo-location requirements].

[31] The average price for the top 40 PEAs (Partial Economic Area) was much higher $1.25/MHz PoP.

minimum bids for the 600 MHz spectrum auction[32]. Two factors might be driving this reduction: mmWave spectrum has lower propagation than 600 MHz, while its use requires costly electronics and deployment costs, thereby reducing its value. Cognizant of the uncertainty with regards to bidder interest and, consequently, potential proceeds of Auction 102, we chose to retain the 0.88/MHz-PoP as the upper end estimate[33].

In order to calculate the proceeds, the following parameters were relied upon (see table 1).

Table 1. Assumptions for estimating mmWave Auction proceeds

Auction (1)	MHz (2)	Population (3)	Average minimum opening bids (4)	Price per MHz/POP
Auction 101 (28 GHz)	425 MHz	147,952,342	$ 0.00065	$ 0.017 (5)
Auction 102 (24 GHz)	100 MHz	312,846,492	$ 0.00938	$ 0.88 (6)

Sources: (1), (2), (3) and (4) FCC Auction 101 (28GHz) Bidding Units, Upfront Payments, and Minimum Opening Bids and Auction 102 (24 GHz) Bidding Units, Upfront Payments, and Minimum Opening Bids; (5) Moffett Nathanson; (6) Dano. Op.cit.

Based on these assumptions, the three scenarios of proceeds to be derived from Auctions 101 and 102 and the implied AIRWAVES subsidy were estimated (see table 2).

Table 2. Auctions 101 and 102 Estimation of Proceeds (in $ millions)

		Low Scenario	More Likely scenario	High end scenario
Auction Proceeds	Auction 101 (28 GHz)	$ 40.87 (1)	$ 561 (4)	$ 1,082 (7)
	Auction 102 (24 GHz)	$ 293.45 (2)	$ 13,912 (5)	$ 27,530 (8)
	Total	$ 334.32 (3)	$14,473 (6)	$ 28,612 (9)
AIRWAVES subsidy	Auction 101 (28 GHz)	$4.09	$56.12	$108.15
	Auction 102 (24 GHz)	$29.35	$1,391.20	$2,753.05
	Total	$33.43	$1,447.32	$2,861.20

Sources: (1), (2), and (3) FCC Auction 101 (28GHz) Bidding Units, Upfront Payments, and Minimum Opening Bids and Auction 102 (24 GHz) Bidding Units, Upfront Payments, and Minimum Opening Bids; (4), (5), (6), (7), (8), (9) Telecom Advisory Services analysis.

As indicated in table 2, Auctions 101 and 102 could generate an AIRWAVES investment between $33 million and $ 2,861 million, with a more likely estimate of $ 1,447 million. With these values, the AIRWAVES economic impact can be estimated.

[32] The opening bids of 24 GHz "compares with opening bids for the 600 MHz auction ($1,174 million for each 10 MHz block) in the ratio of 117.4/(438/700)= 187.6 or about 188 times higher prices per MHz for 600 MHz spectrum than for 24 GHz spectrum". (Wilkus, S. Only 48% of Counties Available at 28 GHz, April 19, 2018).

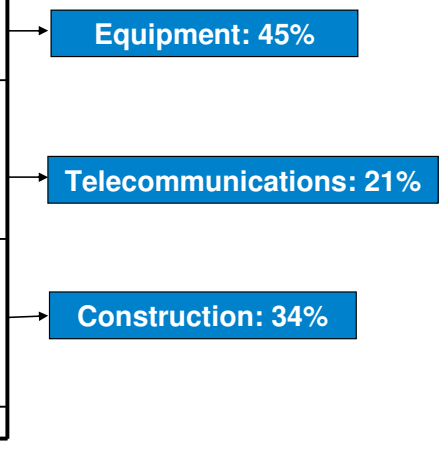
[33] As a calibration point of this upper end estimate, T-Mobile spent close to $8 billion in the 600 MHz auction.

