TELECOM ADVISORY SERVICES

THE ECONOMIC VALUE OF WI-FI: A GLOBAL VIEW (2018 and 2023)

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EXECUTIVE SUMMARY

Wi-Fi technology is an enabling resource that generates economic value across four dimensions:

- Supporting the development of alternative technologies, such as multiple access point (AP)/mesh networking systems and smart speakers, that were developed leveraging Wi-Fi, thus expanding consumer choice;
- Supporting the creation of innovative business models, such as Gogo, a leader in the provision of airline broadband access;
- Expanding access to communications services. Telecommunications companies such as British Telecom (BT) have deployed thousands of Wi-Fi hotspots to enhance connectivity to its fixed and mobile networks; and
- Complementing wireline and cellular technologies, thereby enhancing their effectiveness. For example, Vodafone Germany operates 1,000,000 hotspots, partly as a complement to its cellular network.

There is a significant amount of research-based evidence that Wi-Fi technology has very high social and economic value. Prior research agrees that, contrary to licensed bands where economic value could equate to whatever is paid at auction, the economic value of unlicensed spectrum, such as Wi-Fi, needs to be measured based on the concept of economic surplus and contribution to GDP. Consumer surplus measures the total amount consumers would be willing to pay to have the service compared to going without it altogether, while producer surplus measures the analogous quantity for producers, that is essentially the economic profit they earn from providing the service. Consumer and producer surplus together yield an economic surplus. Adding GDP contribution results in a total economic value estimate.

Despite the fact that Wi-Fi is a worldwide phenomenon, most research studies have so far focused only on the United States[1]. The following study goes further and estimates the total economic value of Wi-Fi in six developed countries: United States, United Kingdom, France, Germany, Japan, and South Korea. The study's purpose is to measure economic value, both to consumers and producers, as well as Wi-Fi's direct net contribution to output (Gross Domestic Product, or GDP) and employment for 2018 and 2023. The result of this analysis estimates the overall economic value of Wi-Fi for each selected country and is used to extrapolate results to a global scale. All figures are represented in US dollars, except where noted.

Using the detailed analysis and methodology explained in the following chapters of this report, the estimated economic value of Wi-Fi in 2018 for the six countries studied is:

- United States: $ 499 billion
- United Kingdom: $ 54 billion
- France: $ 44 billion
- Germany: $ 94 billion
- Japan: $ 171 billion
- South Korea: $ 68 billion

[1] See Thanki (2009), Cooper (2009), Millgrom et al. (2011); Katz (2014a), Katz (2014b), Katz (2018).

Estimates for 2023 represent significant increases in economic value for each market:

- United States: $ 993 billion
- United Kingdom: $ 71 billion
- France: $ 64 billion
- Germany: $ 132 billion
- Japan: $ 248 billion
- South Korea: $ 138 billion

Using these six markets and relying on a leading indicators methodology, global economic value of Wi-Fi in 2018 is estimated at $ 1.96 trillion. By 2023, global value of Wi-Fi should increase to $ 3.47 trillion. As a result of the growth and value of Wi-Fi, increases in jobs related to Wi-Fi are calculated. Current estimates show that global jobs attributable to Wi-Fi will increase by more than 50% to nearly one million by 2023.

I. INTRODUCTION AND BACKGROUND

The debate over the most effective way of allocating frequency spectrum has been conducted over the past seventy years since the publication of Coase's seminal paper (1959) on spectrum management. In particular, a key issue underlying the policy debate has been in the past ten years the assessment of the economic value of certain spectrum bands, more specifically the unassigned or unlicensed[2]. Prior research agrees that, contrary to licensed bands where economic value could equate to whatever is paid at auction, the economic value of unlicensed spectrum, such as Wi-Fi, needs to be measured based on the concept of economic surplus and contribution to GDP.

Part of the difficulty in assessing the value of Wi-Fi resides on the fact that, unlike licensed spectrum that is used for a few, homogeneous services, Wi-Fi provides the environment for the provision of several heterogeneous services and devices. In 2009, Richard Thanki produced the first paper to determine the economic value of unlicensed spectrum. He estimated that three major applications (residential Wi-Fi, hospital Wi-Fi, and retail clothing RFID) in the United States generated value in the range of $16 and $36.8 billion. At the time, the author acknowledged that these estimates covered only a fraction of the economic value[3] and, consequently, were too conservative. Two years later, Milgrom et al. (2011) provided additional support to Thanki's numbers, but also calculated value estimates for other applications. For example, the authors estimated the economic value of Apple's iPad, a device intimately linked to the use of Wi-Fi, at $ 15 billion. Additionally, the authors quantified other benefits in the United States alone, such as Wi-Fi supported cellular off-loading ($ 25 billion) and the value of Wi-Fi's faster data rates compared to cellular service ($ 12 billion).

A year later, Thanki (2012) produced a new piece of research, refining his residential Wi-Fi estimate and quantifying other benefits of unlicensed spectrum. He estimated the annual consumer surplus of residential Wi-Fi to be between $118 and $225 per household[4] (a total of $ 15.5 billion for the United States). Additionally, enlarging the original scope of benefits, he assessed the producer surplus derived from carrier savings resulting from Wi-Fi off-loading ($ 8.5 billion for the United States). Finally, he estimated the value generated by enhanced affordability (an assessment mainly focused on emerging markets) and mentioned potential innovation related benefits related to deployment of Wireless Internet Service Providers. In the same year, Cooper (2012) calculated Wi-Fi's economic value by estimating the number of cell sites that the wireless industry would avoid investing in as a result of traffic off-loading (130,000), which would result in annual savings of $26 billion. The author also updated Thanki's residential wireless consumer surplus as a result of the considerable increase in Wi-Fi adoption that had taken place since 2009.

The author of this study has conducted three successive studies on the economic value of unlicensed spectrum in the United States for 2013, 2014, and 2017 (the last one complemented with a forecast for 2020)[5]. While all three studies included Wi-Fi as one of the sources of value, it

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[2] This is contrary to research on the valuation of consumer welfare derived from the use of licensed spectrum which has been a fairly standard research practice given the availability of auction data and consumption series (see Hazlett, 2005: Hausman, 1997).

[3] Thanki estimated that the three applications represented 15% of the unlicensed wireless chipsets to be shipped in the US in 2014.

[4] In the 2009 study, his estimate of annual consumer surplus per household ranges between $114 and $331.

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

excluded key areas, such as the use of Wi-Fi among enterprises and the value of Wi-Fi enabled equipment, such as home equipment, controllers and access points. Furthermore, the exclusive focus on the United States implicitly raised the issue as to what the economic value of Wi-Fi might be in other key developed countries and, potentially its global scale. This led to the need to produce a study focusing on all sources of value for Wi-Fi, using 2018 as an updated point in time and extending the forecast to 2023.

This document presents first a top line view of economic value for all countries studied in detail, complemented with an extrapolation to the world. It follows by outlining the theoretical framework used to estimate the economic benefits of Wi-Fi and reviews all methodologies relied upon to assess its value. Then, it presents the 2018 and 2023 estimates for each of the countries where value is estimated in depth: United States, United Kingdom, France, Germany, Japan, and South Korea. Based on interpolation techniques (such as regression of lead indicators), it provides then a global value estimate.

A note about Wi-Fi and 5G:
The deployment of 5G is expected within the two to five year window, so it will impact the off-loading economic value for 2023. Wi-Fi is a key enabler of 5G services. A detailed description of how this study accounts for 5G growth is available in an appendix at the end of this paper.

United States, New York: Telecom Advisory Services, August; Katz, R. (2018). *A 2017 assessment of the current and future economic value of unlicensed spectrum in the United States*, Washington, DC: Wi-Fi Forward, April.

II. TOP LINE ESTIMATES OF ECONOMIC VALUE

Wi-Fi, the technology standard for connecting computers and myriad electronic devices to each other and to the Internet, originated in a 1985 decision by the regulatory agency in the United States to open up certain unlicensed radiofrequency bands for communications purposes. In 2003, the International Telecommunications Union World Radio-communication Conference, recognizing the growing value of the technology, decided to open more bands to Wi-Fi use around the world. Ever since then, Wi-Fi technology has taken a prominent position in the wireless ecosystem. Most laptops, tablets, smartphones, security cameras, smart TVs, printers, scanners, home appliances, and even cars, increasingly use Wi-Fi to exchange information and control devices. In fact, Wi-Fi pervasiveness sometimes hides its enormous importance in everyday life:

- By 2016 Wi-Fi was installed at 800 million households around the world[6];
- In August 2016, wireless users in some of the largest countries around the world spent more time connected to Wi-Fi than to cellular networks (63% in China, 62% in Germany, 58% each in Brazil and Saudi Arabia, 53% in the United States, and 51% in Australia, to name a few)[7];
- As of 2018, there are 340,846,887 Wi-Fi hotspots worldwide, of which 12,229,392 are commercially managed and 328,617,495 are community access points[8].

The most important sources of economic value of Wi-Fi are the use by consumers in their homes and the usage of Wi-Fi for enterprise communications. That said, the production side of the economy also benefits from Wi-Fi in terms of the profits received by manufacturers of equipment, such as access points, controllers, routers, gateways, smart speakers, and home security systems, and the savings incurred by the cellular carriers that rely on the technology to offload traffic from their networks. Finally, Wi-Fi also generates economic value through social contributions: the technology represents a useful application to tackle the digital divide in rural and isolated geographies, while also providing an important platform for free internet access.

The measurement of economic value in this study was based on eight value creation effects (see table II-1).

[6] Burger (2015).
[7] Open Signal. *Global State of Mobile Networks* (August 2016).
[8] iPass. *Wi-Fi Growth Map*.

Table II-1. Approaches to Measure Economic Value of Wi-Fi

Dimension	Economic Effect	Quantification	Rationale
1. Value of free Wi-Fi traffic	1.1. Benefit to consumers of free Wi-Fi traffic offered in public sites	Consumer surplus	Price of Wi-Fi traffic if it were to be paid if transported through the cellular network yields consumer benefit
2. Value of residential Wi-Fi	2.1. Internet access for home usage of devices that lack a wired port (e.g. tablets, smartphones, game consoles)	Consumer surplus	Price to be paid if cellular network transports all Wi-Fi traffic; this equals to consumers' willingness to pay
	2.2. Avoidance of investment in in-house wiring	Consumer surplus	Price to be paid of in-house Ethernet wiring if Wi-Fi does not exist
3. Value of enterprise Wi-Fi	3.1. Business internet traffic transmitted through Wi-Fi	Producer surplus	Price to be paid if all business Wi-Fi traffic were to be transported through cellular networks
	3.2. Avoidance of wiring of enterprise buildings	Producer surplus	Price to be paid for wiring enterprise buildings for Internet connectivity of devices and peripherals
4. Value of cellular off-loading	4.1. Total cost of ownership (cumulative CAPEX and OPEX) required to accommodate future capacity requirement with Wi-Fi complementing cellular networks	Producer surplus	Since mobile broadband prices do not decline when traffic is off-loaded to Wi-Fi, the gain triggered by cost reduction reflects a producer surplus
5. Value of locally manufactured Wi-Fi enabled devices	5.1. Locally manufactured residential (wireless speakers, security systems, Home networking systems, routers) and Wi-Fi equipment (routers, gateways, access points)	Producer surplus	Difference between retail price and manufacturing costs for a weighted average of suppliers
		Consumer surplus	Difference between willingness to pay and retail prices
	5.2. Locally manufactured enterprise equipment (access points, controllers)	Producer surplus to manufacturers	Difference between retail price and manufacturing costs for a weighted average of suppliers
6. Value of bridging the digital divide	6.1. Use of Wi-Fi to increase coverage in rural and isolated areas	GDP contribution	Additional GDP resulting from incremental broadband lines in rural areas
7. Wi-Fi return to speed	7.1. Contribution to GDP derived from an increase in average mobile speed resulting from Wi-Fi off-loading	GDP contribution	While speed increase could be considered consumer surplus, recent research finds economic efficiency spillovers
8. Revenues of Wi-Fi carriers in public places and Wi-Fi based ISPs	8.1. Sum of revenues of service providers offering paid Wi-Fi access in public places	GDP contribution	These revenues would not exist without the availability of unlicensed spectrum
	8.2. Aggregated revenues of ISPs offering service over Wi-Fi technology	GDP contribution	These revenues would not exist without the availability of unlicensed spectrum

Source: Telecom Advisory Services

Based on the quantification of these eight effects, the 2018 economic value of Wi-Fi in the six developed countries studied in detail is presented in Table II-2 below. The country with the highest 2018 Wi-Fi economic value creation is the United States ($ 499.09 billion), followed by Japan ($ 171.46 billion), Germany ($ 94.00 billion), South Korea ($ 67.59 billion), the United Kingdom ($54.48 billion), and France ($ 44.23 billion) (see table II-2).

Table II-2. Six Developed Countries: Total Economic Value of Wi-Fi (2018)
(In US$ billions)

Effect	Component	United States Economic Surplus	United States GDP Contribution	United Kingdom Economic Surplus	United Kingdom GDP Contribution	France Economic Surplus	France GDP Contribution	Germany Economic Surplus	Germany GDP Contribution	Japan Economic Surplus	Japan GDP Contribution	S. Korea Economic Surplus	S. Korea GDP Contribution
1. Value of free Wi-Fi		$ 7.36	N.A.	$ 0.27	N.A.	$ 0.11	N.A.	$ 0.30	N.A.	$ 1.44	N.A.	$ 1.53	N.A.
2. Value of residential Wi-Fi	2.1 Home use	$ 183.36	N.A.	$ 3.29	N.A.	$ 1.18	N.A.	$ 5.01	N.A.	$ 28.48	N.A.	$ 18.39	N.A.
	2.2. Inside wiring avoidance	$ 62.77	N.A.	$ 22.60	N.A.	$ 12.98	N.A.	$ 43.13	N.A.	$ 41.08	N.A.	$ 15.81	N.A.
	Subtotal	$ 246.13	N.A.	$ 25.89	N.A.	$ 14.16	N.A.	$ 48.14	N.A.	$ 69.56	N.A.	$ 34.20	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business Internet traffic	$ 125.76	N.A.	$ 2.71	N.A.	$ 1.09	N.A.	$ 4.20	N.A.	$ 18.96	N.A.	$ 10.72	N.A.
	3.2. Inside wiring avoidance	$ 16.86	N.A.	$ 8.59	N.A.	$ 5.03	N.A.	$ 19.06	N.A.	$ 38.23	N.A.	$ 5.12	N.A.
	Subtotal	$ 142.62	N.A.	$ 11.30	N.A.	$ 6.12	N.A.	$ 23.26	N.A.	$ 57.19	N.A.	$ 15.84	N.A.
4. Value of cellular off-loading		$ 10.70	N.A.	$ 6.84	N.A.	$ 7.40	N.A.	$ 6.17	N.A.	$ 20.91	N.A.	$ 4.07	N.A.
5. Value of locally manufac-tured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 67.61	N.A.	$ 8.66	N.A.	$ 12.56	N.A.	$ 10.31	N.A.	$ 13.27	N.A.	$ 11.09	N.A.
	5.2. Locally manufactured enterprise devices	$ 4.51	N.A.	$ 0	N.A.	$ 0	N.A.	$ 0	N.A.	$ 1.26	N.A.	$ 0	N.A.
	Subtotal	$ 72.12	N.A.	$ 8.66	N.A.	$ 12.56	N.A.	$ 10.31	N.A.	$ 14.53	N.A.	$ 11.09	N.A.
6. Value of bridging the digital divide		N.A.	$ 7.11	N.A.	$ 0.30	N.A.	$ 3.38	N.A.	$ 3.57	N.A.	$ 5.05	N.A.	$ 0
7. Wi-Fi return to speed		N.A.	$ 8.51	N.A.	$ 1.00	N.A.	$ 0.01	N.A.	$ 1.55	N.A.	$ 1.91	N.A.	$ 0.42
8. Revenues of Wi-Fi carriers and WISPs		N.A.	$ 4.54	N.A.	$ 0.22	N.A.	$ 0.49	N.A.	$ 0.70	N.A.	$ 0.87	N.A.	$ 0.44
TOTAL		$ 478.93	$ 20.16	$ 52.96	$ 1.52	$ 40.35	$ 3.88	$ 88.18	$ 5.82	$ 163.63	$ 7.83	$ 66.73	$ 0.86

Source: Telecom Advisory Services analysis

Past research has also shown that the economic value of Wi-Fi is permanently increasing as a result of innovation, and technology adoption[9]. Thus, a forecast of these value creation dynamics indicates that the Wi-Fi economic value will continue to grow in the future. In 2023, the economic value of Wi-Fi grows significantly. The United States will remain the country with the highest economic value in 2023 at $ 993.07 billion, roughly the total market capitalization of Apple Inc., followed by Japan at $ 247.53 billion. By 2023, South Korea ($137.55 billion) will overcome Germany ($ 132.03 billion), followed by the United Kingdom ($71.23 billion), and France ($ 63.93 billion) (see table II-3).

[9] Katz, R. (2018). *A 2017 assessment of the current and future economic value of unlicensed spectrum in the United States*, Washington, DC: Wi-Fi Forward, April.

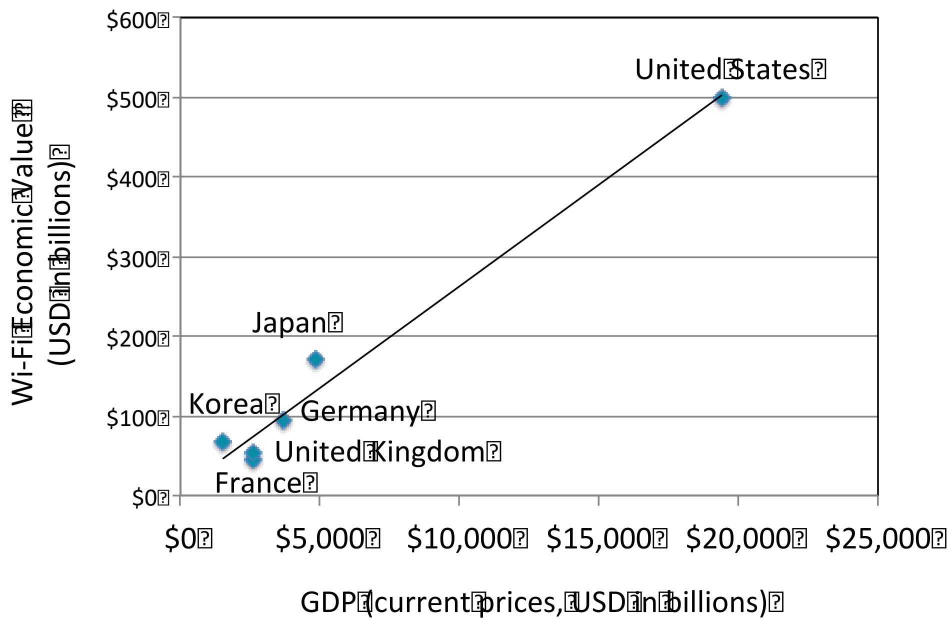
Table II-3. Six Developed Countries: Total Economic Value of Wi-Fi (2023)
(In US$ billions)

Effect	Component	United States		United Kingdom		France		Germany		Japan		South Korea	
		Economic Surplus	GDP Contribution	Economic Surplus	GDP Contribution	Economic Surplus	GDP Contribution	Economic Surplus	GDP Contribution	Economic Surplus	GDP Contribution	Economic Surplus	GDP Contribution
1. Value of free Wi-Fi		$ 8.52	N.A.	$ 0.25	N.A.	$ 0.12	N.A.	$ 0.36	N.A.	$ 2.03	N.A.	$ 1.63	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 385.12	N.A.	$ 8.58	N.A.	$ 5.12	N.A.	$ 15.22	N.A.	$ 70.24	N.A.	$ 54.69	N.A.
	2.2. Inside wiring avoidance	$ 86.46	N.A.	$ 25.97	N.A.	$ 14.91	N.A.	$ 49.60	N.A.	$ 46.22	N.A.	$ 17.96	N.A.
	Subtotal	$ 471.58	N.A.	$ 34.55	N.A.	$ 20.03	N.A.	$ 64.82	N.A.	$ 116.46	N.A.	$ 72.65	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	$ 287.25	N.A.	$ 4.22	N.A.	$ 2.06	N.A.	$ 7.30	N.A.	$ 34.13	N.A.	$ 20.45	N.A.
	3.2. Inside wiring avoidance	$ 16.86	N.A.	$ 10.81	N.A.	$ 5.03	N.A.	$ 19.05	N.A.	$ 38.23	N.A.	$ 5.20	N.A.
	Subtotal	$ 304.11	N.A.	$ 15.03	N.A.	$ 7.09	N.A.	$ 26.35	N.A.	$ 72.36	N.A.	$ 25.65	N.A.
4. Value of cellular re-routing		$ 96.30	N.A.	$ 8.12	N.A.	$ 14.31	N.A.	$ 19.88	N.A.	$ 29.02	N.A.	$ 11.76	N.A.
5. Value of locally manufac-tured Wi-Fi devices	5.1. Locally manufac-tured consumer devices	$ 72.38	N.A.	$ 12.20	N.A.	$ 16.35	N.A.	$ 12.89	N.A.	$ 15.00	N.A.	$ 24.15	N.A.
	5.3. Locally manufac-tured enterprise devices	$ 5.29	N.A.	$ 0	N.A.	$ 0	N.A.	$ 0	N.A.	$ 1.70	N.A.	$ 0	N.A.
	Subtotal	$ 77.67	N.A.	$ 12.20	N.A.	$ 16.35	N.A.	$ 12.89	N.A.	$ 16.70	N.A.	$ 24.15	N.A.
6. Value of bridging the digital divide		N.A.	$ 15.90	N.A.	$ 0.49	N.A.	$ 4.43	N.A.	$ 4.80	N.A.	$ 6.25	N.A.	$ 0
7. Wi-Fi return to speed		N.A.	$ 7.98	N.A.	$ 0.18	N.A.	$ 0.001	N.A.	$ 0.58	N.A.	$ 2.03	N.A.	$ 0.76
8. Revenues of Wi-Fi carriers and WISPs		N.A.	$ 11.01	N.A.	$ 0.41	N.A.	$1.60	N.A.	$ 2.35	N.A.	$ 2.68	N.A.	$ 0.95
TOTAL		$ 958.18	$ 34.89	$ 70.15	$ 1.08	$ 57.90	$ 6.03	$ 124.30	$ 7.73	$ 236.57	$ 10.96	$135.84	$ 1.71

Source: Telecom Advisory Services analysis

Beyond estimates of the economic value in the six advanced nations, the study generated an extrapolation for the rest of the world that relied on two macro-indicators: GDP and the United Nations Human Development Index. Having quantified the economic value for the United States, United Kingdom, Germany, France, Japan and South Korea, it is clear that a country's economy is directly correlated with the economic value of Wi-Fi (see figure II-1).

Figure II-1. GDP vs. Wi-Fi Economic Value



Source: IMF; Telecom Advisory Services analysis

This correlation supports the use of GDP as lead indicator, in addition to relying on the UNDP Human Development Index to control for other non-economic factors to estimate the economic value of Wi-Fi in the rest of the world, and adding it to the six countries under study. The global economic value associated to Wi-Fi in 2018 amounts to 1.96 trillion dollars [10], and is expected to reach $ 3.47[11] trillion by 2023.

The study also provided an estimate of job creation based on Input / Output analysis. As a derived contribution to economic value, Wi-Fi is also generating approximately 290,000 jobs in 2018 in the six developed nations, and is expected to reach close to 450,000 by 2023. Job creation estimates include direct jobs (those jobs created by manufacturing of Wi-Fi enabled equipment and operating Wi-Fi infrastructure), indirect jobs (those jobs created by suppliers to the Wi-Fi equipment manufacturing sector and operators), and induced jobs (those jobs created by spending of direct and indirect workers).

By conducting a similar methodology of GDP prorating, with a control for the Human Development Index, we developed an estimate of global jobs created. According to these models, global employment benefitting from Wi-Fi is expected to reach nearly 1 million jobs by 2023 (see table II-4).

Table II-4. Wi-Fi derived Employment

	2018	2023
Six advanced Countries	291,798	442,381
Rest of World	324,034	491,252
World	615,832	933,633

Source: Telecom Advisory Services

[10] The 2018 value includes $1,879.97 billion in economic surplus and $84.57 in contribution to GDP.
[11] The 2023 value includes $3.341 trillion in economic surplus and $131.69 billion in contribution to GDP.

Based on this evidence, Wi-Fi technology should be recognized as one of the dominant economic engines of the digital ecosystem. Governments should develop the right incentives to stimulate the social and economic benefits of Wi-Fi. This includes assigning enough spectrum to avoid congestion across the globe, promoting the development of start-ups that rely on Wi-Fi to create applications, and leveraging Wi-Fi technology to address the digital divide barrier.

III. THEORETICAL FRAMEWORK FOR ESTIMATING THE ECONOMIC VALUE OF WI-FI

III.1. The intrinsic value of Wi-Fi

As stated earlier in this document, Wi-Fi is what economists call a factor of production (or enabling resource) that yields economic value by: complementing wireline and cellular technologies; supporting the development of alternative technologies which expands consumer choice; supporting the creation of innovative business models; and expanding access to communications services.

As a factor of production, a complementary technology is a resource that, due to its intrinsic strengths, compensates for the limitations of another. In this regard, Wi-Fi can enhance the effectiveness of devices that use licensed spectrum, such as smartphones. For example, Wi-Fi access points can enhance the value of cellular networks by allowing wireless devices to switch to Wi-Fi hotspots, thereby reducing the cost of broadband access and increasing the access speed rate. Consumers accessing the Internet within the reach of a Wi-Fi access point can reduce their costs of access by turning off their cellular service. They can also gain additional access speed because the transfer rate of Wi-Fi sites is generally faster than that offered by cellular technology, even 4G LTE at current loads[12]. Likewise, many wireless operators reduce their capital spending by complementing their cellular networks with carrier-grade Wi-Fi access points, which are considerably less expensive than cellular network equipment with similar capacity. In addition to reducing capital expenditures, wireless carriers can offer fast access service without a base station congestion challenge.

In addition to complementing cellular networks, Wi-Fi can provide the environment needed for operating technologies that are substitutes to those that are operating licensed uses, thereby providing consumers with a larger set of choices. By limiting transmission power and relying on spectrum with low propagation, Wi-Fi avoids interference, rendering the need for property rights resulting from spectrum assigned through a license as barriers to innovation irrelevant. In fact, some of the most important technological innovations in communications are intimately linked to Wi-Fi for gaining access. Numerous products and services, such as the multi-AP/mesh networking systems and smart speakers, launched in the past ten years were developed leveraging Wi-Fi.

By providing consumers with service choices in addition to those offered through cellular services, Wi-Fi also supports the development of innovative business models. Firms developing new applications that rely on Wi-Fi do not need approval from cellular operators, do not incur time-to-market penalties, and do not face financial disincentives derived from costly revenue splits.

In addition to innovative applications, technologies operating in Wi-Fi spectrum can help address the broadband coverage digital gap. A large portion of the population that has not adopted the Internet around the world is located in rural and isolated areas. As in the United States, many of

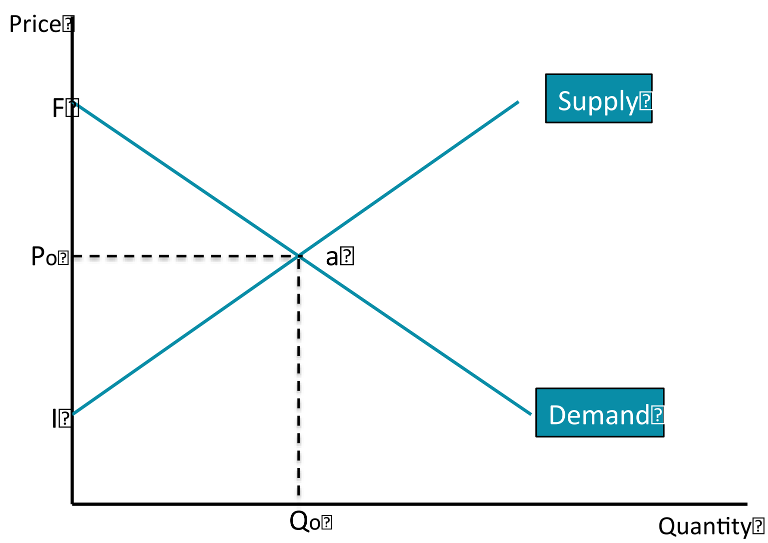
[12] For example, in 2018 the average mobile connection speed in the United States is 14.36 Mbps while the average Wi-Fi speed from a mobile device is 37.03 Mbps. While the cellular speed resulting from 5G deployment is going to increase to 27.06, so will the Wi-Fi speed, expecting to reach 73.79 Mbps by 2023 (Source: Telecom Advisory Services extrapolated from Cisco Visual Networking Index).

them can gain access to broadband services provided by Wireless Internet Service Providers (WISPs), which typically operate through Wi-Fi[13]. In addition, further developments in the areas of spectrum sensing, dynamic spectrum access, and geo-location techniques can improve the quality of Wi-Fi.

III.2. The derived value of Wi-Fi

Wi-Fi yields economic gains at several levels, both to consumers and producers, as well as a direct net contribution to output (GDP) and employment. Prior research[14] agrees that, contrary to licensed bands where economic value could equate to whatever is paid at auction, the economic value of unlicensed spectrum, such as Wi-Fi, needs to be measured based on the concept of economic surplus. The methodology implicit in relying on the economic surplus approach is captured in Figure III-1.

Figure III-1. Measurement of Economic Surplus



The concept of economic surplus is based on the difference between the value of units consumed and produced up to the equilibrium price and quantity, allowing for the estimation of consumer surplus (area of F, Po, a) and producer surplus (area of Po, I, a).[15] Consumer surplus measures the total amount consumers would be willing to pay to have the service compared to what they actually pay while producer surplus measures the analogous quantity for producers, which is essentially the economic profit they earn from providing the service. Thus, in Figure III-1 the total surplus is contained in the area F, I, a.

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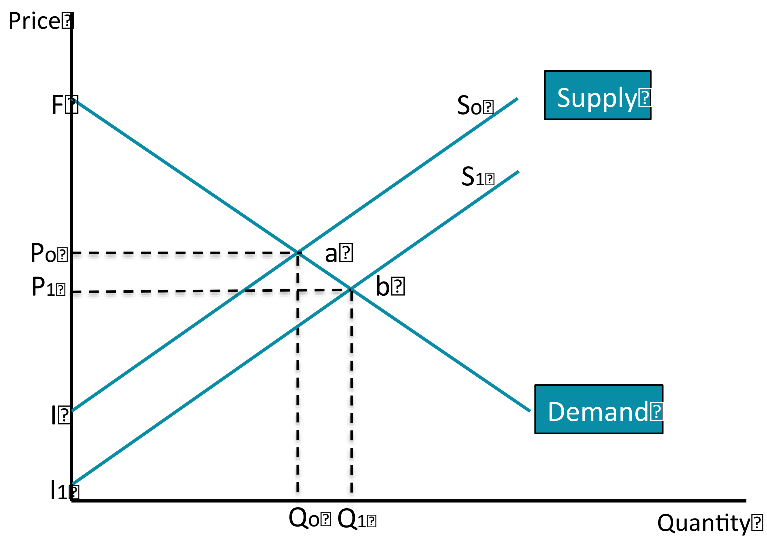
[13] In the United States, the largest WISPs are Rise Broadband, Agile Networks, Skyriver Communications, and GHz Wireless.

[14] Thanki, R. (2009). *The economic value generated by current and future allocations of unlicensed spectrum*. London: Perspective Associates; Thanki, R. (2012). *The Economic Significance of License- Exempt Spectrum to the Future of the Internet.* London; Perspective Associates; Milgrom, P., Levin, J., and Eilat, A. (2011). *The case for unlicensed spectrum*. Stanford Institute for Economic Policy Research Discussion Paper No. 10-036; Katz, R. ibid.

[15] Following Alston (1990), we acknowledge that this approach ignores effects of changes in other product and factor markets; for example, Wi-Fi also increases the economic value of technologies operating in licensed bands (Alston, J.M. and Wohlgenant, M.K. (1990). "Measuring Research Benefits Using Linear Elasticity Equilibrium Displacement Models". John D. Mullen and Julian M. Alston, *The Returns to Australian Wool Industry from Investment in R&D*, Sydney, Australia: New South Wales Department of Agriculture and Fisheries, Division of Rural and Resource Economics).

Consistent with the concept presented above, the approach relied upon in this study to measuring economic value of Wi-Fi focuses first on the surplus generated after its adoption.[16] The underlying assumption is that the Wi-Fi resource generates a shift both in the demand and supply curves resulting from changes in the production function of services as well as the corresponding willingness to pay for its acquisition. On the supply side, the approach measures changes in the value of inputs in the production of wireless communications. The most obvious example is, as mentioned above, whether Wi-Fi represents a positive contribution to wireless carriers' capital expenditures (CAPEX) and operating expenses (OPEX) insofar as they can control their spending while meeting demand for increased wireless traffic. From an economic theory standpoint, the telecommunications industry can then increase its output, yielding a marginal benefit exceeding the marginal cost. This results in a shift in the supply curve by a modification in the production costs (see Figure III-2).

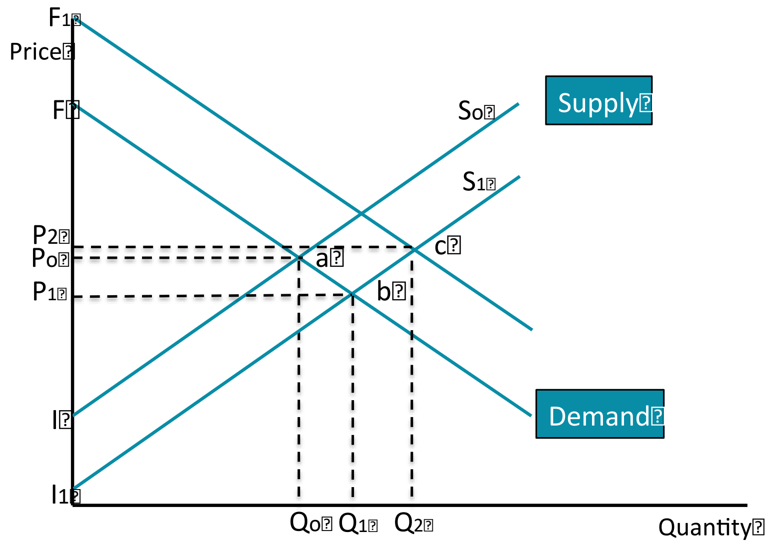
Figure III-2. Measurement of Economic Surplus resulting from a supply shift



The development and adoption of carrier-grade Wi-Fi technology causes the shift in the supply curve, yielding a new equilibrium price and quantity. Under this condition, producer surplus is represented by the triangle F, b, P_1, and consumer surplus by the area within P_1, b, I_1. Additionally, since the demand curve is derived from the utility function, higher benefit to the consumer derived from the reliance on Wi-Fi at a stable price will yield an increase in the willingness to pay, and consequently a shift in the demand curve (see Figure III-3).

[16] See a similar approach used by Mensah and Wohlgenant (2010) to estimate the economic surplus of adoption of soybean technology (Mensah, E., and Wohlgenant, M. (2010). "A market impact analysis of Soybean Technology Adoption", *Research in Business and Economics Journal*).

Figure III-3. Measurement of Economic Surplus resulting from a supply and demand shift



Under these conditions, total economic value is now represented by the area I_1, c, F_1, in Figure III-3, representing both changes in consumer and producer surplus.

To quantify incremental surplus derived from the adoption of Wi-Fi, we need to itemize all the effects linked to this standard. In addition, we complement the concept of economic surplus with an assessment of the direct contribution of the technologies and applications relying on Wi-Fi, such as Wi-Fi service providers, to the nation's GDP. By including the GDP contribution measurement, we follow Greenstein et al. (2010) and prior literature measuring the economic gains of new goods.[17] On the one hand, we focus on consumer and producer surplus, but, on the other hand, we consider the new economic growth enabled by Wi-Fi. In measuring the GDP direct contribution, we strictly consider the revenues added "above and beyond" what would have occurred had the Wi-Fi spectrum been licensed.

Finally, after quantifying the contribution of Wi-Fi to GDP, the impact on job creation can also be ascertained not only on the telecommunications industry itself but, more importantly, in terms of the spill-overs through the rest of the economy.

Based on the theoretical framework that formalizes the value creation of Wi-Fi, we have identified eight sources of value:

1) ***Free Wi-Fi traffic driving consumer surplus***: As mentioned above, consumer surplus measures the difference between the user's willingness to pay and the price paid for the service; for example, if a consumer accesses the Internet in a public hotspot for free (e.g. coffee shop), surplus would equate to the monetary value he would pay to a cellular operator for gaining similar access[18].

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[17] Greenstein, S. and McDevitt, R. (2009). *The broadband bonus: accounting for broadband Internet's impact on U.S. GDP.* National Bureau of Economic Research Working Paper 14758. Cambridge, MA.

[18] The introduction of what are called "unlimited" wireless plans does not invalidate this point since all of them include some explicit caps.

2) ***Residential Wi-Fi driving consumer surplus:*** Wi-Fi routers installed in residential dwellings provide Internet access for devices that lack a wired port (e.g. tablets, smartphones), allowing consumers to avoid the investment in Ethernet wiring, provide easy networking between devices (printers, storage devices, computers), allow for sharing and streaming of media content (sound systems, home theaters, etc.), represent a hub of a network handling home automation, and may interface with the smart grid. All these benefits can be aggregated in terms of the residential consumer surplus.

3) ***Cellular re-routing driving enterprise efficiencies:*** Wi-Fi technology in office buildings and campus allow for voice and data communications without incurring the cost of "capped" connectivity and limited in-building coverage of cellular networks. Additionally, Wi-Fi would support the communication of enterprises and their customers (e.g. customer/client access in financial services, employee/guest connections in the hospitality industry) as well internal production efficiencies (product/inventory tracking, remotely control equipment and POS ordering in the retail industry). This equates to producer surplus.

4) ***Cellular re-routing driving producer surplus:*** In light of the explosive growth in data traffic, wireless carriers operating in licensed bands deploy Wi-Fi access points to reduce both capital and operating expenses, while dealing with congestion challenges. Since they monetize the Wi-Fi access they provide, surplus measures the difference in capital and operating expenses for the off-loaded traffic. This model will be critical in understanding Wi-Fi's contribution to 5G deployment, an endeavor that is well within the study's time horizon.

5) ***Revenues of locally manufactured Wi-Fi devices:*** The difference between market prices and manufacturing costs of Wi-Fi enabled devices represents the manufacturer's margin as well as a surplus for consumers. Such products include home networking devices, Wi-Fi enabled wireless speakers, routers, and security systems (on the consumer side), and access points and controllers (on the enterprise side). On the enterprise side, the surplus associated to enterprise efficiencies is considered to be additional producer surplus.

6) ***Reducing the digital divide and contributing to GDP growth:*** Wi-Fi is an appropriate technology to offer Internet access in rural and isolated areas. Since the technology allows for increasing broadband penetration without the need for more cabling and wiring, it is a key factor in driving GDP growth. An ISP relying on Wi-Fi technology and providing service in a rural area can be a positive contribution to increasing broadband coverage to previously unserved populations. This could have multiple positive effects such as job creation, productivity enhancement of rural businesses, access to public services, and the like. [19]

7) ***Return to faster speed:*** Since Wi-Fi accessibility allows, in general, faster access to the Internet than cellular networks do, higher speeds have a positive contribution on the economy in terms of increased overall efficiency and innovation. The purpose here is to compare two technologies that allow the operation of untethered devices, which therefore excludes fixed broadband. That said, it is also the case that Wi-Fi provides faster access speeds than conventional DSL technologies. The contribution is measured in terms of economic growth.

[19] Katz, R. and Beltran, F. (2015). *Socio-economic impact of alternative spectrum assignment approaches.* Presentation to the International telecommunications Society Regional Conference, Los Angeles, CA.

8) ***Revenues of Wi-Fi carriers in public places and Wi-Fi based ISPs:*** Wi-Fi allows for the entry of service providers of paid Internet access in public places (such as venues, stadiums, airports, airlines, hotels, etc.). They generate new revenues that would not exist if Wi-Fi were not available. In addition, Wireless Internet Service Providers rely on Wi-Fi to offer broadband connectivity in areas typically not served by wireline carriers, such as inflight connectivity.