IV. AGGREGATE SHORT-TERM ECONOMIC IMPACT OF AIRWAVES

With the three AIRWAVES investment values estimates, we proceed to estimate their short-term economic effect by relying on input-output tables. The first step consists in breaking down the total AIRWAVES resulting investment in cost categories in order to be able to enter them into specific sectors of the input-output matrix (construction, telecommunications antennae, electronic equipment). The assumptions to be relied upon are the following (see table 3).

Table 3. Wireless broadband cost breakdown

Category	Item	Installation	Cost	Average	Total
Equipment	Telecom equipment		$50 K	$50,000	$91,500
	Ancillary	Greenfield	$50K	$41,500	
		Collocation	$40K		
Telecom	EF&I	Greenfield	$ 9K	$6,450	$41,450
		Existing	$ 6K		
	Tower	Greenfield	$80K	$29,000	
		Existing	$20K		
	RF Engineering		$ 6K		
Construction	Civil works	Greenfield	$65K	$54,375	$68,825
		Collocation	$52K		
	Architecture & engineering	Greenfield	$ 9K	$6,450	
		Existing	$ 6K		
	Site acquisition & zoning		$ 8K	$8,000	
Total					$201,775



Note: 15% of installations are greenfield and 85% are based on existing infrastructure

Source: Spectrum management consulting (2008)

The benchmarks of table 3 were compared with estimates imputed by the submission of US Cellular counsel to the FCC[34] (see table 4).

[34] LaFuria, D. Oral ex parte presentation in connection with the WT Docket No. 10-208 WC Docket No. 10-90 proceedings, May 31, 2016.

Table 4. Comparison of wireless broadband cost benchmarks (percent of total cost)

	Spectrum Management Consulting (2008)	U.S. Cellular (2016)
Equipment (antenna, microwave, power equipment, radio equipment)	45%	40%
Telecommunications towers	21%	22%
Construction (building, leasehold improvements)	34%	38%

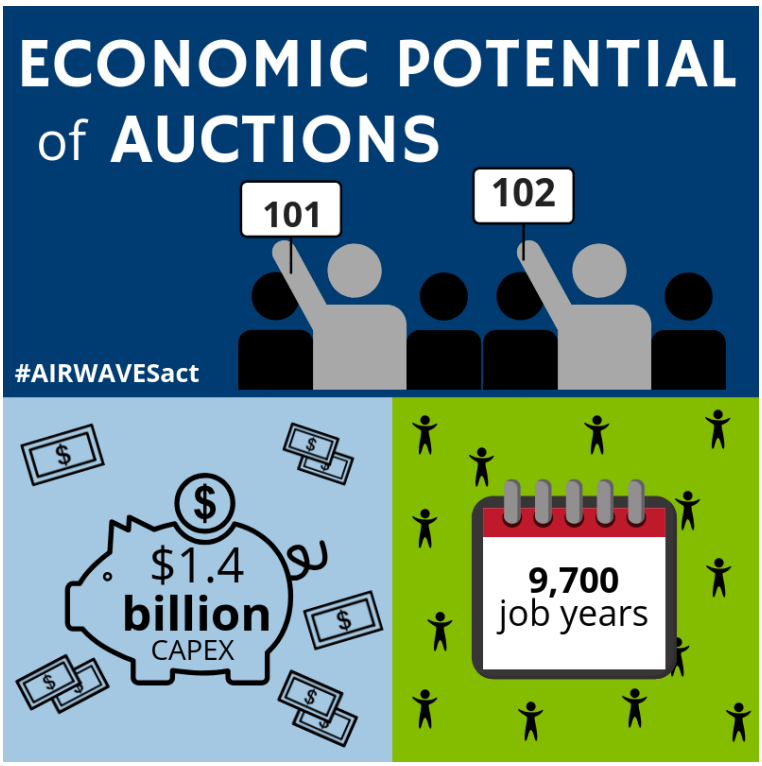
Source: Telecom Advisory Services analysis

While the Spectrum Management Consulting benchmarks are based on national averages, the US Cellular reflects costs incurred in network deployment in rural areas (with a higher proportion in construction due to the need to build access roads to base stations). Consequently, given that the AIRWAVES investment will be focused on rural network deployment, the amounts to be entered in the input-output matrix are based on the US Cellular benchmarks (see table 5).