Table III-1 on the following page presents the formalization of each value creation effect and underlying rationale in terms of its economic contribution.

Table III-1. Approaches to Measure Economic Value of Wi-Fi

Dimension	Economic Effect	Quantification	Rationale
1. Value of free Wi-Fi traffic	1.1. Benefit to consumers of free Wi-Fi traffic offered in public sites	Consumer surplus	Price of Wi-Fi traffic if it were to be paid if transported through the cellular network yields consumer benefit
2. Value of residential Wi-Fi	2.1. Internet access for home usage of devices that lack a wired port (e.g. tablets, smartphones)	Consumer surplus	Price to be paid if cellular network transports all Wi-Fi traffic; this equals consumer willingness to pay
	2.2. Avoidance of investment in in-house wiring	Consumer surplus	Price to be paid of in-house wiring equals willingness to pay
3. Value of enterprise Wi-Fi	3.1. Business internet traffic transmitted through Wi-Fi	Producer surplus	Price to be paid if all business Wi-Fi traffic were to be transported through cellular networks
	3.2. Avoidance of wiring of enterprise buildings	Producer surplus	Price to be paid if wiring enterprise buildings for Internet connectivity of devices and peripherals
4. Value of cellular re-routing	4.1. Total cost of ownership (cumulative CAPEX and OPEX) required to accommodate future capacity requirement with Wi-Fi complementing cellular networks	Producer surplus	Since mobile broadband prices do not decline when traffic is off-loaded to Wi-Fi, the gain triggered by cost reduction is producer surplus
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured residential (wireless speakers, security systems, Home networking systems, routers) and Wi-Fi equipment (routers, gateways, access points)	Producer surplus	Difference between retail price and manufacturing costs for a weighted average of suppliers
		Consumer surplus	Difference between willingness to pay and retail prices
	5.2. Locally manufactured enterprise equipment (access points, controllers)	Producer surplus to manufacturers	Difference between retail price and manufacturing costs for a weighted average of suppliers
		Producer surplus to enterprises	Efficiencies to enterprises
6. Value of bridging the digital divide	6.1. Use of Wi-Fi to increase coverage in rural and isolated areas	GDP contribution	Additional GDP resulting from incremental broadband lines in rural areas
7. Wi-Fi return to speed	7.1. Contribution to GDP derived from an increase in average mobile speed resulting from Wi-Fi off-loading	GDP contribution	While speed increase could be considered consumer surplus, recent research finds economic efficiency spillovers
8. Revenues of Wi-Fi carriers in public places and Wi-Fi based ISPs	8.1. Sum of revenues of service providers offering paid Wi-Fi access in public places	GDP contribution	These revenues would not exist without the availability of unlicensed spectrum
	8.2. Aggregated revenues of ISPs offering service over Wi-Fi technology	GDP contribution	These revenues would not exist without the availability of unlicensed spectrum

Source: Telecom Advisory Services

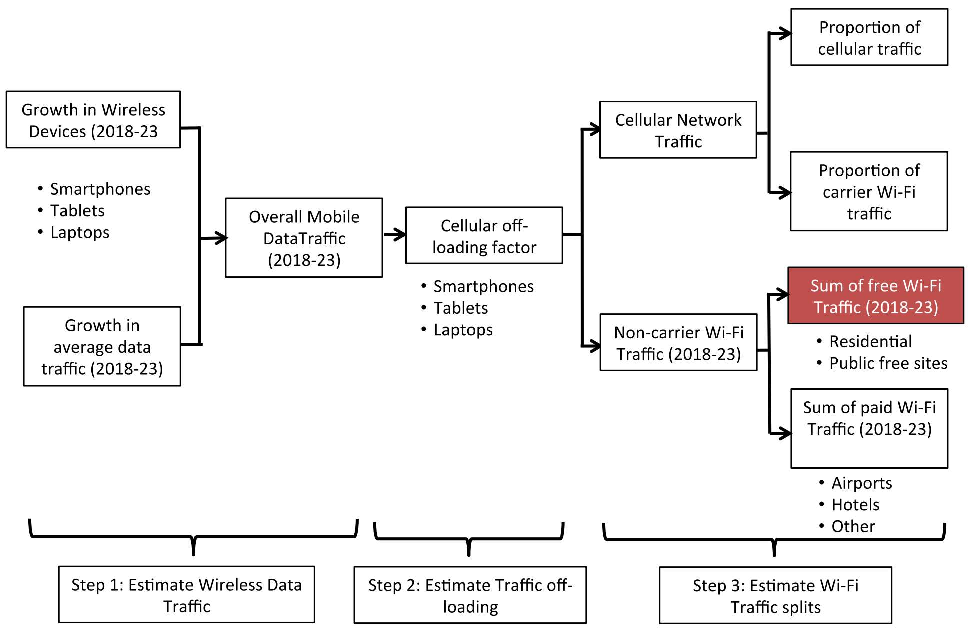
Having reviewed the theoretical framework and different sources of Wi-Fi economic value that will be addressed in the study, we will detail the methodologies used to measure it.

III.3. Methodologies to estimate the economic value of Wi-Fi

III.3.1. Free Wi-Fi traffic

The estimation of the economic value of free Wi-Fi traffic requires first to estimate the portion of mobile data traffic that is channeled through Wi-Fi access points. We start by estimating current and future wireless data traffic. Estimates are calculated "bottom-up" from the installed base of devices and traffic by device. They are calibrated with existing measurements, such as Cisco's Visual Networking Index. After estimating wireless data traffic, we calculate the portion of traffic off-loaded to Wi-Fi access points. However, since off-loading patterns vary by device, off-loading traffic is calculated by type of terminal (tablet, laptop, smartphone) and then aggregated. Finally, since the economic value differs by the type of Wi-Fi site (for example, revenues from a paid site such as Boingo represent a direct contribution to GDP, while the benefit of accessing the Internet via a free public site has to be measured in terms of consumer surplus), we split Wi-Fi traffic across type of sites. Figure III-4 describes this analysis.

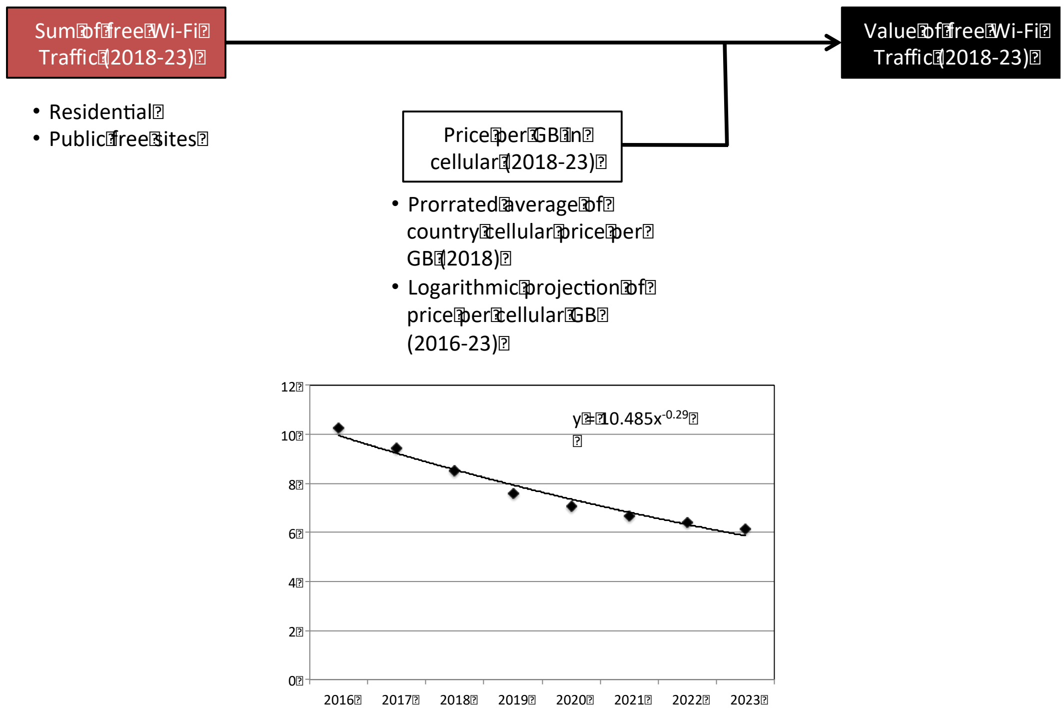
Figure III-4. Methodology for Estimating Free Wi-Fi Traffic



Source: Telecom Advisory Services

Once the total free Wi-Fi traffic is estimated, we calculate the consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we need an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculate by averaging the most economic "dollar per GB" (generally the unlimited) plan of major wireless carriers of the country under analysis (see figure III-5).

Figure III-5. Methodology for Estimating Consumer Surplus of Free Wi-Fi Traffic



Source: Telecom Advisory Services

III.3.2. Residential Wi-Fi

As detailed above, the economic value of residential Wi-Fi is driven by two sources:

- Home traffic generated by devices that have no wireline connectivity and access the fixed network through Wi-Fi rather than relying on cellular networks;
- Avoidance of investment to deploy inside Ethernet wiring to connect home devices and peripherals.

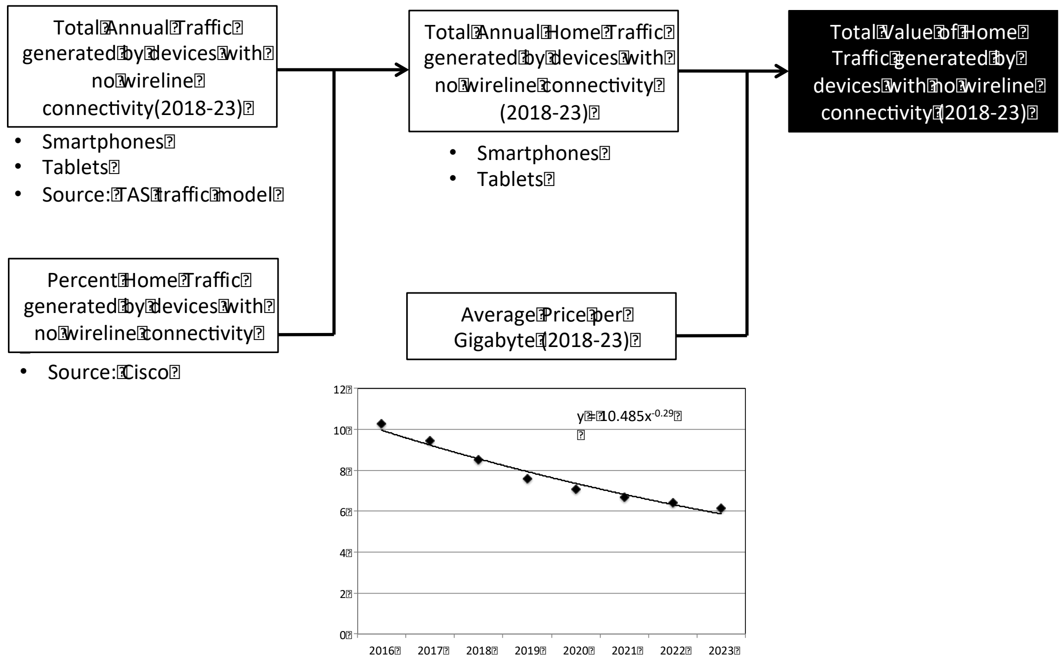
Home Internet access for devices that lack an Ethernet port

The underlying premise of this analysis is that in the absence of Wi-Fi, users would have to depend on the cellular network to gain Internet access. For this reason, estimating value would first measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers.

To estimate this value, we have chosen a subset of available data: smartphones and tablets. We add the total wireless traffic generated by devices with no wireline connectivity and multiply it by the percent of which is generated at home. This estimate is used to calculate the consumer surplus in an approach similar to the one used for calculating the value of free Wi-Fi traffic (see figure III-6).

Note that future research can explore other home device traffic, such as that traversing smart TVs and laptops or netbooks via Wi-Fi, once reliable sources are available. This study opted for a conservative approach to avoid over-estimation. It is likely that the values in home internet access are even higher.

Figure III-6. Methodology for estimating Consumer Surplus of Residential Wi-Fi traffic

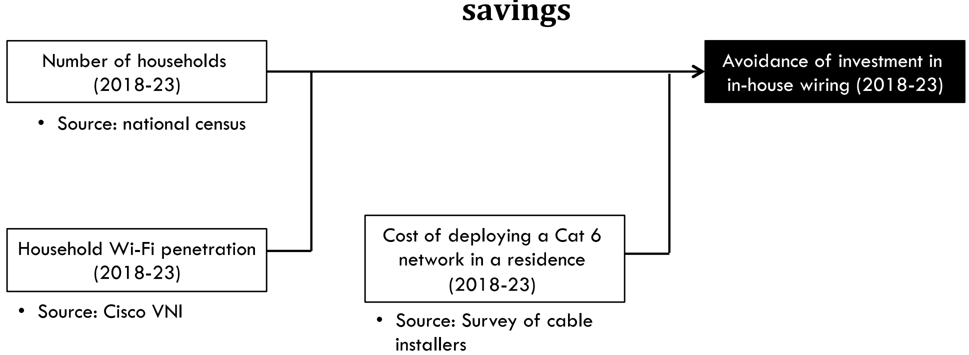


Source: Telecom Advisory Services

Avoidance in investment in in-house wiring

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.), which represents a saving for consumers. To calculate this consumer surplus, we estimate the number of households equipped with a Wi-Fi access point and multiply this value by a standard cost of deploying a CAT 6-based network with multiple connections in the country under analysis (see figure III-7).

Figure III-7. Methodology for estimating Consumer Surplus derived from inside wiring savings



Source: Telecom Advisory Services

III.3.3. Enterprise Wi-Fi

Similar to residential Wi-Fi, the economic value of enterprise Wi-Fi has two sources:

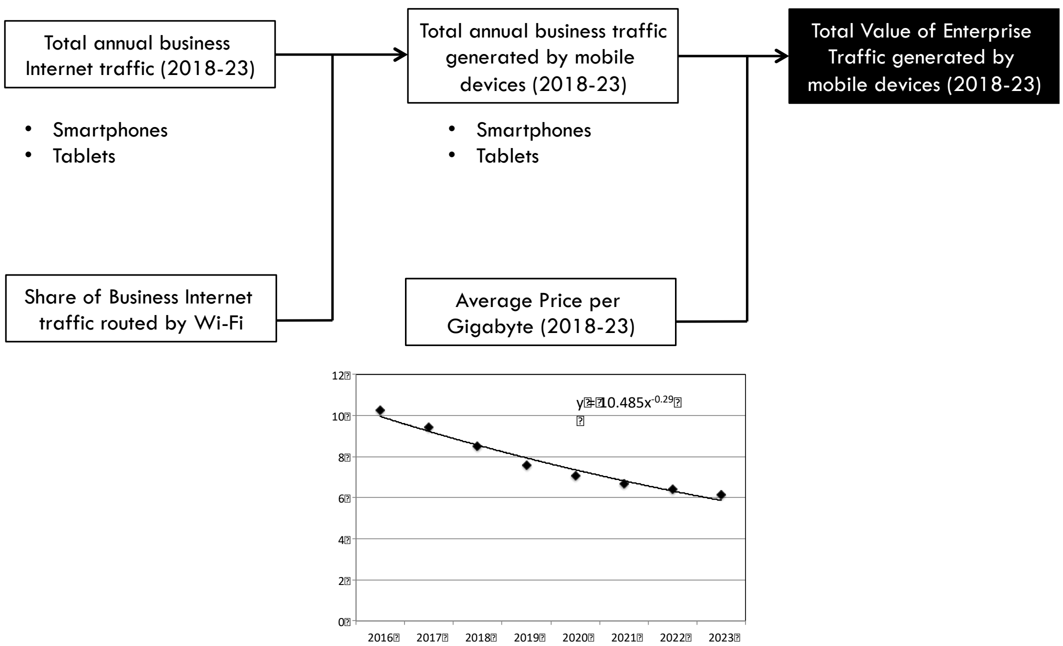
- Mobile business traffic routed through Wi-Fi access points rather than cellular networks;

- Avoidance of capital investment to deploy Ethernet wiring inside enterprise buildings and campus to connect devices and peripherals.

Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. The methodology is similar to residential Wi-Fi savings in that the cost of Wi-Fi traffic is calculated by multiplying it by the average price per Gigabyte of wireless data transmitted by wideband networks, which we calculate by averaging the most economic "dollar per GB" (generally the unlimited) plan of major wireless carriers of the country (see figure III-8).

Figure III-8. Methodology for estimating Economic Surplus of Enterprise Wi-Fi traffic

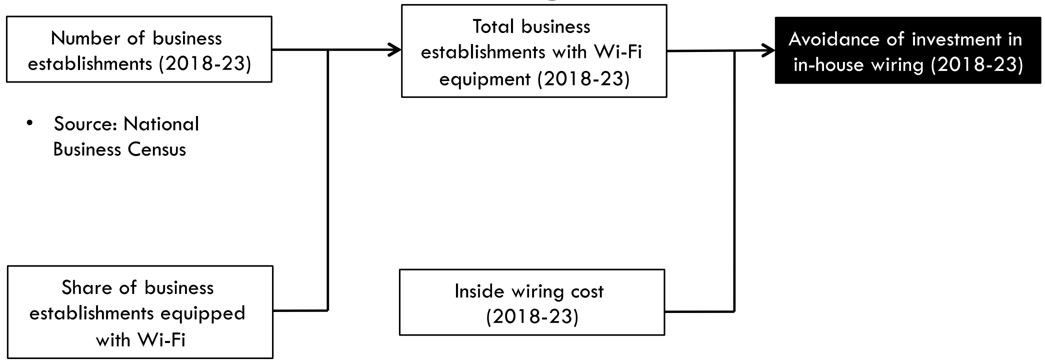


Source: Telecom Advisory Services

Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points and multiply this value by a standard cost of deploying a CAT 6-based network (although in this case, the cost is obviously higher than for a residence) (see figure III-9).

Figure III-9. Methodology for estimating Economic Surplus derived from inside wiring savings



Source: Telecom Advisory Services

III.3.4. Cellular off-loading

Beyond consumer surplus, Wi-Fi also yields a benefit to the producers of wireless communications: the carriers. Carrier-class Wi-Fi allows the operator to leverage wideband access (for mobility) and Wi-Fi offloading (for network capacity).[20] By building hybrid networks, carriers preserve spectrum and reduce the capital expenditures required to deploy additional base stations.[21] In addition, some service providers also claim they monetize their Wi-Fi offerings by directly charging customers. Carriers also benefit from service differentiation and an improvement in the customer experience.

The estimation of producer surplus is predicated on the assumption that in the absence of Wi-Fi, service providers would have to deploy cellular base stations to accommodate the growth in traffic. For example, a cellular pico-cell (needed to offer access via conventional cellular service) in the United States costs between $7,500 and $15,000[22], while a carrier-grade Wi-Fi access point requires an investment of $2,500[23]. Thus, the calculation of producer surplus is based on the portion of capital investments (and potential incremental network operations and maintenance operating expenses) that service providers can avoid when they shift allocations from cellular network to carrier-grade Wi-Fi. Thus, the analysis is then based on the following methodology (see figure III-10).

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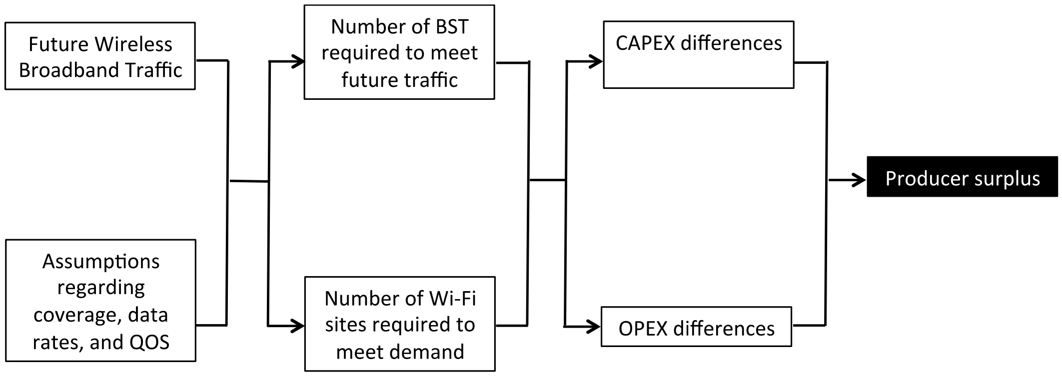
[20] Carriers can also off-load traffic by deploying femtocells, which provide higher capacity. However, since these operate in licensed spectrum bands, they are not part of this analysis.

[21] Hybrid network architectures allow wireless operators to shift traffic away from the cellular network, where the capacity constraints are most acute, to cheaper shorter-range small cells network, connected over a variety of backhaul connections.

[22] When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.

[23] Cisco Airnet 1552H Wireless Access Point.

Figure III-10. Methodology for estimating Producer Surplus derived from cellular re-routing



Source: Telecom Advisory Services

III.3.5. Locally manufactured Wi-Fi devices

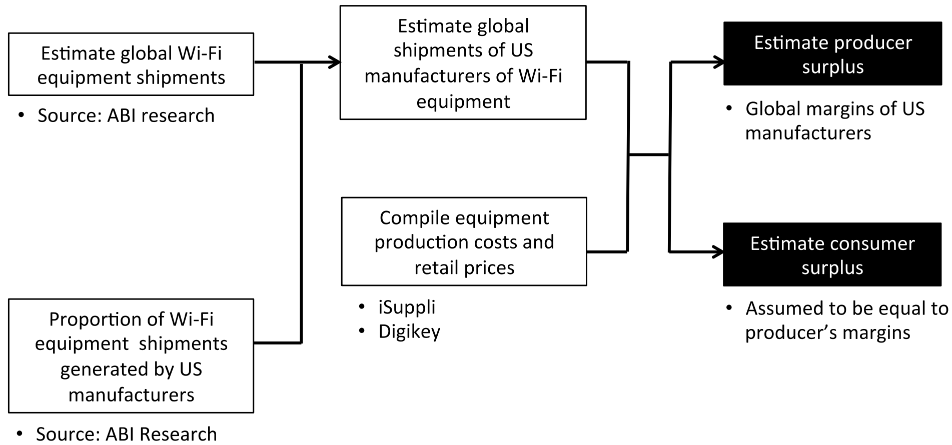
The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. Such products include the following (see table III-2):

Table III-2. Locally Manufactured Wi-Fi enabled equipment

Market segment	Equipment
Consumer	• Wireless speakers • Home security systems • Home networking devices • Tablets • Access points • External adapters • Routers • Gateways
Enterprise	• Access points • Controllers

Once the list of equipment is defined, we start by compiling statistics on worldwide shipments (even if a piece of locally produced equipment is shipped beyond the borders of the local market, that yields economic value to the country of origin). With these statistics, we calculate average retail value and gross margins. The margin represents producer surplus. In the absence of willingness to pay data for each piece of equipment, it is assumed that consumer surplus would equal the producer's margin (see figure III-11).

Figure III-11. Methodology for estimating Economic Value derived from locally manufactured Wi-Fi devices

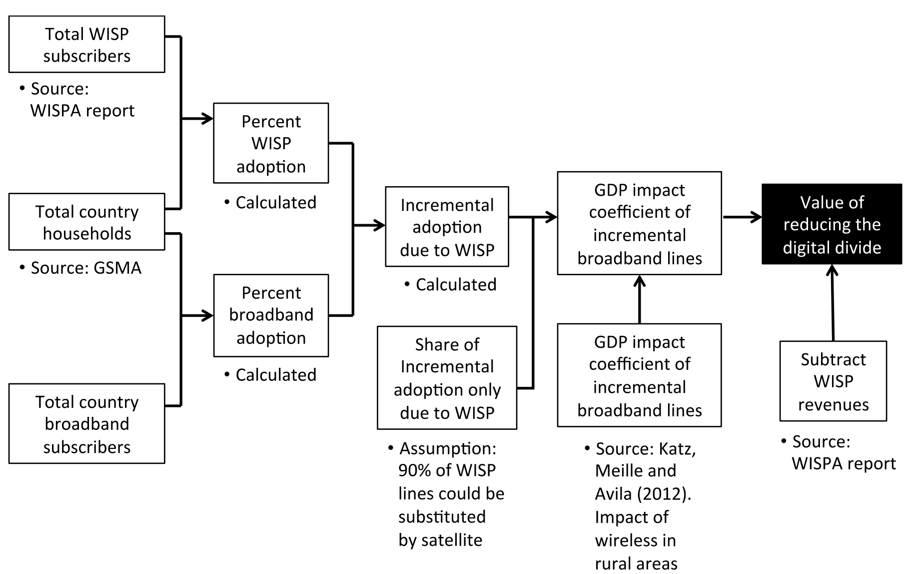


Source: Telecom Advisory Services

III.3.6. Bridging the digital divide

As explained above, Wi-Fi is an appropriate technology to offer Internet access in rural and isolated areas. Given that Wireless ISPs (discussed below in section III.3.8) tend to be prevalent in rural areas, the calculation of the Wi-Fi value of reduction of the digital divide has to subtract the impact of WISPs to avoid double counting. The analysis then proceeds by subtracting WISP broadband lines from the incremental growth in rural areas as a result of extending broadband service by leveraging Wi-Fi. Once this is done, we calculate the impact on the GDP by relying on the coefficient estimated through regression models that links increase in broadband lines to economic growth. The contribution to GDP materializes through multiple effects: creation of new businesses, increasing productivity of existing enterprises (in particular, agriculture), and growth of average income per household (see Figure III-12).

Figure III-12. Methodology for estimating GDP Contribution derived from reducing the digital divide

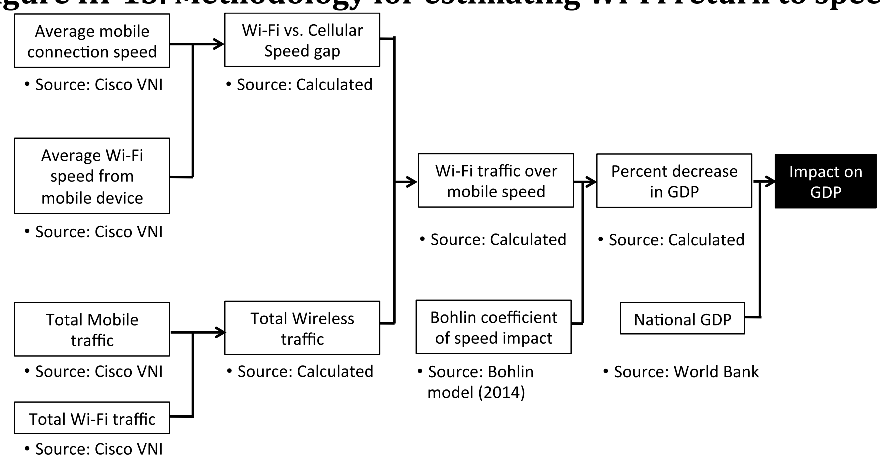


Source: Telecom Advisory Services

III.3.7. Wi-Fi return to speed

In addition to the sum of producer and consumer surplus generated by the aforementioned effects, wideband off-loading generates a "return to speed" economic value. As such, when a user accesses the Internet, the speed of access could be significantly higher via a Wi-Fi access point than on either 3G or 4G LTE networks. While Milgrom et al. (2011) estimate the additional value of speed based on the research on consumer surplus of high-speed networks (Dutz et al., 2009), more recent econometric research has been conducted aiming at measuring the impact on GDP of higher broadband speed (see Bohlin et al., 2013). At a higher level, the research concludes that in Organization for Economic Co-operation and Development (OECD) countries a doubling of broadband speed is associated with per capita GDP growth of 0.3%. To measure the economic value of Wi-Fi speed, our analysis focuses on understanding how slow the network would become if it did not have the Wi-Fi technology as a complement. In this case, we consider the total traffic without differentiating between points of access (residences or public places). Our analysis begins by quantifying the speed differential between average cellular and Wi-Fi access. By factoring offloading effects in relation to cellular we can then understand speed increases and apply the Bohlin et al. (2013) model to estimate the impact on GDP (see figure III-13).

Figure III-13. Methodology for estimating Wi-Fi return to speed



Source: Telecom Advisory Services

III.3.8. Revenues of Wi-Fi carriers and Wireless ISPs

In addition to the value generated by the other effects, Wi-Fi off-loading can create new business opportunities for service providers offering wireless broadband services in public places (airports, hotels) for a fee. In the last three years, operators in this space have deployed next-generation hotspot technologies to replicate the ease of access and security provided by cellular networks. At the same time, to facilitate interoperability, they are signing up roaming agreements. From a business model standpoint, innovation has allowed this sector to expand beyond the original pay-as-you-go access offering. In particular, it is worth mentioning retailer "push" marketing and promotions, neutral host provision to multiple cellular carriers, and bandwidth exchange for Wi-Fi capacity[24] (Maravedis-Rethink, 2013). The most straightforward

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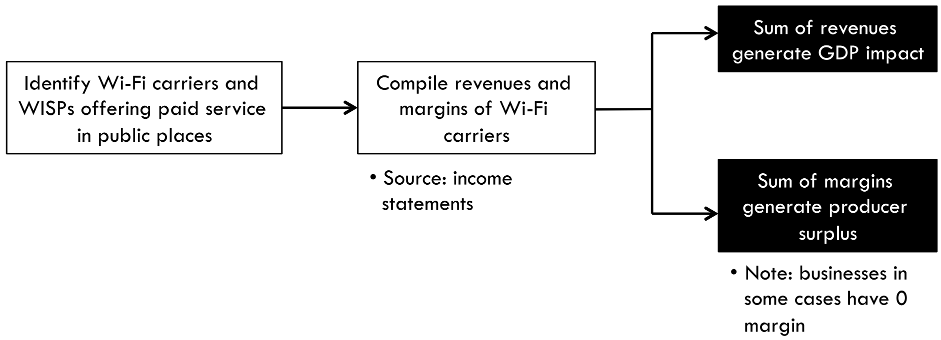
[24] BandwidthX offers an open market exchange of capacity between public Wi-Fi operators and any partners in need of Wi-Fi capacity. The solution allows carriers to bid for and purchase Wi-Fi capacity dynamically from available WISPs, with pricing based on a range of network selection policies, including place, time of day, etc.

way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in the United States, excluding firms that offer services as a wholesaler.

Figure III-14. Methodology for estimating the economic value generated by paid Wi-Fi services



Source: Telecom Advisory Services

III.3.9. Wi-Fi contribution to employment

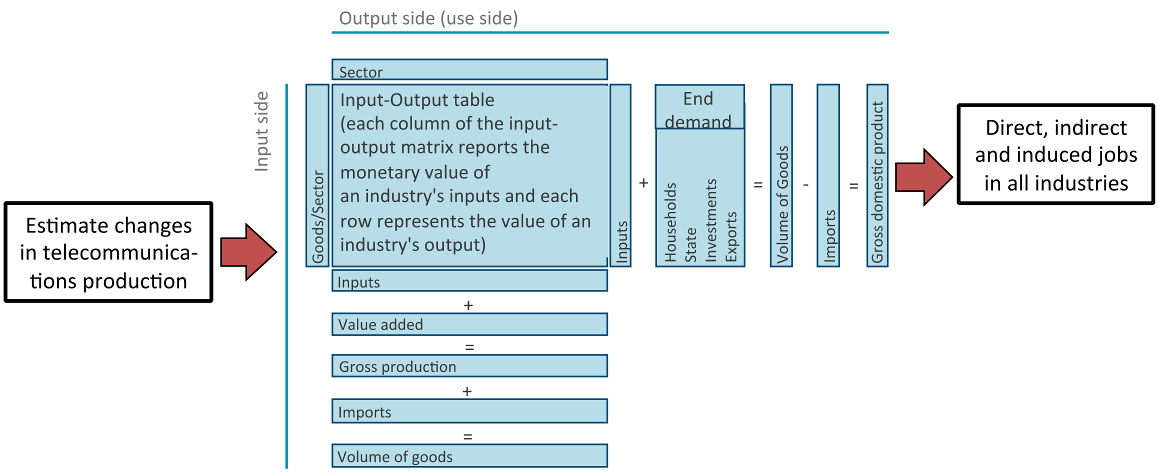
This economic technique, which measures the interdependence of an economy's various productive sectors, has been applied to estimate what the impact on all sectors of employment might be as a result of changes in output of the telecommunications sector. According to this approach, telecommunications output related to Wi-Fi is defined as a factor of production of other goods and services, creating spillover economic effects, with significant job creation effects.

- Employment effects are calculated based on input/output table (I-O table) for each country's economy. I-O tables depict the interdependencies between economic sectors, and are used to estimate the impact of positive or negative economic shocks through an economy.

- I-O tables assume that some inputs are used by sectors that produce output (intermediate output), which in turn is sold to another sector for consumption (final output); total output adds intermediate and final outputs. By using labor productivities, one can calculate job creation from output.

The structure of an I-O table comprises horizontal rows describing how an industry's total output is divided among various production processes and final consumption, and each column denotes the combination of productive resources used within one industry (see Figure III-15).

Figure III-15. Example of an Input / Output Table



Source: Katz (2012)

Each country has a specific table to reflect the particularities of its economy.

In order to calculate employment impact, the multiplier cumulative impact on GDP resulting from the effects analyzed above, would become an input that would generate employment effects through different sectors of the economy of the country under study. Employment effects can be disaggregated among direct, indirect, and induced.

IV. ECONOMIC VALUE OF WI-FI IN THE UNITED STATES

The United States is the country with the widest adoption and use of Wi-Fi in the world. Wi-Fi has become a pervasive feature in the US telecommunications landscape. According to the iPass Wi-Fi Growth Map, there are currently 1,701,578 commercial hotspots and 74,217,145 community access points operating in the US territory which, in the aggregate, represents 22% of all Wi-Fi hotspots around the world. Given the Wi-Fi access point density, hotspots have become a very important connectivity feature. According to OpenSignal[25], US wireless users spend 53.08% of their communications time connected to Wi-Fi networks rather than relying on their cellular data connection. Furthermore, the Wi-Fi standard has created an industry around equipment manufacturing that is a world leader.

The important weight of Wi-Fi technology on the digital ecosystem should have a significant contribution on its social and economic benefits. This chapter presents first the summary of results and then reviews each of the particular effects. The methodology reviewed in chapter III was utilized to calculate the economic value of Wi-Fi in the United States. Please refer to chapter III for detailed descriptions of each economic effect.

IV.1. Total economic value (2018 and 2023)

The total economic value of Wi-Fi in the United States in 2018 amounts to $ 499.09 billion, approximately the size of Belgium's GDP. This is comprised of $ 478.93 billion in economic surplus and $ 20.16 billion in contribution to the GDP (see table IV-1).

Table IV-1. United States: Total Economic Value of Wi-Fi (2018) (in US$ billions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 7.36	N.A.	$ 7.36	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 183.36	N.A.	183.36	N.A.
	2.2. Inside wiring avoidance	$ 62.77	N.A.	$ 62.77	N.A.
	Subtotal	$ 246.13	N.A.	$ 246.13	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 125.76	$ 125.76	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 16.86	$ 16.86	N.A.
	Subtotal	N.A.	$ 142.62	$ 142.62	
4. Value of cellular off-loading		N.A.	$ 10.70	$ 10.70	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 31.53	$ 36.08	$ 67.61	N.A.
	5.3Locally manufactured enterprise devices	N.A.	$ 4.51	$ 4.51	N.A.
	Subtotal	$ 31.53	$ 40.59	$ 72.12	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 7.11
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 8.51
8. Revenues of Wi-Fi carriers	8.1. Wi-Fi carriers in public places	N.A.	N.A.	N.A.	$ 1.23
	8.2. Wireless ISPs	N.A.	N.A.	N.A.	$ 3.31
	Subtotal	N.A.	N.A.	N.A.	$ 4.54
TOTAL		$ 285.02	$ 193.91	$ 478.93	$ 20.16

[25] OpenSignal. *Global State of Mobile Networks* (August 2016).

Source: Telecom Advisory Services analysis

The key sources of Wi-Fi economic value are residential use ($ 246.13 billion in consumer surplus) and business traffic ($ 125.76 billion in producer surplus, or enterprise efficiencies). Beyond this, the value of locally manufactured Wi-Fi equipment (access points, controllers, gateways, routers, etc.) has a significant impact in terms of economic surplus ($ 72.12 billion).

A 2023 forecast of economic value will reach $ 993.07 billion, composed of $ 958.18 billion in economic surplus, and $ 34.89 billion in GDP contribution (see table IV-2).

Table IV-2. United States: Total Economic Value of Wi-Fi (2023) (in US$ billions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 8.52	N.A.	$ 8.52	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 385.12	N.A.	$ 385.12	N.A.
	2.2. Inside wiring avoidance	$ 86.46	N.A.	$ 86.46	N.A.
	Subtotal	$ 471.58	N.A.	$471.58	
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 287.25	$ 287.25	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 16.86	$ 16.86	N.A.
	Subtotal	N.A.	$ 304.11	$ 304.11	
4. Value of cellular off-loading		N.A.	$ 96.30	$ 96.30	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 33.72	$ 38.66	$ 72.38	N.A.
	5.3Locally manufactured enterprise devices	N.A.	$ 5.29	$ 5.29	N.A.
	Subtotal	$ 33.72	$ 43.95	$ 77.67	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 15.90
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 7.98
8. Revenues of Wi-Fi carriers	8.1. Wi-Fi carriers in public places	N.A.	N.A.	N.A.	$ 2.68
	8.2. Wireless ISPs	N.A.	N.A.	N.A.	$ 8.33
	Subtotal	N.A.	N.A.	N.A.	$ 11.01
TOTAL		$ 513.82	$ 444.36	$ 958.18	$ 34.89

Source: Telecom Advisory Services analysis

The relative importance of sources of economic value by 2023 remains the same as in 2018, although the producer surplus associated to 5G deployment has triggered a substantial increase of $85.6 billion.

IV.2. Free Wi-Fi traffic

One dimension of Wi-Fi's economic value is derived from savings consumers receive by accessing the Internet through no cost sites (in retail shops, cafes, etc.) rather than relying on their cellular data plan. The following section presents the quantification of such benefit.

While total Internet traffic in the United States is growing at 24%, mobile Internet traffic has been growing at 34% per annum, indicating a growing share of wireless. Table IV-3 presents historical data.

Table IV-3. United States: Internet Traffic (2014-2018)
(In exabytes[26] per month)

	2016	2017	2018	CAGR
Total Internet	21.70	26.94	33.45	24.15 %
Wireless Internet	1.30	1.74	2.33	33.92 %

Source: Cisco; Telecom Advisory Services analysis

The increased adoption of wireless data-enabled devices (smartphones, tablets, PCs) combined with an increase in usage has driven overall traffic growth. The installed base of smartphones in the US is forecast to reach 284 million in 2018, while this number amounted to 127 million for tablets. On the other hand, the number of laptops remains relatively stable at 182 million (2016-18 CAGR: 3.90%) due to tablet and, secondarily, smartphone substitution (see table IV-4).

Table IV-4. United States: Device Installed Base and Penetration (2016-2018)

Device	Metrics	2016	2017	2018 (E)	CAGR
Smartphones	Units (in millions)	275	275	284	1.56%
	Penetration (%)	85.03 %	84.38 %	86.47 %	0.84%
Tablets	Units (in millions)	122	126	127	1.95%
	Penetration (%)	37.79 %	38.76 %	38.73 %	1.24%
Laptops	Units (in millions)	169	175	182	3.90%
	Penetration (%)	52.25 %	53.86 %	55.61 %	3.17%
Devices per user		1.75	1.77	1.81	1.63%

Sources: Cisco; GSMA Intelligence; Telecom Advisory Services analysis

Beyond the laptop to tablet substitution, the installed base of smartphones has shifted to 4G (LTE) network standards that provide faster speed of access and, consequently, stimulate more intense data usage. Looking forward, it is projected that the average speed of mobile devices by 2023 would have almost double from the current 14.36 Mbps. Data also shows that as connected devices increasingly penetrate the subscriber base, the number of "devices per user" increases commensurately: from 1.75 in 2016 to 1.81 in 2018.