Table 5. AIRWAVES investment by sector (in $ millions)

		Low Scenario	More likely Scenario	High end Scenario
Auction 101 (28 GHz)	Electronic equipment	$1.62	$22.29	$42.96
	Telecommunications antennae	$0.90	$12.38	$23.85
	Construction	$1.56	$21.45	$41.34
	TOTAL	$4.09	$56.12	$108.15
Auction 102 (24 GHz)	Electronic equipment	$11.66	$552.67	$1,093.68
	Telecommunications antennae	$6.47	$306.83	$607.18
	Construction	$11.22	$531.70	$1,052.19
	TOTAL	$29.35	$1,391.20	$2,753.05
Total	Equipment	$13.28	$574.96	$1,136.64
	Telecommunications antennae	$7.37	$319.20	$631.03
	Construction	$12.78	$553.15	$1,093.53
	TOTAL	$33.43	$1,447.32	$2,861.20

Note: Detail may not add to total due to rounding
Source: Telecom Advisory Services analysis



The three cost components for each scenario were then entered in the corresponding sectors of the input-output matrix of the US economy to calculate output growth and employment effects. Short-term economic effects resulting from network deployment triggered by AIRWAVES are, at the more likely level, $ 2.49 billion in output and 9,700 in jobs created. It could reach $ 4.91 billion in GDP and 19,100 jobs (see table 6).

Table 6. AIRWAVES aggregate economic impact

		Low end Scenario ($ 33.43 million)	More likely Scenario ($ 1,447.32 million)	High end Scenario ($ 2,861.20 million)
Output (in $ million)	Direct effect	$ 12.78	$ 553.15	$ 1,093.53
	Indirect effect	$ 44.64	$ 1,932.85	$ 3,821.08
	Total effect	$ 57.42	$ 2,486.00	$ 4,914.61
Employment (job years)	Direct effect	102	4,401	8,700
	Indirect effect	122	5,267	10,412
	Total effect	224	9,668	19,112

Source: Telecom Advisory Services analysis

As indicated in table 6, the short-term economic effect of investing 10% of the proceeds of Auctions 101 and 102 will generate up to 4,914 million in additional GDP and the creation of 19,112 job/years.

V. IMPACT OF AIRWAVES IN INCREASING WIRELESS BROADBAND COVERAGE

AIRWAVES should have an impact on wireless broadband (4G) coverage. In order to estimate this contribution, it is necessary to quantify current coverage and model the impact of additional investment on coverage. As reviewed in the methodology, the estimation of increased coverage requires establishing what the current coverage is.

GSMA Intelligence estimates 4Q2018 4G population coverage in the United States to reach 98%. The FCC reports that as of December 2016, 100% of non-rural POPs were covered by at least one LTE carrier, while the equivalent number for rural POPs was 98.8%[35]. As mentioned above, the FCC mentions that the fact that a service provider reports coverage in a particular census block does not necessarily mean that it provides coverage everywhere in that block. Therefore, we opted for relying on OpenSignal crowdsourced data[36]. According to our analysis of the OpenSignal coverage report, the year end 2017 nationwide 4G US coverage is 95.78%, broken down as follows (see table 7).

Table 7. United States: 4G Coverage

State	3Q16	4Q16	1Q17	2Q17	3Q17	4Q17	1Q18	1Q18	CAGR
Arizona	91.82%	92.04%	92.27%	92.84%	93.42%	94.20%	94.98%	95.87%	2.50%
California	88.60%	89.54%	90.49%	91.96%	93.46%	94.30%	95.14%	95.91%	4.63%
Colorado	85.69%	86.98%	88.28%	89.22%	90.16%	91.76%	93.38%	93.37%	5.03%
Delaware	88.15%	89.32%	90.50%	91.92%	93.37%	94.16%	94.96%	95.56%	4.72%
District of Columbia	91.06%	91.78%	92.50%	93.14%	93.78%	94.39%	95.00%	96.38%	3.30%
Florida	91.66%	92.10%	92.54%	93.48%	94.44%	94.98%	95.52%	96.24%	2.83%
Georgia	87.41%	88.47%	89.55%	90.52%	91.50%	92.58%	93.67%	94.22%	4.38%
Illinois	90.27%	90.80%	91.33%	92.32%	93.31%	94.16%	95.03%	95.61%	3.34%
Indiana	91.12%	91.60%	92.08%	93.14%	94.22%	94.83%	95.43%	96.09%	3.08%
Kansas	91.74%	92.76%	93.79%	94.74%	95.69%	95.86%	96.03%	96.43%	2.89%
Kentucky	92.70%	93.67%	94.65%	94.94%	95.24%	95.86%	96.49%	97.42%	2.88%
Maryland	89.70%	90.76%	91.83%	92.75%	93.68%	94.42%	95.16%	95.83%	3.85%
Massachusetts	86.96%	88.13%	89.31%	90.49%	91.69%	93.08%	94.49%	95.77%	5.67%
Michigan	90.04%	91.05%	92.07%	92.82%	93.57%	94.13%	94.69%	95.82%	3.62%
Minnesota	90.70%	91.26%	91.82%	92.79%	93.78%	94.62%	95.46%	96.30%	3.48%
Missouri	91.74%	92.76%	93.79%	94.74%	95.69%	95.86%	96.03%	96.43%	2.89%
Nevada	89.55%	90.22%	90.89%	91.57%	92.25%	93.74%	95.25%	95.83%	3.95%
New Hampshire	86.96%	88.13%	89.31%	90.49%	91.69%	93.08%	94.49%	95.77%	5.67%
New Jersey	87.92%	89.07%	90.23%	91.08%	91.93%	93.32%	94.74%	95.63%	4.92%
New York	87.92%	89.07%	90.23%	91.08%	91.93%	93.32%	94.74%	95.63%	4.92%
Ohio	92.58%	93.35%	94.14%	94.52%	94.91%	95.70%	96.50%	96.67%	2.50%
Oklahoma	93.22%	93.65%	94.09%	94.53%	94.97%	95.41%	95.85%	96.30%	1.87%

[35] FCC. Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services, FCC-CIRC1709-08, Twentieth Report, Page 59.

[36] OpenSignal. State of Mobile Networks (February 2016 through January 2018).