Adding to the proliferation of devices, traffic per device has grown between 19.15% and 28.74% per annum driven by increased applications and content availability (see table IV-5).

Table IV-5. United States: Average Traffic Per Device (in Gigabytes per month)

	2016	2017	2018 (E)	CAGR
Smartphones	10.96	14.08	17.98	28.08%
Tablets	11.33	14.79	18.78	28.74%
Laptops	39.28	47.52	55.76	19.15%

Source: Cisco VNI

With the installed base and average data usage per device, total mobile Internet traffic in the United States can be calculated for the next five years. Our numbers estimate a total traffic of 10.04 Exabytes per month in 2023[27]. Projections regarding traffic growth from other sources vary, although they all agree directionally (see table IV-6).

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[26] 1 Exabyte equals 1,073,741,824 gigabytes.

[27] For comparison, the entire Library of Congress, including all audio, video and digital material is estimated to be 3 petabytes, although some estimates reach 20 petabytes. This last figure would be the equivalent to 0.02 exabytes. ← should we just say this is 500 times the entire Library of Congress?

Table IV-6. United States: Internet Traffic (2018-2023)
(In million Exabytes per month)

	2018	2019	2020	2021	2022	2023
Total Internet	33.45	41.52	51.55	64.00	79.46	98.64
Mobile Internet	2.33	3.12	4.18	5.60	7.50	10.04

Source: Cisco; Telecom Advisory Services analysis

This growth has and will continue to put pressure on the public networks of all service providers to accommodate the traffic without incurring congestion while generating acceptable levels of revenue. We will now estimate the portion of traffic that is off-loaded to Wi-Fi.

Based on the premise that cellular off-loading varies by device, and assuming that off-loading will increase over time with the deployment of more Wi-Fi sites, this study looks at smartphones, tablets, and laptops to calculate the portion of overall mobile traffic transmitted through Wi-Fi (see table IV-7).

Table IV-7. United States: Wireless Device Off-Loading Factors (2016-2018)

	2016	2017	2018 (E)
Smartphones	48%	48%	48%
Tablets	35%	36%	38%
Laptops	35%	36%	38%

Source: Cisco; Opensignal; TAS analysis

By applying these off-loading factors to the total data traffic generated by each type of device, we project that total Wi-Fi traffic in the United States is currently 6.17 Exabytes per month in 2018[28], reflecting a 30.66% annual growth rate (see table IV-8).

Table IV-8. United States: Total Wi-Fi Traffic Per Device (2016-2018)
(In Exabytes per month)

	2016	2017	2018(E)	CAGR
Smartphones	1.34	1.72	2.27	30.08%
Tablets	0.30	0.44	0.59	39.29%
Laptops	1.97	2.59	3.31	29.66%
Total	3.61	4.75	6.17	30.66%

Source: Telecom Advisory Services analysis

The estimation of consumer surplus proceeds, then, by multiplying the total Wi-Fi traffic from table IV-8 by 4.32%, representing the "true free traffic" conducted by public sites[29].

Table IV-9. United States: Total Free Wi-Fi Traffic (2016-2018)

	2016	2017	2018(E)
Total Wi-Fi Traffic	3.61	4.75	6.17
Total Free Traffic (in Exabytes per month)	0.16	0.21	0.27
Total Free Traffic (in Exabytes per year)	1.87	2.47	3.20
Total Free Traffic (in million Gigabytes per year)	2013.19	2646.95	3437.02

Source: Telecom Advisory Services analysis

[28] For comparison purposes, the National Climatic Data center (NOAA) database had 400 Terabytes, or approximately 0.04% of an Exabyte, meaning Wi-Fi traffic per month is more than 154 times NOAA data (source: University of California Berkeley)
[29] Source: Mobidia

We calculated consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we needed an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculated by averaging the most economic "dollar per GB" plan (so-called "unlimited") of four major US wireless carriers (see table IV-10).

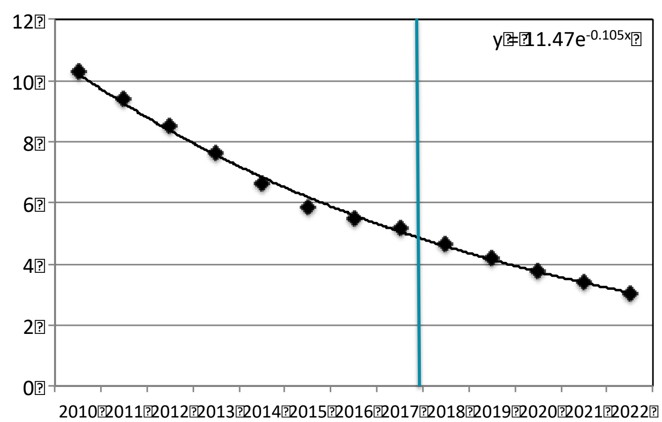
Table IV-10. United States: Average Price Per Gigabyte (2017)

Carrier	Plan	Price per Gb
ATT	Mobile Share Data: $335/50 Gigabytes cap	$ 6.70
Verizon	Data Only, 100 Gb: $710/100 Gigabytes cap	$ 7.10
Sprint	Unlimited data: $25/10 Gigabytes cap 4G	$ 2.50
T-Mobile	Mobile Internet 22 Gb: $95/22 Gigabytes cap	$ 4.32
Average		$ 5.16

Source: Telecom Advisory Services analysis

Historical data allowed for a projection of future prices per Gigabyte (see figure IV-1).

Figure IV-1. Estimate of Future Average Price Per Gigabyte (2010-2022)



Source: TAS analysis

According to these prices, while the average price per GB in 2017 is $ 5.16, by 2023, it will reach an estimated $2.75. As to the cost of offering the Wi-Fi service, this would include an additional router and needed bandwidth. For estimation purposes, we assume those costs to be prorated at $2.50 per Gigabyte, which was what some Wi-Fi services in public sites charge per 2 hr. service (assuming this to be costs passed through to the customer)[30]. By relying on the total free Wi-Fi traffic shown in table IV-9 and the average price per cellular Gigabyte minus the cost of provisioning Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic (see table IV-11).

Table IV-11. United States: Consumer Surplus of Free Wi-Fi Traffic (2018-2023)

	2018	2019	2020	2021	2022	2023
Total Free Traffic (in million Gigabytes per year)	3437.02	4417.00	5540.66	6876.38	8516.37	10526.95
Price per cellular gigabyte ($)	$ 4.64	$ 4.18	$ 3.76	$ 3.39	$ 3.05	$ 2.75
Cost per Wi-Fi provisioning ($)	$ 2.50	$ 2.38	$ 2.26	$ 2.14	$ 2.04	$ 1.94
Consumer surplus per Gigabyte ($)	$ 2.14	$ 1.80	$ 1.51	$ 1.24	$ 1.01	$ 0.81
Total Consumer surplus (in $ million)	7,359	7,965	8,339	8,544	8,617	8,521

Source: Telecom Advisory Services analysis

[30] This is assumed to decline to $ 1.94 per Gigabyte by 2023.

As indicated in table IV-11, consumer surplus of free Wi-Fi traffic in 2018 would reach an estimated $ 7.359 billion and $ 8.521 billion in 2023.

IV.3. Value of Residential Wi-Fi

The value of residential Wi-Fi is a combination of Internet access for home usage and avoidance of in-house wiring.

IV.3.1. Home Internet access for devices that lack an Ethernet port

As mentioned in Chapter III, the underlying premise of this analysis is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on the cellular network to gain Internet access. For this reason, estimating value would first measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers.

Based on our traffic model, the total traffic generated by these types of devices in 2018 in the United States amounts to 91,624 million Gigabytes[31] (see table IV-12).

Table IV-12. United States: Total Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	31,699	44,997	62,994	86,054	114,758	149,940	195,907	255,966
Tablets	16,617	22,403	28,630	35,397	42,502	50,039	58,913	69,361
Total	48,316	67,400	91,624	121,451	157,260	199,979	254,820	325,327

Source: Cisco; GSMA; analysis Telecom Advisory Services

According to Cisco IBSG (2012), 43.12% of use time of devices that lack an Ethernet port occurs at home. Therefore, the portion of said traffic generated at home reached 39,506 million Gigabytes (see table IV-13).

Table IV-13. United States: Home Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	13,668	19,402	27,161	37,105	49,481	64,651	84,471	110,367
Tablets	7,165	9,660	12,345	15,262	18,326	21,576	25,402	29,907
Total	20,833	29,062	39,506	52,367	67,807	86,227	109,873	140,274

Source: Cisco; GSMA; analysis Telecom Advisory Services

If this traffic had to be transported by cellular networks, at the average price per GB estimated in the model of figure IV-1, it would result in costs of $183.36 billion in 2018 and $385.12 billion in 2023.

IV.3.2. Avoidance of investment in in-house wiring

[31] For comparison purposes, when it is full up and running, the four massive detectors on the new Large Hadron Collider at the CERN particle-physics lab are expected to produce 15 million gigabytes.

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in an average US residence reaches approximately $660 per household[32]. Considering that 75% of US households currently have Wi-Fi[33], the avoidance cost of inside wiring for 95 million households, which in the absence of Wi-Fi yields a total cost of wiring of $62.77 billion. By 2023, all households are expected to have adopted Wi-Fi, so the savings would have reached $86.46 billion.

IV.4. Enterprise Wi-Fi

As stated in chapter III, the economic value of enterprise Wi-Fi has two sources:

- Business traffic routed through Wi-Fi access points rather than cellular networks;
- Avoidance of capital investment to deploy Ethernet wiring inside enterprise establishments to connect devices and peripherals.

IV.4.1. Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. In 2018, Cisco VNI and Telecom Advisory Services analysis estimate that total business Internet traffic will reach 71.3 billion GB, of which 27.10 billion GB would have been transported through Wi-Fi access points. Considering that the average price per GB transported by cellular is $4.64, savings from Wi-Fi would have reached $125.76 billion, an addition to the producer surplus. By 2023, this benefit will reach $ 287.25 billion (see table IV-14).

Table IV-14. United States: Savings in business wireless traffic (2016-2023)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Share of Business Internet Traffic by Wi-Fi	35.00%	36.47%	38.00%	39.60%	41.27%	43.00%	44.81%	46.69%
Total Business Internet Traffic (Gb)	45,097	56,704	71,298	89,649	112,722	141,734	178,213	224,080
Total Gb Wi-Fi enterprise traffic	15,784	20,681	27,096	35,502	46,515	60,946	79,852	104,624
Average Price per Gb	$5.49	$5.16	$4.64	$4.18	$3.76	$3.39	$3.05	$2.75
Economic Impact	$ 86,604	$ 106,608	$ 125,758	$ 148,347	$ 174,994	$ 206,427	$ 243,507	$ 287,247

Source: Cisco; analysis Telecom Advisory Services

IV.4.2. Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points, and multiply this value by a standard cost of deploying a CAT 6 network (although in this case, the cost is $2,200 per building) (see table IV-15).

[32] National average for wiring a 2-room residence with CAT 6.
[33] Source: Watkins, David. *Broadband and Wi-Fi Households Global Forecast 2012*. Strategy Analytics

Table IV-15. United States: Savings in business wiring CAPEX (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Total Wiring Cost	$2,200	$2,200	$2,200	$2,200	$2,200	$2,200	$2,200	$2,200
Number of Establishments	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938
Establishments with Wi-Fi	100%	100%	100%	100%	100%	100%	100%	100%
Establishments with Wi-Fi	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938	7,663,938
Inside Wiring Costs (US$ million)	$16,861	$16,861	$16,861	$16,861	$16,861	$16,861	$16,861	$16,861

Source: Telecom Advisory Services

IV.5. Cellular off-loading

The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks.

This analysis starts with the predicted incremental wireless data traffic generated between 2018 and 2023. According to Cisco, future monthly wireless data traffic will amount to 51.52 Exabytes per month in 2023. It is obvious that a cellular-only network could not economically handle all future traffic. While the economic advantage of Wi-Fi off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are considerably less expensive than cellular network equipment with similar capacity. For example, a cellular pico-cell (needed to offer access via conventional cellular service) costs between $7,500 and $15,000[34], while a carrier-grade Wi-Fi access point requires an investment of $2,500[35]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table IV-16).

Table IV-16. Comparative Carrier Grade Wi-Fi and LTE Macro Cell CAPEX and OPEX

	Wi-Fi Site	LTE Macro Cell
New Site acquisition	$ 600	$ 150,000
Collocation	-	$ 50,000
Backhaul	$ 300	$ 5,000
Monthly site rental	$ 20	$ 1,000
Site maintenance/month	$ 10	$ 200

Source: LCC Wireless (2012)

As it can be seen, Wi-Fi has significant economic advantages at the unit level. However, we must add a caveat here. Site density requirements for Wi-Fi are much higher than for cellular. For example, in a dense urban environment with high traffic, for each cellular site, 23 Wi-Fi hotspots are required. The difference means that, from a Total Cost of Ownership (CAPEX and OPEX) standpoint, the driver that erodes some of the Wi-Fi economic advantage is OPEX, especially Wi-Fi site rental and backhaul costs. Along these lines, for the carrier-class Wi-Fi off-loading to materialize, site deployment needs to be managed on a case-by-case basis, by surgically placing sites primarily in high traffic areas.

In this context, a simulation was run to determine the economic advantage of relying on carrier-grade Wi-Fi sites to complement the deployment of LTE in the United States. According to Thanki (2012), achieving full LTE coverage in the United States relying on 2100 MHz to accommodate

[34] "When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.
[35] Cisco Aironet 1552H Wireless Access Point.

incremental wireless data traffic would require approximately 34,000 new base stations[36], representing a total capital investment of $ 8.5 billion. On two simulation cases of off-loading in New York and San Diego, LCC Wireless assumed a CAPEX benefit of Wi-Fi off-loading ranging between 22.3 % and 44.7 %. When averaging these two estimates, the CAPEX reduction would amount to $2.76 billion. Even under the OPEX considerations mentioned above, the Total Cost of Ownership remains lower under the Wi-Fi off-loading scenario (see table IV-17).

Table IV-17. Total Cost of Ownership of LTE only versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
Total Cost of Ownership	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) OPEX to CAPEX ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

In sum, the producer surplus of deploying carrier-grade Wi-Fi complementing the rollout of LTE to accommodate future traffic growth would amount to $ 10.7 billion. This amount does not include the CAPEX saved by traffic off-loading to residential and business Wi-Fi networks[37].

However, starting in 2020, 5G deployment will increase the value of cellular re-routing. Given current announcements and trials, it is conceivable that at least the two ILECs (incumbent local exchange carriers) will launch fixed 5G services to residences in 2019 in the United States. That being said, the migration to 5G has already started from a network topology standpoint. A survey study conducted by Rethink Research among U.S. operators reports that while 8% of service providers are targeting to deploy 5G by 2020, 79% expect to have dense Wi-Fi/cellular HetNets in place in locations of high traffic and 69% will have started to implement virtualization in the access network. As for 5G implementation, 47% of operators would have started between 2020 and 2023 and the remainder in 2024 and later.

In this context, unlicensed spectrum becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands. To calculate the economic value of Wi-Fi in this context, we rely on the only known cost estimation of 5G to date: the one developed by Oughton and Frias (2016) for OFCOM in the United Kingdom. The authors' baseline case estimates a CAPEX of £42 billion, of which urban coverage investment amounts only to 700 million, while suburban deployment demands £5.6 billion, and rural coverage £35.6 billion. Considering the cost decomposition of Oughton and Frias (2016), it is reasonable to assume that current CAPEX levels and Wi-Fi utilization will not allow deployment beyond the urban centers. Therefore, one should consider the U.S. 5G suburban deployment as part of the future producer surplus not yet estimated (see Table IV-18).

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[36] This model was adapted by the author from Ofcom, the UK regulator, to assess the effect of differing traffic levels on cell site numbers in urban areas in its consultation "Application of spectrum liberalization and trading to the mobile sector" (Ofcom, 2009).
[37] See Cooper (2012).

Table IV-18. Producer surplus of 5G in the United Kingdom v. United States

Geography	United Kingdom			United States	
	Population Breakdown (%)	5G CAPEX (£ Billion)	5G CAPEX (%)	Population Breakdown (%)	Producer Surplus ($ million)
Urban (cities>1 million)	29%	£0.7 ($0.948)	1.66%	27%	$10,700
Suburban	54%	£5.6 ($7.592)	13.33%	53%	$85,600
Rural	17%	£35.6 ($48.263)	84.76%	19%	$544,171
TOTAL	**100%**	**£41.9 ($56.803)**	**100%**	**100%**	**$640,471**

Sources: Oughton and Frias (2016); Trading Economics; World Bank; U.S. Census Bureau; Trulia; Telecom Advisory Services analysis

A simple interpolation in Table IV-18 assumes that, if 5G CAPEX in the United Kingdom suburban areas is eight times that of the urban areas, the producer surplus associated with 5G deployment in the United States suburban areas would be eight times that of urban areas: $85.6 billion, to which we would add $10.7 billion from 4G. Based on this, we would add this amount to Wi-Fi's economic value due to cellular off-loading in 2023.

IV.6. Locally manufactured Wi-Fi enabled equipment

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. It is assumed that the consumer surplus is roughly equal to consumer surplus (see Milgrom et al., 2011). Both consumer products and enterprise equipment are considered as part of the economic surplus generated by locally manufactured Wi-Fi enabled devices in the United States.

IV.6.1. Consumer products

As detailed in section III.3.5, we identified seven consumers products which are intrinsically linked to Wi-Fi: smart home devices and systems such as Wi-Fi speakers and home security systems), home networking systems such as Apple's HomePod, Amazon Echo, and Google Home, Wi-Fi tablets, access points[38], external adapters[39], routers, and gateways.

Since our focus is estimating economic surplus in the United States, the estimation of economic value begins by compiling revenues of US manufacturers for each product[40]. For example, the worldwide market for residential routers in 2018 is estimated at $6,389 million, of which US manufacturers control 5.9% share. This results in global sales of US manufacturers of $ 377.53 million.

Of this amount, the prorated margin estimated by CSI markets is 44.41%, which yields a producer surplus for this particular product of $167.66 million. Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic

[38] Access points (APs) allow devices to connect to a wireless network.

[39] Wireless client device. It can be PCI adapter, which A PCI wireless adapter card is a device that is connected to a desktop computer's PCI bus to provide wireless capability to the desktop, a PC card, or a USB adapter.

[40] Lack of data of US manufacturers worldwide revenues for wireless speakers, home security systems, and home networking devices obliged us to rely on the US market size for these three products. We believe the US manufacturers control most of this market, so the only portion missing in this estimate would be overseas revenues of US manufacturers.

value in 2018 would amount to $ 378 million. A similar analysis was conducted for the remainder of Wi-Fi enabled consumer equipment (see table IV-19).

Table IV-19. United States: Economic Value of Wi-Fi enabled consumer products (In $ million)

	2016	2017	2018	2019	2020	2021	2022	2023
Wireless speakers	32,114	41,120	52,652	54,515	56,444	58,442	60,510	62,652
Home security systems	4,598	4,506	4,416	4,328	4,241	4,157	4,074	3,992
Home networking devices	2,505	3,352	4,485	4,799	5,135	5,494	5,879	6,290
Wi-Fi tablets[41]	35.49	40.99	37.48	33.63	29.82	27.33	25.12	23.44
Access points	920	933	984	1,029	1,072	1,054	1,029	1,049
External adapters	81	61	57	41	42	33	30	26
Routers	429	371	378	379	376	371	364	362
Gateways	401	414	421	423	419	414	406	404
TOTAL SALES	41,048	50,757	63,391	65,514	67,729	69,965	72,292	74,777
Gross margin for all products (ex. Tablets)	42.87%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%
Consumer surplus	17,597	22,541	28,152	29,095	30,079	31,071	32,105	33,209
Producer surplus	17,597	22,541	28,152	29,095	30,079	31,071	32,105	33,209
Consumer surplus for tablets	3,386	3,905	3,380	3,172	650	595	547	511
Producer surplus for tablets	8,921	9,182	7,922	7,454	6,931	6,352	5,839	5,448

Sources: Consumer Technology Association; ABI Research; CS Markets; Telecom Advisory Services analysis

By adding the consumer and producer surplus for all product categories, the economic surplus of Wi-Fi enabled consumer equipment in the United States would be $ 67.61 billion in 2018 and reach $ 72.38 billion in 2023.

Table IV-20. United States: Economic Value of Wi-Fi enabled consumer products (In $ million)

	2016	2017	2018	2019	2020	2021	2022	2023
Consumer surplus	20,984	26,445	31,533	32,267	30,728	31,666	32,653	33,720
Producer surplus	26,518	31,723	36,074	36,549	37,010	37,423	37,944	38,657
Total	47,502	58,168	67,607	68,816	67,738	69,089	70,597	72,377

Sources: Consumer Technology Association; ABI Research; CS Markets; Telecom Advisory Services analysis

IV.6.2. Enterprise products

US manufacturers control the largest share of the enterprise access points and controllers world market (see table IV-21).

Table IV-21. Enterprise products: Global Market shares (2018)

Product	Market (in millions)	United States	United Kingdom	Germany	South Korea	France	Japan	China	Taiwan	ROW
Access points	$ 5,357.9	82.9 %	0 %	0 %	0 %	0 %	0 %	17.1 %	0 %	0%
Controllers	$ 1,024.7	67.3 %	0 %	0 %	0 %	0 %	0 %	19.9 %	0 %	12.8 %

Sources: ABI Research; Telecom Advisory Services analysis

For example, in 2018 Cisco controls 40.3% of the enterprise access points and 16.3% of the enterprise controller world market, while HP garners 22.1% and 11.5% of the same markets[42].

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[41] Calculated as the US manufacturers share of global Wi-Fi tablet shipments.

[42] ABI Research. *Wireless Connectivity Technology Segmentation Addressable Markets*, 1Q2018.

Of the revenues of US manufacturers, the prorated margin estimated by CSI markets is 44.41%, which yields a producer surplus for US manufacturers of these particular products of $ 2,254 million. Following again Milgrom et al. (2011) in their assumption that consumer value for enterprises[43] is of the same magnitude as producer value, total economic value in 2018 would amount to $ 4,508 million (see table IV-22).

Table IV-22. United States: Economic Value of Wi-Fi enabled enterprise equipment (In $ million)

	2016	2017	2018	2019	2020	2021	2022	2023
Access points	4,165	4,339	4,386	4,426	4,771	4,873	4,925	5,061
Controllers	715	649	690	724	798	838	867	890
Total	4,880	4,988	5,076	5,150	5,569	5,711	5,792	5,951
Gross margin	42.87%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%
Producer surplus (buy)	2,092	2,215	2,254	2,287	2,473	2,536	2,572	2,643
Producer surplus (sells)	2,092	2,215	2,254	2,287	2,473	2,536	2,572	2,643

Sources: ABI Research; CSI markets; Telecom Advisory Services analysis

IV.7. Bridging the digital divide

The digital divide is defined as the gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory).

Given that Wireless ISPs (economic value calculated in section IV.9 below) tend to be prevalent in rural areas, the calculation of the Wi-Fi value of reduction of the digital divide has to subtract the impact of WISPs to avoid double counting. The analysis then proceeds by subtracting WISP broadband lines from the incremental growth in rural areas as a result of extending broadband service by leveraging Wi-Fi. Once this is done, we calculate the impact on the GDP by relying on coefficient estimated through regression models that link increase in broadband lines to economic growth (see table IV-23).

Table IV-23. United States: GDP Contribution Resulting from reduction of the digital divide

	2016	2017	2018	2019	2020	2021	2022	2023
WISP subscribers (million)	4.00	4.60	5.20	6.00	6.90	8.10	9.51	11.16
Total Broadband Subscribers (million)	106.07	110.10	114.28	118.61	12311	125.23	127.56	130.14
Households (million)	124.19	125.17	126.16	127.15	128.15	129.16	130.18	131.21
Adoption WISP	3.22%	3.67%	4.12%	4.72%	5.38%	6.27%	7.30%	8.51%
Adoption broadband	85.41%	87.96%	90.58%	93.28%	96.07%	96.95%	97.99%	99.19%
WISP additional	3.77%	4.18%	4.55%	5.06%	5.60%	6.47%	7.45%	8.58%
Economic coefficient impact	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
GDP per capita	57,559	59,501	62,152	64,674	66,637	68,517	70,165	71,805
Population (million)	323.32	325.61	327.93	330.26	332.61	334.97	337.34	339.71
WISP TOTAL impact	56.14	64.76	74.20	86.44	99.38	118.76	141.15	167.37
WISP Revenues	2.30	2.70	3.10	3.70	4.40	5.20	6.85	8.33
Share that exist because WISP	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
WISP Indirect Impact on GDP (in $ billion)	$ 5.38	$ 6.21	$ 7.11	$ 8.27	$ 9.50	$ 11.36	$ 13.43	$ 15.90

Sources: WISPA (2017); Thomson and Garbacz (2008); Telecom Advisory Services analysis

[43] The enterprise surplus is considered here as a producer surplus for companies that benefit from Wi-Fi technology.

Based on these calculations, Wi-Fi's contribution to GDP by reducing the digital divide in the United States would amount to $ 7.11 billion in 2018 and $ 15.90 billion in 2023.

IV.8. Wi-Fi return to speed

Since Wi-Fi accessibility allows, in general, faster access to the Internet than cellular networks do, higher speeds have a positive contribution on the economy in terms of increased overall efficiency and innovation. This contribution is measured in terms of economic growth.

We start with the quantification of speed differentials, which we calculate by subtracting the weighted average of Wi-Fi and cellular speeds (averaged according to traffic off-loading factors) and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (see table IV-24).

Table IV-24. United States: Estimation of speed differential for total traffic (In Mbps)

	2016	2017	2018	2019	2020	2021	2022	2023
Average speed of cellular networks	11.14	12.65	14.36	16.30	18.50	21.00	23.84	27.06
Average Wi-Fi speed	28.10	32.26	37.03	42.50	48.79	56.00	64.28	73.79
Average speed of weighted average of cellular and Wi-Fi traffic	23.61	27.00	30.81	35.10	39.82	45.08	50.97	57.57
Speed decrease (average speed of cellular/average weighted average speed)	-52.82%	-53.16%	-53.40%	-53.57%	-53.55%	-53.41%	-53.23%	-53.00%

Source: Cisco; TAS analysis

Having calculated the speed decrease percentage, we then apply this percentage to the coefficient derived from the model developed by Bohlin et al. (2011 and 2013) to gauge the potential impact on GDP if cellular networks transported all traffic (see table IV-25).

Table IV-25. Econometric model measuring the impact of broadband speed on GDP

Independent Variables	Coefficient
Average GDP growth (2008-2010)	0.577 *
Population density	-0.0441 *
Urban population	-0.0103 **
Labor force growth (%)	0.0492 *
Telecom revenue growth (%)	0.0492 *
Population growth (%)	-0.630 **
Average achieved downlink speed	-0.00214
Average achieved downlink speed squared	0.00142 *

*, ** significant at 1% and 5% critical value respectively
Source: Rohman and Bohlin (2011)

As table IV-25 shows, by incorporating the elasticity of the coefficient of broadband speed and the square of the variable, the model assumes that the doubling of broadband speed causes a 0.3% increase in GDP growth. Our case shows the GDP impact on the **decrease** in speed. This is applied in turn to the GDP of the United States at current prices (see table IV-26).

Table IV-26. United States: Broadband speed impact on GDP

	2016	2017	2018	2019	2020	2021	2022	2023
Speed decrease (%)	-52.82%	-53.16%	-53.40%	-53.57%	-53.55%	-53.41%	-53.23%	-53.00%
Model coefficient	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%
Decrease in GDP per capita	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%
GDP per capita (current prices)	57,558.95	59,501.11	62,152.07	64,674.09	66,637.36	68,516.69	70,165.35	71,805.32
Wi-Fi Traffic (% Total Traffic)	27.18%	26.70%	26.07%	25.34%	24.15%	22.86%	21.68%	20.58%
GDP Reduction (in $ millions, current prices)	$ -8,014	$ -8,248	$ -8,512	$ -8,696	$ -8,597	$ -8,408	$ -8,194	$ -7,980

Source: Cisco; TAS analysis

Table IV-26 indicates that if all cellular data traffic that is currently being off-loaded to Wi-Fi were to shift to cellular networks, the reduction in speed (in 2018 from an average 37.03 Mbps to 14.36) would have an $8.512 billion impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data. In 2023, the amount would reach $7.980 billion.

IV.9. Revenues of Wi-Fi carriers and Wireless ISPs

The value of carriers and wireless ISPs includes the sum of revenues through paid public Wi-Fi access and revenues of ISPs offering Wi-Fi as a service. The most straightforward way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in the United States, excluding firms that offer services as a wholesaler.

Table IV-27 presents a compilation of US Wi-Fi service providers and their revenues through 2017. The forecast through 2023 was estimated based on the growth rate over the past years. As table IV-27 indicates, estimated total revenues generated by this sector in the United States have reached $ 1.23 billion, and are expected to reach $2.68 in 2023.

Table IV-27. Compilation of Retail Wi-Fi Service Providers in the United States (in $ millions)

Company	Business focus	2016	2017	2018 *	2019 *	2020 *	2021 *	2022 *	2023 *
Boingo Wireless	Retail access; wholesale access (to ATT, Verizon); military bases; advertising	$159.34	$204.37	$244.54	N.A.	N.A.	N.A.	N.A.	N.A.
iPass	Enterprise Wi-Fi services; wholesale access	$63.22	$54.40	$54.40	N.A.	N.A.	N.A.	N.A.	N.A.
SONIFI Solutions	Hotels and Health care (cable and Wi-Fi)	N.A.	$95.77	$95.77	N.A.	N.A.	N.A.	N.A.	N.A.
Gogo	In-flight Internet access	$596.55	$699.09	$836.21	N.A.	N.A.	N.A.	N.A.	N.A.
Total		$819	$1,054	$1,231	$1,438	$1,680	$1,963	$2,293	$2,679

Note: (*) Estimated
Source: Company Annual reports and 10-K reports; TAS analysis

Wireless Internet Service Providers (WISPs) rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas of the United States. While some WISPs utilize licensed spectrum (Clear and Digital Bridge), the majority relies on UNII and ISM bands or lightly licensed spectrum in the 3.65 GHz band: 26mhz of unlicensed spectrum just above 900mhz, 50mhz in 2.4ghz and 100mhz in 5.8ghz (Larsen, 2011). According to Wireless mapping.com, the WISP Directory Database compiled by the WISP Association includes over 1,800 "documented and verified" WISPs. While WISPs initially utilized the 802.11b platform, they have mostly migrated to 802.11n, which allows them to deliver 10 Mbps service or higher to 200 customers from a single four sector base station (Larsen, 2011).

The 2018 GDP contribution related to the WISP industry was calculated as a function of the number of subscribers (5,200,000) and ARPU ($49.68 per month), yielding a total of $3,307 million.

Table IV-28. United States: Wireless Internet service providers

Variable	2016	2017	2018	2019	2020	2021	2022	2023
Subscribers ('000)	4,000	4,600	5,200	6,000	6,900	8,100	9,509	11,162
ARPU	$ 47.92	$ 48.91	$ 49.68	$ 51.39	$ 53.14	$ 53.50	$ 60.07	$ 62.22
Revenues ($ million)	$ 2,448	$2.870	$ 3,307	$ 3,960	$4.636	$ 5,637	$ 6,854	$ 8,334

Source: Katz (2014); WISPA (2017)

IV.10. Wi-Fi contribution to employment

The estimation of employment generated is calculated by relying on the total GDP contribution resulting from the effects analyzed above and using that as an input in the communications sector of an input-output matrix of the US economy. Table IV-29 presents the GDP contribution of each of the effects analyzed above.

Table IV-29. United States: Total GDP Contribution of Wi-Fi (in $ billion)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$ 7.11	$ 8.27	$ 9.50	$ 11.36	$ 13.43	$ 15.90
Return to speed	$ 8.51	$ 8.70	$ 8.60	$ 8.41	$ 8.19	$ 7.98
Wi-Fi carriers	$ 4.54	$ 5.14	$ 6.08	$ 7.16	$ 9.14	$ 11.01
Total	$ 20.16	$ 22.11	$ 24.18	$ 26.93	$ 30.76	$ 34.89

Source: Telecom Advisory Services analysis

These inputs generate the following annual employment effects based on the Input/output matrix for the US economy (table IV-30).

Table IV-30. United States: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	82,675	143,110
Indirect jobs	29,578	51,199
Induced jobs	6,434	11,137
Total	118,687	205,446

Source: Telecom Advisory Services analysis

According to the contribution to the GDP, Wi-Fi is generating approximately 120,000 jobs in 2018 and is expected to generate 205,000 in 2023. Job estimates include direct jobs (those jobs created by the a specific Wi-Fi contribution), indirect jobs (those jobs created by suppliers to the Wi-Fi sector); induced jobs (those jobs created by spending of direct and indirect workers).

The sector breakdown of 2018 employment is as follows (table IV-31).

Table IV-31. United States: Sector Breakdown of Wi-Fi generated annual employment

Sector	Direct	Indirect	Induced	Total
Agriculture	0	0	210	210
Extractive industries	0	172	67	239
Manufacturing	0	2,281	97	2,378
Construction	0	2,555	0	2,555
Trade	0	2,982	2,982	5,964
Transportation	0	469	865	1,334
Communications	82,675	0	0	82,675
Financial Services	0	6,889	0	6,889
Business services	0	12,805	0	12,805
Other services	0	1,425	2,213	3,638
TOTAL	82,675	29,578	6,434	118,687

Source: Telecom Advisory Services analysis

V. ECONOMIC VALUE OF WI-FI IN THE UNITED KINGDOM

Wi-Fi has become a pervasive feature in the United Kingdom telecommunications landscape. According to the iPass Wi-Fi Growth Map, there are currently 494,101 commercial hotspots and 13,547,231 community access points operating in the UK territory. Given the Wi-Fi access point density, hotspots have become a very important connectivity feature. According to OpenSignal[44], UK wireless users spend 60.13% of their communications time connected to Wi-Fi networks rather than relying on their cellular data connection.

The important weight of Wi-Fi technology on the digital ecosystem should have a significant contribution on its social and economic benefits. This chapter presents first the summary of results and then reviews each of the particular effects. The methodology reviewed in chapter III was utilized to calculate the economic value of Wi-Fi in the United Kingdom. Please refer to chapter III for detailed descriptions of each economic factor.

V.1. Total economic value (2018 and 2023)

The total economic value of Wi-Fi in the United Kingdom in 2018 amounts to $ 54.48 billion, which is roughly equivalent to the GDP of Belarus[45]. This amount breaks down in $ 52.96 billion in economic surplus and $ 1.52 billion in contribution to the GDP (see table V-1).

Table V-1. United Kingdom: Total Economic Value of Wi-Fi (2018) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 268	N.A.	$ 268	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 3,286	N.A.	$ 3,286	N.A.
	2.2. Inside wiring avoidance	$ 22,600	N.A.	$ 22,600	N.A.
	Subtotal	$ 25,886	N.A.	$ 25,886	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 2,711	$ 2,711	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 8,588	$ 8,588	N.A.
	Subtotal	N.A.	$ 11,299	$ 11,299	
4. Value of cellular off-loading		N.A.	$ 6,842	$ 6,842	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 4,332	$ 4,332	$ 8,664	N.A.
	5.2. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 4,332	$ 4,332	$ 8,664	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 295
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 1,001
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 224
TOTAL		$ 30,486	$ 22,473	$ 52,959	$ 1,520

Source: Telecom Advisory Services analysis

The key sources of Wi-Fi economic value are residential use ($ 25.89 billion in consumer surplus) and cellular rerouting ($ 6.84 billion). Beyond this, the value of Wi-Fi enabled equipment (wireless speakers, security systems, etc.) has a significant impact in terms of economic surplus ($ 8.66 billion).

[44] OpenSignal. *Global State of Mobile Networks* (August 2016).

[45] Source: International Monetary Fund (2017).

A 2023 forecast of the same value will reach $ 71.23 billion, composed of $ 70.15 billion in economic surplus, and $ 1.08 billion in GDP contribution (see table V-2).

Table V-2. United Kingdom: Total Economic Value of Wi-Fi (2023) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 253	N.A.	$ 253	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 8,585	N.A.	$ 8,585	N.A.
	2.2. Inside wiring avoidance	$ 25,970	N.A.	$ 25,970	N.A.
	Subtotal	$ 34,555	N.A.	$ 34,555	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 4,220	$ 4,220	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 10,808	$ 10,808	N.A.
	Subtotal	N.A.	$ 15,028	$ 15,028	
4. Value of cellular off-loading		N.A.	$ 8,118	$ 8,118	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 6,100	$ 6,100	$ 12,200	N.A.
	5.3. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 6,100	$ 6,100	$ 12,200	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 486
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 184
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 411
TOTAL		$ 40,908	$ 29,246	$ 70,154	$ 1,081

Source: Telecom Advisory Services analysis

The relative importance of sources of economic value by 2023 remains the same as in 2018. Residential Wi-Fi usage remains the largest source of economic value ($ 34.55 billion), followed by enterprise use ($ 15.03 billion) and cellular carrier rerouting ($ 8.12 billion).

V.2. Free Wi-Fi traffic

One dimension of Wi-Fi's economic value is derived from savings consumers receive by accessing the Internet through no cost sites (in retail shops, cafes, etc.) rather than relying on their cellular data plan. The following section presents the quantification of such benefit.

Total Internet traffic in the United Kingdom is growing at 23.78 %, while mobile Internet traffic has been growing in excess of 38 % per annum, indicating a growing share of wireless (increasing from 3.43 % to 4.48 % in three years) as indicated in Table V-3.

Table V-3. United Kingdom: Internet Traffic (2016-2018)
(In exabytes[46] per month)

	2016	2017	2018	CAGR
Total Internet	3.20	3.96	4.90	23.78 %
Wireless Internet	0.11	0.16	0.22	38.45 %

Source: Cisco; Telecom Advisory Services analysis

The growing adoption of wireless data-enabled devices (smartphones, tablets, PCs) combined with an increase in usage per device has driven overall traffic growth. The installed base of smartphones reached 62.63 million in 2018, while this number amounted to 27.54 million for

[46] 1 Exabyte equals 1,073,741,824 gigabytes.

tablets. On the other hand, the number of laptops declined from 47.00 in 2016 to 44.80 in 2018 (2016-18 CAGR: -2.36%[47]) due to smartphone substitution[48] (see table V-4).

Table V-4. United Kingdom: Device Installed Base and Penetration (2016-2018)

Device	Metrics	2016	2017	2018 (E)	CAGR
Smartphones	Units (in millions)	56.60	59.54	62.63	5.19%
	Penetration (%)	85.78%	89.70%	93.80%	4.57%
Tablets	Units (in millions)	28.40	27.97	27.54	-1.52%
	Penetration (%)	43.04%	42.13%	41.25%	-2.10%
Laptops	Units (in millions)	47.00	45.89	44.80	-2.36%
	Penetration (%)	71.23%	69.13%	67.11%	-2.94%

Sources: Cisco; GSMA Intelligence; Telecom Advisory Services analysis

Beyond the laptop and tablet substitution, the installed base of smartphones has shifted to 4G (LTE) network standards that provide faster speed of access and, consequently, stimulate more intense data usage. Looking forward, it is projected that the average speed of mobile devices by 2023 would have more than double from the current 19.27 Mbps to 40.56 Mbps.

Adding to the proliferation of devices, traffic per device has grown between 12.41% per annum for laptops and 36.23% for smartphones driven by increased applications and content availability (see table V-5).

Table V-5. United Kingdom: Average Traffic Per Device (2016-2018) (In Gigabytes per month)

	2016	2017	2018 (E)	CAGR
Smartphones	3.900	5.31	7.24	36.23%
Tablets	13.30	17.03	21.81	28.06%
Laptops	43.80	49.23	55.34	12.41%

Source: Cisco VNI; Telecom Advisory Services analysis

It is interesting to note that, with the exception of smartphones, traffic per device in the United States by 2018 is roughly aligned with that of the United Kingdom. That being said, the growth rate for traffic per smartphone in the United Kingdom is higher than that of the United States, indicating a process of gradual convergence.

Based on the installed base and average data usage per device, total mobile Internet traffic in the United Kingdom was calculated for the next five years. We estimate a total traffic of 1.11 Exabytes per month in 2023. Projections regarding traffic growth from other sources vary, although they all agree directionally (see table V-6).