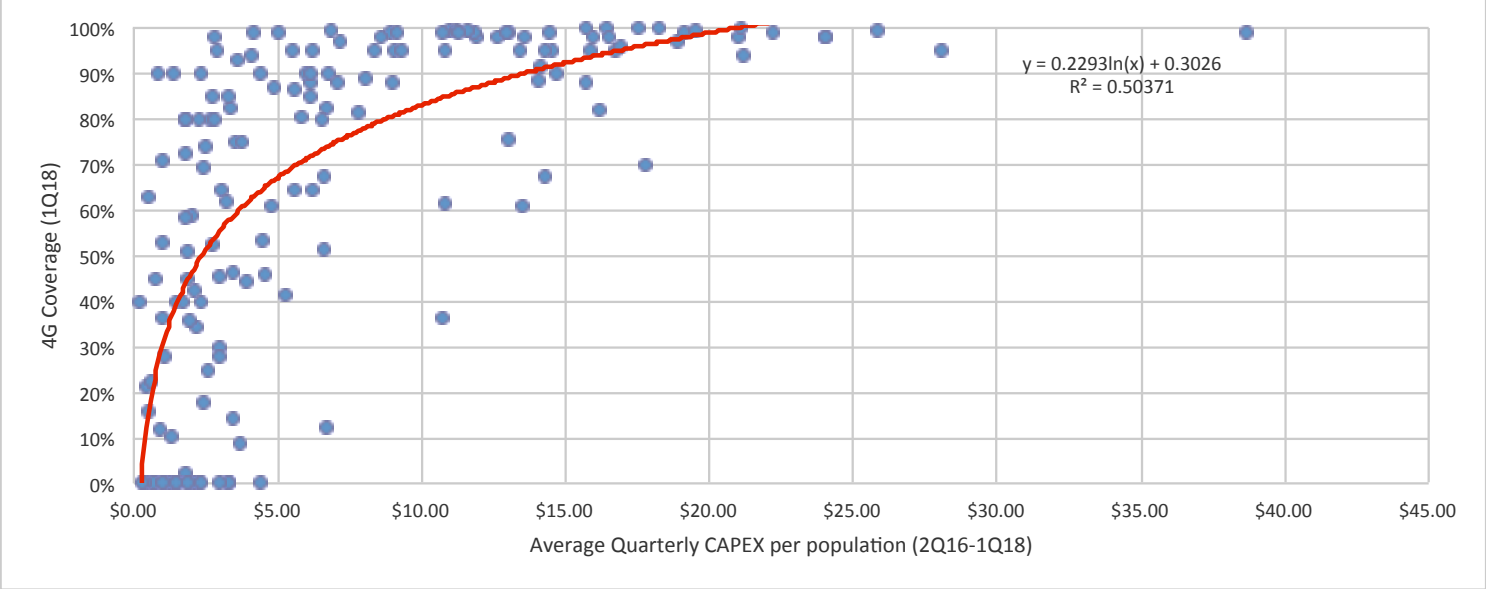
State	3Q16	4Q16	1Q17	2Q17	3Q17	4Q17	1Q18	1Q18	CAGR
Oregon	89.42%	89.75%	90.08%	91.30%	92.54%	93.73%	94.94%	94.55%	3.24%
Pennsylvania	87.17%	88.51%	89.88%	91.45%	93.06%	93.92%	94.78%	95.45%	5.32%
Texas	90.28%	91.19%	92.10%	92.57%	93.04%	94.04%	95.05%	95.69%	3.38%
Virginia	91.06%	91.78%	92.50%	93.14%	93.78%	94.39%	95.00%	96.38%	3.30%
Washington	87.79%	88.09%	88.39%	90.31%	92.28%	93.51%	94.75%	94.97%	4.59%
West Virginia	91.06%	91.78%	92.50%	93.14%	93.78%	94.39%	95.00%	96.38%	3.30%
Wisconsin	90.36%	90.89%	91.42%	92.42%	93.44%	94.28%	95.13%	95.87%	3.44%
TOTAL	89.63%	90.48%	91.33%	92.30%	93.27%	94.17%	95.08%	95.78%	3.86%

NOTE: OpenSignal network coverage does not include all 50 states.
Source: OpenSignal; Telecom Advisory Services analysis.

This likely overstates coverage, particularly in rural areas, but assuming that 95.78% represents a more accurate 4G coverage metric than the FCC data, we now proceed to estimate the impact of AIRWAVES additional CAPEX on future coverage.

As mentioned above, the lack of extensive enough time series for coverage and CAPEX for the United States compels us to use international cross-sectional data. In order to do this, a model calculating the relationship between capital spending and 4G coverage was constructed based on cross-sectional data for 160 countries from GSMA Intelligence (see Graphic 1).

Graphic 1. Relationship between CAPEX and 4G Coverage



Source: GSMA Intelligence; Telecom Advisory Services analysis

According to this model, both variables (CAPEX and 4G coverage) appear to be linked by a logarithmic function:

4G Coverage = 0.2293 * log (Quarterly CAPEX) + 0.3026

The model also validates the notion that the cost of increasing coverage at higher coverage levels requires larger amounts of capital.

With this model, we can now estimate the impact of AIRWAVES imputed investment (from table 2) on 4G coverage, using as a starting point the OpenSignal coverage data. The estimates are based on the three CAPEX scenarios calculated for AIRWAVES (see table 8).

Table 8. Coverage Impact of AIRWAVES

AIRWAVES Scenarios	Investment Scenarios	Quarterly Investment (*)	Implied additional CAPEX per POP	Current CAPEX per POP (**)	New CAPEX per POP	Incremental 4G coverage (***)
High	$ 2,861,200,000	$ 357,650,000	$ 1.10	$ 23.81	$ 24.91	1.08%
More likely	$ 1,447,320,000	$ 180,915,000	$ 0.55		$ 24.37	0.55%
Low	$ 33,430,000	$ 4,178,750	$ 0.01		$ 23.83	0.01%

(*) Assumes AIRWAVES capital will be spread over eight quarters
(**) From GSMA Intelligence
(***) Calculated based on model presented above
Source: Telecom Advisory Services analysis

According to calculations presented in table 7, AIRWAVES triggered investment could yield a reduction in uncovered area between 24.46% to 0.29%, depending on investment scenario (or an incremental 4G coverage between 1.03% and 0.01%). This would equate up to 3,367,000 additional population being served by 4G.