Table V-6. United Kingdom: Mobile Internet Traffic (2018-2023) (in million Exabytes per month)

	2018	2019	2020	2021	2022	2023	CAGR
Total Internet	4.90	6.07	7.51	9.30	11.51	14.25	23.78%
Mobile Internet	0.22	0.30	0.42	0.58	0.80	1.11	38.45%

Source: Cisco; Telecom Advisory Services analysis

[47] Note than the laptop installed base in the United States is still growing, albeit at only 3.90% (see chapter IV).
[48] Notice also the decline in the tablet installed base.

This growth has and will continue to put pressure on the public cellular networks to accommodate the traffic without incurring congestion while generating acceptable levels of revenue. This prompts the communications system to rely on Wi-Fi to handle a portion of the traffic. We will now estimate the portion of traffic that is off-loaded to Wi-Fi.

Juniper Research estimates that up to 60% of mobile data traffic will be offloaded to Wi-Fi by 2019 in Western Europe[49]. iPass reports that there are 13.9 million Wi-Fi hotspots in the United Kingdom, of which 212,722 are operated by mobile network operators. O2 launched its Wi-Fi offloading network in 2013, while Vodafone relies on BT Wi-Fi for offloading its traffic.

By applying a 58% off-loading factor to the total mobile data traffic, we estimate that total Wi-Fi traffic in the United Kingdom is currently 1.62 Exabytes per month, reflecting a 15.05% growth rate (see table V-7).

Table V-7. United Kingdom: Total Wi-Fi Traffic Per Device (2016-2018) (In Exabytes per month)

	2016	2017	2018(E)	CAGR
Smartphones	0.11	0.16	0.22	42.55%
Tablets	0.21	0.22	0.28	25.59%
Laptops	0.94	1.03	1.12	9.30%
Total	1.22	1.40	1.62	15.05%

Source: Telecom Advisory Services analysis

The estimation of consumer surplus is conducted by multiplying the total Wi-Fi traffic from table V-7 by the portion representing the "true free traffic" generated in public sites. Again, precise estimates for this value are non-existent for the United Kingdom. However, it has estimated that there are 13.5 million community Wi-Fi access points in the country[50]. Considering that statistics for the United States indicate 4.32% of Wi-Fi traffic to be "free", we opted to stay within the conservative side, and utilize this value (see table V-8).

Table V-8. United Kingdom: Total Free Wi-Fi Traffic (2016-2018)

	2016	2017	2018(E)
Total Wi-Fi Traffic	1.22	1.40	1.62
Total Free Traffic (in Exabytes per month)	0.05	0.06	0.07
Total Free Traffic (in Exabytes per year)	0.63	0.73	0.84
Total Free Traffic (in million Gigabytes per year)	680.19	782.54	900.29

Source: Telecom Advisory Services analysis

We calculated consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we needed an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculated by averaging the most economic "dollar per GB" plan (so-called "unlimited") of four major wireless carriers providing service in the United Kingdom: EE (BT), Vodafone, O2, and 3 (CK Hutchinson) (see table V-9).

[49] Juniper Research. *Wi-Fi to carry up to 60% of Mobile Data Traffic by 2019.*
[50] Source: iPass. *Wi-Fi Growth Map.*

Table V-9. United Kingdom: Average Price Per Gigabyte (2017)

Carrier	Market share	Plan	Price per Gb (Pounds)
EE (BT)	32	EE 4G Multi SIM (Up to 60Mbps, 40 GB data, Unlimited minutes, Unlimited text messages, 12 months plan)	£ 0.55
Vodafone	24	50GB Data SIM plan (50 GB Data, Unlimited minutes, Unlimited texts, Vodafone Global Roaming, 3-month free trial of Secure Net, Your choice of entertainment for 12 months)	£ 0.6
O2 (Telefonica)	30	50GB data (4G) (50Gb, £25.50 for up to 12 months. £30 + RPI after)	£ 0.51
3 (CK Hutchison)	14	The Advanced Plan (100Gb, All-you-can-eat minutes, All-you-can-eat texts, 100GB, Feel At Home Around the World, Go Binge)	£ 0.27
Average			£ 0.51

Note: The average is calculated by prorating every price per GB by the carrier's market share.
Source: Operator websites (December 2017); Telecom Advisory Services analysis

Since the assessment of economic value is done in US dollars, the average price per GB is converted to $ 0.67. Historical data compiled for the US market allowed for projecting the future price per Gigabyte (see figure III-1 in chapter III).

According to these projections, while the average price per GB in 2017 is $ 0.67, it is estimated that by 2023, it will reach an estimated $0.36. As to the cost of offering the service through Wi-Fi, this would include an additional router and needed bandwidth. For estimation purposes, we assume those costs to be 45% of the cost of offering the same GB via cellular networks[51]. This means that the cost per Gigabyte offered by the site providing the service for free would be $0.30 in 2017, declining to $0.24 in 2023. By relying on the total free Wi-Fi traffic shown in table VII-8 and the average price per cellular Gigabyte minus the cost of provisioning free Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic (see table V-10).

Table V-10. United Kingdom: Consumer Surplus of Free Wi-Fi Traffic (2018-2023)

	2018	2019	2020	2021	2022	2023
Total Free Traffic (in million Gigabytes per year)	900.29	1050.98	1232.24	1458.42	1742.91	2103.28
Price per cellular gigabyte ($)	$ 0.60	$ 0.54	$ 0.49	$ 0.44	$ 0.40	$ 0.36
Cost per Wi-Fi provisioning ($)	$ 0.30	$ 0.29	$ 0.28	$ 0.26	$ 0.25	$ 0.24
Consumer surplus per Gigabyte ($)	$ 0.30	$ 0.25	$ 0.21	$ 0.18	$ 0.15	$ 0.12
Total Consumer surplus (in $ million)	$ 268	$ 266	$ 263	$ 260	$ 257	$ 253

Source: Telecom Advisory Services analysis

As indicated in table V-10, consumer surplus of free Wi-Fi traffic in 2018 would reach an estimated $ 268 million and $ 253 million in 2023. The declining surplus results from a decreasing difference between paid cellular access and cost of provisioning free access.

V.3. Value of Residential Wi-Fi

The value of residential Wi-Fi is a combination of Internet access for home usage and avoidance of in-house wiring.

V.3.1. Home Internet access for devices that lack an Ethernet port

As mentioned in Chapter III, the underlying assumption of this analysis is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on the cellular network to

[51] This is relationship found in the case of the United States (see chapter IV).

access the Internet. As a consequence, estimating value of home access requires first to measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers.

Based on our traffic model, the total traffic generated by these types of devices in 2018 in United Kingdom amounts to 12,648 million Gigabytes, reaching 55,862 million Gigabytes by 2023 (see table V-11).

Table V-11. United Kingdom: Total Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	2,649	3,796	5,440	7,795	11,171	16,009	22,941	32,876
Tablets	4,533	5,716	7,208	9,090	11,462	14,454	18,228	22,986
Total	7,182	9,512	12,648	16,885	22,633	30,463	41,169	55,862

Source: Cisco; GSMA; analysis Telecom Advisory Services

A portion of this traffic is, as expected, generated while the subscriber is in his residence, relying on the Wi-Fi service. According to a Cisco study conducted in 2012[52], 43.12% of use time of devices that lack a wired port occurs at home. While we consider that the estimate is from the United States and time has passed since the Cisco study, we opt to rely on the in-home usage of 43.12%. Therefore, the portion of said traffic generated at home reached 5,453 million Gigabytes in 2018 and is expected to amount for 24,086 million Gigabytes in 2023 (see table V-12).

Table V-12. United Kingdom: Annual Home Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	1,142	1,637	2,345	3,361	4,817	6,903	9,892	14,175
Tablets	1,954	2,464	3,108	3,919	4,942	6,232	7,859	9,911
Total	3,096	4,101	5,453	7,280	9,759	13,135	17,751	24,086

Source: Cisco; GSMA; analysis Telecom Advisory Services

If this traffic had to be transported by cellular networks, at the average price per GB estimated in the model of table V-9, it would result in costs of $3,286 million in 2018 and $8,585 million in 2023.

V.3.2. Avoidance of investment in in-house wiring

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in a residence in the United Kingdom reaches approximately $ 980 per household[53].

In order to estimate the benefit derived from wiring avoidance, the number of total Wi-Fi households in the United Kingdom is required. Strategy Analytics reported that in 2012, 75% of

[52] Cisco IBSG (2012)

[53] Our sources indicate two price points for wiring a residence with CAT 5 wire in Germany: € 2,500 and € 1,200. We opted for the lower estimate, although it is important to note the significant difference with US prices (Germany: $ 1,390 at current exchange rate versus US: $ 660, as reported in chapter IV).

British households were equipped with Wi-Fi[54], out of total universe of broadband Internet households of 80%[55]. Considering that broadband households have reached 90% in 2017[56], we estimate Wi-Fi households to amount to 85% in 2018, reaching 95% by 2023.

Considering that 85% of UK households currently have Wi-Fi[57], the avoidance cost of inside wiring for 23.6 million households, which in the absence of Wi-Fi, yields a total cost of wiring of $ 22,600 million. By 2023, with 95% of households having adopted Wi-Fi, the savings would have reached $25,970 million[58].

V.4. Enterprise Wi-Fi

As stated in chapter III, the economic value of enterprise Wi-Fi has two sources:

- Business traffic routed through Wi-Fi access points rather than cellular networks;
- Avoidance of capital investment to deploy Ethernet wiring inside enterprise establishments to connect devices and peripherals.

V.4.1. Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. Cisco VNI and Telecom Advisory Services analysis estimate that total British business Internet traffic has reached 9.26 billion GB in 2018, of which 4.50 billion are transported through Wi-Fi access points. Considering that the average price per GB transported by cellular is $0.60 (per the analysis presented above), savings from Wi-Fi would have reached $ 2.71 billion, an addition to the producer surplus. By 2023, this benefit will reach $ 4.22 billion (see table V-13).

Table V-13. United Kingdom: Savings in business wireless traffic (2016-2023)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Share of Business Internet Traffic by Wi-Fi	49.00%	48.80%	48.60%	48.40%	48.20%	48.00%	47.80%	47.61%
Total Business Internet Traffic (million Gb)	6,236	7,599	9,259	11,282	13,747	16,750	20,410	24,869
Total Business Wi-Fi enterprise traffic (million Gb)	3,056	3,708	4,500	5,460	6,626	8,040	9,756	11,839
Average Price per Gb	$0.67	$0.67	$0.60	$0.54	$0.49	$0.44	$0.40	$0.36
Economic Impact (in million $)	$ 2,045	$ 2,482	$ 2,711	$ 2,962	$ 3,236	$ 3,536	$ 3,863	$ 4,220

Source: Cisco; analysis Telecom Advisory Services

V.4.2. Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points, and multiply this value by a standard cost of deploying a CAT 6 network with 42 sockets (average for a small office): GBP 2,350 (or $ 3,072).

[54] Burger, A. (2012) "Wi-Fi households to approach 800 million by 2016", *Telecompetitor*
[55] Office for National Statistics. *Internet access – households and individuals: 2012*.
[56] Office for National Statistics. *Internet access – households and individuals: 2017*.
[57] Source: Watkins, David. *Broadband and Wi-Fi Households Global Forecast 2012*. Strategy Analytics
[58] This assumes that inside wiring costs will remain constant.

Assuming all 2,795,647 business establishments in the United Kingdom[59] are utilizing Wi-Fi which therefore allows them to save in wiring costs and that number is expected to remain stable, the savings resulting from avoiding inside wiring amounts to $ 8,588 million, which is expected to increase to $ 10,808 million by 2023.

V.5. Cellular off-loading

The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks.

This analysis starts with the predicted incremental wireless data traffic generated between 2018 and 2023. According to the traffic forecast presented in table V-6 above, future monthly wireless data traffic in the United Kingdom amounts to 0.22 Exabytes per month in 2018 and will reach 1.11 Exabytes per month in 2023. Until 2020, when 5G deployment is expected to launch, this traffic should be handled through a combination of 3G and primarily 4G.

It is obvious that a cellular-only network does not economically handle all this traffic. So far, the available statistics indicate that all three wireless carriers operating in the United Kingdom have, to different degrees, deployed an important number of carrier grade Wi-Fi sites. Due to their relative economic advantage relative to cellular base stations, carrier grade Wi-Fi deployment allows wireless operators to save both on CAPEX and OPEX. While the economic advantage of Wi-Fi off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are considerably less expensive than cellular network equipment with similar capacity. For example, a cellular pico-cell (needed to offer access via conventional cellular service) costs between $7,500 and $15,000[60], while a carrier-grade Wi-Fi access point requires an investment of $2,500[61]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table V-14).

Table V-14. Comparative Carrier Grade Wi-Fi and LTE Macro Cell CAPEX and OPEX

	Wi-Fi Site	LTE Macro Cell
New Site acquisition	$ 600	$ 150,000
Collocation	-	$ 50,000
Backhaul	$ 300	$ 5,000
Monthly site rental	$ 20	$ 1,000
Site maintenance/month	$ 10	$ 200

Source: LCC Wireless (2012)

As it can be seen, Wi-Fi has significant economic advantages at the unit level. However, we must add a caveat here. Site density requirements for Wi-Fi are much higher than for cellular. For example, in a dense urban environment with high traffic, for each cellular site, 23 Wi-Fi hotspots are required. The difference means that, from a Total Cost of Ownership (CAPEX and OPEX) standpoint, the driver that erodes some of the Wi-Fi economic advantage is OPEX, especially Wi-Fi site rental and backhaul costs. Along these lines, for the carrier-class Wi-Fi off-loading to materialize, site deployment needs to be managed on a case-by-case basis, by surgically placing sites primarily in high traffic areas.

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[59] Source: https://www.ons.gov.uk/businessindustryandtrade/business/activitysizeandlocation
[60] "When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.
[61] Cisco Aironet 1552H Wireless Access Point.

In a prior report by this author[62], a simulation was presented to determine the economic advantage of relying on carrier-grade Wi-Fi sites to complement the deployment of LTE in the United States. According to Thanki (2012), achieving full LTE coverage in the United States relying on 2100 MHz to accommodate incremental wireless data traffic would require approximately 34,000 new base stations[63], representing a total capital investment of $ 8.5 billion. On two simulation cases of off-loading in New York and San Diego, LCC Wireless assumed a CAPEX benefit of Wi-Fi off-loading ranging between 22.3 % and 44.7 %. When averaging these two estimates, the CAPEX reduction would amount to $2.76 billion. Even under the OPEX considerations mentioned above, the Total Cost of Ownership remains lower under the Wi-Fi off-loading scenario (see table V-15).

Table V-15. Total Cost of Ownership of LTE only versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
Total Cost of Ownership	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) OPEX to CAPEX ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

According to the simulation run for the United States, presented in table IV-15, Wi-Fi carrier grade yields economic savings for a carrier of 18.71%.

Now, let's turn to the British situation. According to GSMA intelligence, as of 2018 4G coverage has reached 99%. Considering that 5G is not expected to launch before 2020, it is reasonable to assume that the 2018 CAPEX is benefitting from a proportion of the network infrastructure being deployed in terms of Wi-Fi sites. In 2018, total CAPEX of wireless operators in the United Kingdom is estimated by GSMA Intelligence to be $ 3.65 billion. If this number already factors in the savings derived from deploying Wi-Fi sites, it would then mean that the CAPEX savings resulting from deploying carrier-grade Wi-Fi as a complement to cellular base stations for the rollout of LTE to accommodate traffic growth in 2018 in the United Kingdom would amount to $ 1.79 billion[64]. This amount does not include the CAPEX saved by traffic off-loading to residential and business Wi-Fi networks[65]. In addition to the CAPEX driven savings, one would have to add the OPEX in order to understand total producer surplus. According to table VII-17, each $1 billion in CAPEX savings triggers $2.82 billion in OPEX. As a result, total 2018 producer surplus in 2018 triggered by Wi-Fi carrier grade rollout amounts to $ 6.84 billion.

Moving on to estimating the value in 2023, 5G deployment will increase the value of cellular re-routing. Given current announcements and trials, it is expected that carriers operating in the United Kingdom will begin investing to deploy 5G in 2020 (see table V-16).

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[62] Katz, R. (2018). A 2017 *Assessment of the current and future economic value of unlicensed spectrum in the United States*. Washington, DC: Wi-Fi Forward.
[63] This model was adapted by the author from Ofcom, the UK regulator, to assess the effect of differing traffic levels on cell site numbers in urban areas in its consultation "Application of spectrum liberalization and trading to the mobile sector" (Ofcom, 2009).
[64] CAPEX without Wi-Fi – (CAPEX without Wi-Fi * .329) = $ 3,295 million or
$ 4,910 million – 4,910*.329) = $ 3,295 million
[65] See Cooper (2012).

Table V-16. United Kingdom: Deployment of 5G

	2020	2021	2022	2023
5G Coverage	57.78 %	75.73 %	83.34 %	83.34 %

Source: GSMA Intelligence

For purposes of this analysis, it is assumed that all the CAPEX invested in 2022 in the United Kingdom would be dedicated to 5G deployment. In this context, Wi-Fi becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands. To calculate the economic value of Wi-Fi in this context, we rely on the cost estimation of 5G developed by Oughton and Frias (2016) for OFCOM in the United Kingdom. The authors' baseline case estimates a CAPEX of £42 billion, of which urban coverage investment amounts only to £700 million, while suburban deployment demands £5.6 billion, and rural coverage £35.6 billion. We have used Oughton and Frias (2016) and broke down by year, based on the coverage statistics provided in table V-16 (see Table V-17).

Table V-17. United Kingdom: 5G Investment

Year	Coverage (%)	5G CAPEX (In US$ millions)
2020	57.78%	$ 32,899
2021	75.73%	$10,220
2022	83.34%	$ 4,333
2023	100%	$56.803

Sources: Oughton and Frias (2016); GSMA Intelligence; Telecom Advisory Services analysis

Considering that the total CAPEX required to deploy 5G in the United Kingdom would be $56,803, and that the incremental 5G coverage between 2021 and 2022 would be 11.6%, it is assumed that the 5G CAPEX in that year will be $ 4.33 billion. Considering that this amount reflects the saving incurred by relying on Wi-Fi sites, and applying the same approach as used in 2018, would result in a total producer surplus (adding CAPEX and OPEX savings) of $ 8.12 billion.

V.6. Locally manufactured Wi-Fi enabled equipment

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. It is assumed that the consumer surplus is roughly equal to consumer surplus (see Milgrom et al., 2011). Both consumer products and enterprise equipment are considered as part of the economic surplus generated by locally manufactured Wi-Fi enabled devices.

V.6.1. Consumer products

As detailed in section III.3.5, we identified seven consumers products which are intrinsically linked to Wi-Fi: Wi-Fi enabled wireless speakers, home security systems, home networking systems (such Apple's HomePod, Amazon Echo, and Google Home), access points[66], external

[66] Access points (APs) allow devices to connect to a wireless network.

adapters[67], routers, and gateways. As conducted in the case of the United States, our focus is to estimate economic surplus in the United Kingdom, based by revenues of UK manufacturers for each product.

In the case of access points, external adapters, routers and gateways, data indicates that the major global players are the US, Chinese, and Taiwanese manufacturers (see table V-18).

Table V-18. Consumer products: Global Market shares (2018)

Product	Market (in millions)	United States	United Kingdom	Germany	South Korea	France	Japan	China	Taiwan	ROW
Access points	$ 11,631	0.2 %	0.0%	0.0%	0.0%	13.5%	0.0%	69.1%	7.7%	9.5
External adapters	$ 465.92	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	42.1%	9.7%	41.0%
Routers	$ 4,972.30	5.9%	0.0%	0.0%	0.0%	6.7%	0.0%	52.6%	15.5%	19.3%
Gateways	$ 6,389.25	6.6%	0.0%	0.0%	0.0%	29.0%	0.0%	38.1%	10.3%	16.0%

Sources: ABI Research; Telecom Advisory Services analysis

Therefore, no economic value was associated to these products.