VI. ECONOMIC IMPACT OF AIRWAVES-TRIGGERED WIRELESS BROADBAND COVERAGE

In addition to the aggregate economic impact generated by AIRWAVES triggered network deployment presented in section IV above, incremental wireless coverage has secondary spill-overs on specific sectors of the economy of rural areas. For this purpose, three industries that are particularly important to rural America have been selected: agriculture, health care, and transportation. For each industry, a specific econometric model was constructed, relying on 4G coverage as independent variable by state, and sector GDP by state as a dependent variable, complemented with several control variables. The assumptions underlying such models would be that AIRWAVES triggered network roll-out in rural areas would augment 4G network coverage with resulting benefits in each of the three industries under study (see table 9). Because coverage is more likely to be overstated in rural areas, these benefits may be greater.

Table 9. Impact of an increase in 4G coverage in the sectorial GDP

Dependent variable: ln of the sectorial GDP_t	Agriculture[37]	Health[38]	Transportation[39]
Ln_4G $Coverage_t$	2.6248 ** (1.0134)	0.9481 *** (0.1379)	0.6173 *** (0.1589)
Ln_Download $Speed_t$	0.2091 (0.1971)	-0.0090 (0.0256)	0.0366 (0.0309)
Ln_Rest of the State GDP_t	-2.5573 *** (0.8920)	0.4308 *** (0.1123)	0.3184 ** (0.1416)
Ln_Sector GDP_{t-1}	0.1629 (0.1021)	-0.1174 (0.0812)	0.0394 (0.0833)
Constant	26.7959 *** (8.1265)	1.6758 * (1.0126)	1.9137 (1.2145)
Observations	168	174	174
Groups	28[40]	29	29
Fixed effects	Yes	Yes	Yes
Time	4Q16-1Q18	4Q16-1Q18	4Q16-1Q18
Overall R-squared	0.2350	0.9125	0.8502

Source: Coverage data from OpenSignal; Economic data from Bureau of Economic Analysis data; Telecom Advisory Services analysis

The three models presented in table 9 yield the following results:

- An increase of 1% in 4G coverage will increase the agriculture GDP by 2.62%. The high coefficient might be related to the important benefit of serving rural areas, dedicated to agriculture, with a technology that is a direct enabler of precision agriculture[41]. The negative and statistically significant relationship between the agriculture GDP and the output of the rest of the economy might mean that the sector output is more related to exogenous factors, such as commodity prices;

- An increase of 1% in 4G coverage yields a 0.95% in the Health Sector and Social Assistance GDP, with a positive and statistically significant relationship between the sector GDP and the output of all other sectors;

[37] Agriculture, forestry, fishing, and hunting (Bureau of economic analysis definition).

[38] Health care and social assistance (Bureau of economic analysis definition).

[39] Transportation and warehousing (Bureau of economic analysis definition).

[40] No data exists for Delaware in the agriculture sector.

[41] The impact of agricultural automation can be estimated based on its contribution to the increase in Total Factor Productivity through more efficient use of labor, timeliness of operations (optimization of agronomic windows, reduction of spoilage and harvest losses), and efficient use of inputs (water, seeds, fertilizers). The United States had a total of 310 million crop acres in 2016, within which the adoption of precision agriculture was likely to reach 40% in 2017, with producer benefits of $20 per hectare.

- An increase of 1% in 4G coverage yields 0.62% increase in transportation and warehousing GDP, with a positive and statistically significant relationship between the sector GDP and the output of all other sectors.

A few caveats need to be raised regarding these models. First, the variables not included in the models due to lack of quarterly data, such as urbanization rate, are captured in the fixed effects. Second, these models are based on states with 4G coverage higher than 90%. This means that, as indicated in the logarithmic model, the effect of coverage on GDP could be different in cases with 4G coverage of less than 90%. Third, the effect captured in these models comprises both the direct contribution, potentially captured in the I/O analysis in each sector as well as externalities. However, in the case of the three sectors under study, the direct effects captured in the short-term estimates provided in section 3 are less than 1%.

The models allow estimating the annual impact of increased 4G coverage on sector GDP (see table 10).

Table 10. Annual Impact[42] of AIRWAVES increased coverage on sector GDP (in $ millions unless indicated)

Sector	Additional 4G coverage (from models in table 7)	Coefficient (from models in table 9) (*)	GDP (**)	High-end Impact	More likely Impact	Low-end Impact
Agriculture (***)	0.01%/0.55%/1.08%	2.6248	$ 173,445	$2,453.04	$1,254.65	$29.31
Health (****)	0.01%/0.55%/1.08%	0.9481	$ 1,283,287	$6,555.79	$3,353.07	$78.33
Transportation (*****)	0.01%/0.55%/1.08%	0.6173	$ 524,961	$1,746.10	$893.07	$20.86
Total	-	-	$ 19,390,605	$10,754.93	$5,500.79	$128.50

(*) Coefficients are estimated in the model over a two-year period; therefore, annual impact requires dividing total GDP impact by two.
(**) 2017 GDP in current values (from Bureau of Economic analysis)
(***) "Agriculture, forestry, fishing, and hunting" (Bureau of economic analysis definition)
(****) "Ambulatory health care services" and "Hospitals and nursing and residential care facilities" (Bureau of economic analysis definition)
(*****) "Air transportation"; "Rail transportation"; "Water transportation"; "Truck transportation"; "Transit and ground passenger transportation"; "Pipeline transportation" and "Other transportation and support activities" (Bureau of economic analysis definition)
Note: Detail may not add to total due to rounding
Source: Telecom Advisory Services analysis and BEA

[42] We assume that the impact occurs over two years. Therefore the numbers presented, are the total impact divided by 2.

As indicated in table 10, additional 4G coverage derived from the AIRWAVES high-end scenario investment will grow output by up to $2.45 billion in agriculture, $ 6.56 billion in health care, and $ 1.75 billion in transportation. At the more likely level, the economic impact could be $1.25 billion in agriculture, $3.35 billion in health care, and $ 0.89 billion in transportation.

VII. CONCLUSION

The AIRWAVES Act was introduced with the purpose of encouraging the federal government to continue freeing up spectrum for licensed and unlicensed use, and use proceeds of spectrum auctions to help close the urban-rural divide. This study has estimated the economic impact of AIRWAVES resulting only from the proceeds of Auctions 101 and 102. By relying on benchmarks from the acquisition of Straight Path and the 600 MHz reverse auction, it is estimated that AIRWAVES could generate up to $ 2,861 million, with a more likely estimate of $ 1,447 million to be invested in rural wireless broadband[43]. Additional auctions in the 3.5 GHz, and the 3.7 to 4.2 GHz bands could increase this amount.

Using the 101 and 102 auctions as a starting point, it is estimated that, only in terms of the short-term construction effect, an infusion of $ 2,861 million capital spending will generate an incremental GDP of $ 4,914 million and create 19,100 job years, of which 8,700 could be in construction and the remainder in industries supplying inputs to the telecommunications industry (e.g. towers, telecommunications equipment, electrical equipment, etc.). A more likely scenario of $ 1,447 million CAPEX could result in $ 2,486 billion in additional GDP and 9,700 job years.

Beyond this short-term effect, the AIRWAVES generated capital should increase 4G coverage by up to 1.08 percentage points, with a more likely estimate of 0.55 percentage points. This represents a reduction of the rural coverage gap between 24% and 12%. This reduction in uncovered population will have an impact on the output of industries that are critically important in rural areas. Additional 4G coverage derived from AIRWAVES investment will grow output by up to $ 2.45 billion in agriculture, $ 6.56 billion in health care, and $ 1.75 billion in transportation. Within a more likely scenario, the impact would be $ 1.25 billion in agriculture, $ 3.35 billion in health care, and $ 0.89 billion in transportation. These figures underline the importance of AIRWAVES in terms of its economic effect in rural America.

[43] For reference, GSMA Intelligence estimates the annual wireless CAPEX in the United States to reach $ 32.33 billion.

APPENDICES

Table A. Scenarios estimation

	Low Scenario	High end scenario
Price perMHz/PoP		
101	0.0007	0.0172
102	0.0094	0.8800
Population		
101	147,952,342	147,952,342
102	312,846,492	312,846,492
MHz		
101	425	425
102	100	100
Proceeds		
101	40,871,834	1,081,531,620
102	293,450,009	27,530,491,296
Total	334,321,844	28,612,022,916

Auction	Low Scenario	Midpoint scenario	High end scenario
Auction 101 (28 GHz)	$40.87	$561	$1,082
Auction 102 (24 GHz)	$293.45	$13,912	$27,530
Total	$334.32	$14,473	$28,612

AIRWAVE Proceeds	Low Scenario	Midpoint scenario	High end scenario
Auction 101 (28 GHz)	$4.09	$56.12	$108.15
Auction 102 (24 GHz)	$29.35	$1,391.20	$2,753.05
Total	$33.43	$1,447.32	$2,861.20

Auction 101 (28 GHz)	Low Scenario	Midpoint scenario	High end scenario
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TOTAL	$4.09	$56.12	$108.15

Auction 102 (24 GHz)	Low Scenario	Midpoint scenario	High end scenario
Equipment	$11.66	$552.67	$1,093.68
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TOTAL	$29.35	$1,391.20	$2,753.05

Total	Low Scenario	Midpoint scenario	High end scenario
Equipment	$13.28	$574.96	$1,136.64
Telecommunications	$7.37	$319.20	$631.03
Construction	$12.78	$553.15	$1,093.53
TOTAL	$33.43	$1,447.32	$2,861.20

Source: Telecom Advisory Services analysis

Table B. Detailed analysis for Annual Impact of AIRWAVES increased coverage on sector GDP (in $ millions unless indicated)

AIRWAVES Scenarios	Investment	Periods	Quarterly Investment	Population	Add CAPEX per inh	Last USA data	New USA data	Impact	Actual no coverage	No coverage reduction	Additional coverage (%)	Pop impact
High end scenario	$ 2,861,202,292	8	$357,650,286	326,189,927	$ 1.10	$ 23.81	$ 24.91	1.03%	95.78%	24.46%	1.08%	3,366,839
Midpoint scenario	$ 1,447,317,238	8	$180,914,655	326,189,927	$ 0.55	$ 23.81	$ 24.37	0.53%	95.78%	12.51%	0.55%	1,722,027
Low Scenario	$ 33,432,184	8	$4,179,023	326,189,927	$ 0.01	$ 23.81	$ 23.83	0.01%	95.78%	0.29%	0.01%	40,228

				Total Impact			Total by year			Numer of years	2.00
	Sector	Coefficient	GDP 2017	O.S. Impact High	O. S. Impact Medium	O. S. Impact Low	O.S. Impact High	O. S. Impact Medium	O. S. Impact Low		
	Agriculture (*)	2.6248	$ 173,445	$ 4,906	$ 2,509	$ 59	$2,453.04	$1,254.65	$29.31		
	Health (**)	0.9481	$ 1,283,287	$ 13,112	$ 6,706	$ 157	$6,555.79	$3,353.07	$78.33		
	Transportation (***)	0.6173	$ 524,961	$ 3,492	$ 1,786	$ 42	$1,746.10	$893.07	$20.86		
	Total	-	$ 19,390,605	$ 21,510	$ 11,002	$ 257	$10,754.93	$5,500.79	$128.50		

(*) Agriculture, forestry, fishing, and hunting
(**) Ambulatory health care services; Hospitals and nursing and residential care facilities
(***) Air transportation; Rail transportation; water transportation; truck transportation; transit and ground passenger transportation; pipeline transportation and other transportation and support activities

Source: Telecom Advisory Services analysis