On the other hand, the markets for wireless speakers, home security systems, and home networking systems is served by firms like Armstrong Audio, Bowers & Wilkins, Castle, Celestion, Gale, Martin Audio, Frontier Silicon for speakers, British Security Technologies, and Verisure for home security, and Dyson Technologies for home networking systems. In the absence of market estimates, we opted to estimate the British market by prorating it against the US market for which statistics are abundant. As a result, the market estimates for the United Kingdom are as follows (see table V-19).

Table V-19. United Kingdom: Consumer Electronics market (in $ million) (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Wireless speakers	$ 4,614	$ 5,827	$ 8,344	$ 8,893	$ 9,513	$ 10,193	$ 10,969	$ 11,798
Home security systems	$ 661	$ 638	$ 700	$ 706	$ 715	$ 725	$ 738	$ 752
Home networking equipment	$ 360	$ 475	$ 711	$ 783	$ 865	$ 958	$ 1,066	$ 1,185

Sources: Consumer Technology Association; Telecom Advisory Services analysis

Of these amounts, the prorated profit margin estimated by CSI markets is 44.41%, which yields a producer surplus for these particular products of $ 4.33 billion. Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic surplus in 2018 would amount to $ 8.66 billion and would reach $ 12.20 billion in 2023.

V.6.2. Enterprise products

In the case of enterprise Wi-Fi enabled products, the United Kingdom is not included among the main manufacturing countries (see table V-20).

[67] Wireless client device. It can be PCI adapter, which A PCI wireless adapter card is a device that is connected to a desktop computer's PCI bus to provide wireless capability to the desktop, a PC card, or a USB adapter.

Table V-20. Enterprise products: Global Market shares (2018)

Product	Market (in millions)	United States	China	ROW
Access points	$ 5,398	81.3 %	16.8 %	1.9 %
Controllers	$ 1,025	67.3 %	19.9 %	12.8 %

Sources: ABI Research; Telecom Advisory Services analysis

As a result, Wi-Fi enabled enterprise products was not included as a source of economic value.

V.7. Bridging the digital divide

The digital divide is defined as the gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory).

This analysis assumes that Wi-Fi enabled ISPs would be the primary approach for addressing broadband demand in rural areas. Along these lines, it is considered that the incremental penetration in broadband subscribers will have an impact on the economy according to a coefficient estimated through regression models that links the increase in broadband lines to economic growth (see table V-21).

Table V-21. United Kingdom: GDP Contribution resulting from reduction of the digital divide

	2016	2017	2018	2019	2020	2021	2022	2023
WISP subscribers (million)	0.25	0.30	0.33	0.35	0.38	0.41	0.45	0.48
Total Broadband Subscribers (million)	25.15	25.66	26.19	26.72	27.26	27.81	28.38	28.96
Households (million)	26.83	26.98	27.13	27.28	27.43	27.59	27.74	27.89
Adoption WISP (million)	0.00%	1.12%	1.21%	1.30%	1.39%	1.50%	1.61%	1.73%
Adoption broadband	93.75%	95.12%	96.52%	97.93%	99.37%	99.47%	99.58%	99.70%
WISP additional	0.00%	1.18%	1.25%	1.32%	1.40%	1.50%	1.61%	1.73%
Impact coefficient	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
GDP per capita	$ 40,530	$ 39,735	$ 44,177	$ 45,217	$ 46,462	$ 47,827	$ 49,452	$ 51,114
Population (million)	65.98	66.38	66.77	67.15	67.52	67.88	68.23	68.57
Indirect Impact on GDP (in $ billion)	$ 0.00	$ 0.250	$ 0.295	$ 0.322	$ 0.352	$ 0.391	$ 0.436	$ 0.486

Sources: UKWISPA (2018); Thomson and Garbacz (2008); Telecom Advisory Services analysis

Based on these calculations, Wi-Fi's contribution to GDP by reducing the digital divide in the United Kingdom would amount to $0.295 billion in 2018 and $0.486 billion in 2023.

V.8. Wi-Fi return to speed

Since Wi-Fi accessibility allows, in general, faster access to the Internet than cellular networks do, higher speeds have a positive contribution on the economy in terms of increased overall efficiency and innovation. This contribution is measured in terms of economic growth.

We start with the quantification of speed differentials for the United Kingdom, which we calculate by subtracting the weighted average of Wi-Fi and cellular speeds (averaged according to traffic off-loading factors) and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (see table V-22).

Table V-22. United Kingdom: Estimation of speed differential for total US traffic (in Mbps)

	2016	2017	2018	2019	2020	2021	2022	2023
Average speed of cellular networks	13.19	15.94	19.27	23.28	28.14	34.00	37.14	40.56
Average Wi-Fi speed	23.80	26.00	28.39	31.01	33.87	37.00	40.41	44.14
Average speed of weighted average of cellular and Wi-Fi traffic	22.89	24.98	27.31	29.95	32.96	36.46	39.74	43.33
Speed decrease (average speed of cellular/average weighted average speed)	-42.37%	-36.18%	-29.45%	-22.25%	-14.64%	-6.74%	-6.56%	-6.38%

Source: Cisco; TAS analysis

Having calculated the speed decrease percentage, we then apply this percentage to the coefficient derived from the model developed by Bohlin et al. (2011 and 2013) to gauge the potential impact on GDP if cellular networks transported all traffic (see table V-23).

Table V-23. Econometric model measuring the impact of broadband speed on GDP

Independent Variables	Coefficient
Average GDP growth (2008-2010)	0.577 *
Population density	-0.0441 *
Urban population	-0.0103 **
Labor force growth (%)	0.0492 *
Telecom revenue growth (%)	0.0492 *
Population growth (%)	-0.630 **
Average achieved downlink speed	-0.00214
Average achieved downlink speed squared	0.00142 *

*, ** significant at 1% and 5% critical value respectively
Source: Rohman and Bohlin (2011)

As table V-23 shows, by incorporating the elasticity of the coefficient of broadband speed and the square of the variable, the model assumes that the doubling of broadband speed causes a 0.3% increase in GDP growth. Our case shows the GDP impact on the **decrease** in speed. This is applied in turn to the British GDP at current prices (see table V-24).

Table V-24. United Kingdom: Broadband speed impact on GDP

	2016	2017	2018	2019	2020	2021	2022	2023
Speed decrease (%)	-42.37%	-36.18%	-29.45%	-22.25%	-14.64%	-6.74%	-6.56%	-6.38%
Model coefficient	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%
Decrease in GDP per capita	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%
GDP per capita (current prices)	40,529	39,734	44,177	45,217	46,462	47,827	49,451	51,114
Wi-Fi Traffic (% Total Traffic)	46.72%	42.36%	38.42%	35.36%	32.70%	30.52%	28.76%	27.37%
GDP Reduction (in $ millions, current prices)	-1,588	-1,213	-1,001	-717	-450	-200	-191	-184

Source: Cisco; TAS analysis

Table V-24 indicates that if all cellular data traffic that is currently being off-loaded to Wi-Fi were to shift to cellular networks, the reduction in speed would have a $1.00 billion impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data. In 2023, the amount would reach $184 million. The reduction in economic value is explained by a gradual closing of the speed gap between cellular networks and Wi-Fi in the United Kingdom.

V.9. Revenues of Wireless ISPs and Wi-Fi service providers

Wi-Fi off-loading can create new business opportunities for service providers offering wireless broadband services in public places (airports, hotels) for a fee. In addition to this segment, Wireless Internet Service Providers (WISPs) rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas. While some WISPs utilize licensed spectrum, the majority relies on unlicensed Wi-Fi spectrum.

The most straightforward way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in the United Kingdom. According to UKWISP, the fixed wireless operators association, estimates that these carriers serve over 2 million households, and accounted as of December 2017 303,490 subscribers[68]. Assuming a broadband ARPU of 41.7 GBP[69], results in 2017 overall industry revenues of $ 198.57 million and $224.13 million in 2018, reaching $410.62 million in 2023.

V.10. Wi-Fi contribution to employment

The estimation of employment generated is calculated by relying on the total GDP contribution resulting from the effects analyzed above and using that as an input in the communications sector of an input-output matrix of the UK economy. Table V-26 presents the GDP contribution of each of the effects analyzed above.

Table V-26. United Kingdom: Total GDP Contribution of Wi-Fi (in $ billion)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$ 0.30	$ 0.32	$ 0.35	$ 0.39	$ 0.44	$ 0.49
Return to speed	$ 1.00	$ 0.72	$ 0.45	$ 0.20	$ 0.19	$ 0.18
WISPs	$ 0.22	$ 0.25	$ 0.29	$ 0.32	$ 0.36	$ 0.41
Total	$1.52	$1.29	$1.09	$0.91	$0.99	$1.08

Source: Telecom Advisory Services analysis

These inputs generate the following annual employment effects based on the I-O matrix for the UK economy (table V-27).

Table V-27. United Kingdom: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	14,379	10,217
Indirect jobs	2,205	1,567
Induced jobs	722	512
Total	17,306	12,296

Source: Telecom Advisory Services analysis

According to the contribution to the GDP, Wi-Fi is generating approximately 17,000 jobs in 2018 and is expected to generate more than 12,000 in 2023. Job estimates include direct jobs (those jobs created by the specific Wi-Fi contribution), indirect jobs (those jobs created by suppliers to the Wi-Fi sector); induced jobs (those jobs created by spending of direct and indirect workers).

The sector breakdown of 2018 employment is as follows (table V-28).

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[68] Point Topic. *Supporting broadband services – the spread of technologies* (March 2018).

[69] Statista. *Consumer ARPU of BT (4th Q of 2017/18).*

Table V-28. United Kingdom: Sector Breakdown of Wi-Fi generated annual employment (2018)

Sector	Direct	Indirect	Induced	Total
Agriculture	0	0	14	14
Extractive industries	0	24	16	40
Manufacturing	0	76	11	87
Construction	0	221	0	221
Trade	0	191	191	382
Transportation	0	36	321	357
Communications	14,379	0	0	14,379
Financial Services	0	56	0	56
Business services	0	1,241	0	1,241
Other services	0	360	169	529
TOTAL	14,379	2,205	722	17,306

Source: Telecom Advisory Services analysis

VI. ECONOMIC VALUE OF WI-FI IN FRANCE

Wi-Fi has become a pervasive feature in the French telecommunications landscape. According to the iPass Wi-Fi Growth Map, there are currently 129,777 commercial hotspots and 23,536,080 community access points operating in the French territory. Given the Wi-Fi access point density, hotspots have become a very important connectivity feature. According to OpenSignal[70], French wireless users spend 47.54% of their communications time connected to Wi-Fi networks rather than relying on their cellular data connection. The intensive reliance on Wi-Fi technology should have a significant impact on its social and economic benefits.

The methodology reviewed in chapter III was utilized to calculate the economic value of Wi-Fi in France. This chapter presents first the summary of results and then reviews each of the particular effects. Please refer to chapter III for detailed descriptions of each economic factor.

VI.1. Total economic value (2018 and 2023)

The total economic value of Wi-Fi in France in 2018 amounts to $ 44.23 billion, which is roughly equivalent to the GDP of Slovenia[71]. This is comprised of $ 40.35 billion in economic surplus and $ 3.88 billion in contribution to the GDP (see table VI-1).

Table VI-1. France: Total Economic Value of Wi-Fi (2018) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 114	N.A.	$ 114	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 1,184	N.A.	$ 1,184	N.A.
	2.2. Inside wiring avoidance	$ 12,973	N.A.	$ 12,973	N.A.
	Subtotal	$ 14,157	N.A.	$ 14,157	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 1,094	$ 1,094	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 5,028	$ 5,028	N.A.
	Subtotal	N.A.	$ 6,122	$ 6,122	
4. Value of cellular re-routing		N.A.	$ 7,401	$ 7,401	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 6,277	$ 6,277	$ 12,554	N.A.
	5.2. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 6,277	$ 6,277	$ 12,554	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 3,384
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 14
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 489
TOTAL		$ 20,548	$ 19,800	$ 40,348	$ 3,887

Source: Telecom Advisory Services analysis

The key sources of Wi-Fi economic value are residential use ($ 14.16 billion in consumer surplus) and locally manufactured consumer devices ($ 12.55 billion).

A 2023 forecast of economic value estimates this to attain $ 63.93 billion, composed of $ 57.90 billion in economic surplus, and $ 6.03 billion in GDP contribution (see table VI-2).

[70] OpenSignal. *Global State of Mobile Networks* (August 2016).
[71] Source: International Monetary Fund (2017).

Table VI-2. France: Total Economic Value of Wi-Fi (2023) (in US$ millions)

Effect	Component	Economic Surplus: Consumer surplus	Economic Surplus: Producer surplus	Economic Surplus: Total	GDP Contribution
1. Value of free Wi-Fi		$ 121	N.A.	$ 121	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 5,124	N.A.	$ 5,124	N.A.
	2.2. Inside wiring avoidance	$ 14,912	N.A.	$ 14,912	N.A.
	Subtotal	$ 20,036	N.A.	$ 20,036	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 2,063	$ 2,063	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 5,028	$ 5,028	N.A.
	Subtotal	N.A.	$ 7,091	$ 7,091	
4. Value of cellular off-loading		N.A.	$ 14,313	$ 14,313	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 8,174	$ 8,174	$ 16,348	N.A.
	5.2. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 8,174	$ 8,174	$ 16,348	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 4,427
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 1
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 1,597
TOTAL		$ 28,331	$ 29,578	$ 57,909	$ 6,025

Source: Telecom Advisory Services analysis

The relative importance of the sources of economic value by 2023 remains the same as in 2018. Residential Wi-Fi usage is still the largest driver of economic benefit ($20.03 billion), followed by locally manufactured consumer devices ($16.35 billion) and cellular carrier off-loading ($14.31 billion).

VI.2. Free Wi-Fi traffic

One dimension of Wi-Fi's economic value is derived from savings consumers receive by accessing the Internet through no cost sites (in retail shops, cafes, etc.) rather than relying on their cellular data plan. The following section presents the quantification of such benefit.

Total Internet traffic in France is growing at 23.87 %, while mobile Internet traffic has been growing close to 49% per annum, indicating a growing share of wireless (increasing from 4.10% to 5.28% in just three years) as indicated in Table VI-3.

Table VI-3. France: Internet Traffic (2016-2018)
(In exabytes[72] per month)

	2016	2017	2018	CAGR
Total Internet	1.20	1.49	1.84	23.87 %
Wireless Internet	0.09	0.13	0.19	48.53 %

Source: Cisco; Telecom Advisory Services analysis

The growing adoption of wireless data-enabled devices (smartphones, tablets, PCs) combined with an increase in usage per device has driven overall traffic growth. The installed base of smartphones reached 52.69 million in 2018, while this number amounted to 17.83 million for tablets. On the other hand, the number of laptops increased slightly from 39.80 million in 2016

[72] 1 Exabyte equals 1,073,741,824 gigabytes.

to 40.69 million in 2018 (2016-18 CAGR: 1.12%[73]), its growth limited by tablet and, secondarily, smartphone substitution (see table VI-4).

Table VI-4. France: Device Installed Base and Penetration (2016-2018)

Device	Metrics	2016	2017	2018 (E)	CAGR
Smartphones	Units (in millions)	49.63	51.54	52.69	3.04 %
	Penetration (%)	76.53 %	79.17 %	80.62 %	2.64 %
Tablets	Units (in millions)	17.50	17.69	17.83	1.12 %
	Penetration (%)	26.99 %	27.18 %	27.38 %	0.72 %
Laptops	Units (in millions)	39.80	40.24	40.69	1.12 %
	Penetration (%)	61.37 %	61.81 %	62.27 %	0.72 %

Sources: Cisco; GSMA Intelligence; Telecom Advisory Services analysis

Beyond the laptop to tablet substitution, the installed base of smartphones has shifted to 4G (LTE) network standards that provide faster speed of access and, consequently, stimulate more intense data usage. Looking forward, it is projected that the average speed of mobile devices in France by 2023 would have more than double from the current 16.86 Mbps to 36.95 Mbps as a result of 5G deployment[74].

Adding to the proliferation of devices, traffic per device has grown between 10.92% per annum for laptops and 45.83% for smartphones driven by increased applications and content availability (see table VI-5).

Table VI-5. France: Average Traffic Per Device (2016-2018)
(In Gigabytes per month)

	2016	2017	2018 (E)	CAGR
Smartphones	3.70	5.40	7.87	45.83 %
Tablets	4.10	5.64	7.76	37.57 %
Laptops	26.80	29.73	32.97	10.92 %

Source: Cisco VNI; Telecom Advisory Services analysis

It is interesting to note that in smartphones and tablets, traffic per device in the United States by 2018 is around 3 times higher than in France. That being said, the growth rate in traffic for all three devices in France is higher than in the United States, indicating a process of gradual convergence.

With the installed base and average data usage per device, total mobile Internet traffic in France was calculated for the next five years. We estimate a total traffic of 1.39 Exabytes per month in 2023, which are approximately 15 million movies in 4K format (see table VI-6).

Table VI-6. France: Mobile Internet Traffic (2018-2023)
(In million Exabytes per month)

	2018	2019	2020	2021	2022	2023	CAGR
Total Internet	1.84	2.28	2.83	3.50	4.34	5.37	23.87%
Mobile Internet	0.19	0.29	0.42	0.63	0.93	1.39	48.53%

Source: Cisco; Telecom Advisory Services analysis

It should be noted that the growth rate of mobile Internet traffic in France almost doubles that of the total Internet, indicating a growing share of mobile traffic (from 7.58% to 20.26% of total IP).

[73] Note than the laptop installed base in the United States is still growing, albeit at only 3.90% (see chapter IV).
[74] Source: Cisco Visual Networking Index.

Traffic growth has and will continue to put pressure on the public cellular networks to accommodate the traffic without incurring congestion while generating acceptable levels of revenue. This prompts the communications system to rely on Wi-Fi technology to handle a portion of the mobile Internet traffic. We will now estimate the portion of traffic that is off-loaded to Wi-Fi.

No public data exists on the portion of cellular traffic that is off-loaded to Wi-Fi sites in France. While subject matter expert interviews indicate that none of the national wireless carriers operating in France has Wi-Fi off-loading agreements with third parties[75], the off-loading rate reaches approximately 65%[76], combining outdoors and in-home access.

As of 2018, there were 1,052,357 mobile open Wi-Fi hotspots in France (490,000 in Paris, 51,000 in Lyon, 34,000 in Nice, and 29,000 in Marseille, among others)[77]. Usage related information ranges free Wi-Fi access between 1% and 5%, although offloading could be fairly high in certain locations (20% in airports, 50% in hotels). We estimate the free Wi-Fi traffic by multiplying the mid point of the range (2.5%) by the total mobile data traffic, calculating that total free Wi-Fi traffic in France is currently 0.04 Exabytes per month in 2018, somewhat equivalent to 4.5 million movies in 4K format (see table VI-7).

Table VI-7. France: Total Free Wi-Fi Traffic (2016-2018)

	2016	2017	2018
Total Free Traffic (in Exabytes per month)	0.03	0.04	0.04
Total Free Traffic (in Exabytes per year)	0.37	0.44	0.53
Total Free Traffic (in million Gigabytes per year)	396.60	472.28	568.58

Source: Telecom Advisory Services analysis

We calculated consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we needed an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculated by averaging the most economic "dollar per GB" plan (so-called "unlimited") of three major wireless carriers providing service in France: Bouygues Telecom, Orange, and SFR (Altice)[78] (see table VI-8).

Table VI-8. France: Average Price Per Gigabyte (2017)

Carrier	Market share	Plan	Price per Gb (Euros)
Bouygues Telecom	17 %	Plan B & YOU 50Gb	€ 0.50
Orange	37 %	Play 30Go (capped at 30 GB)	€ 0.33
SFR (Altice)	25 %	Power 100Go (100 GB at 4G speed and remained at 3G speed)	€ 0.40
Average			€ 0.39

Note: The average is calculated by prorating every price per GB by the carrier's market share.
Source: Telecom Advisory Services analysis

Since the assessment of economic value is done in US dollars, the average price in Euros per GB is converted to $0.45. Historical data compiled for the US market allowed for projecting the future evolution of price per Gigabyte (see figure IV-1 in chapter IV).

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[75] Interview with Jean-Christophe Budin, Wireless Business Line Director – Hubone, 7/30/18.
[76] Interview with Roland Montagne, IDATE on August 1, 2018.
[77] Wiman (2018). *Map of Free Wi-Fi hotspots in France.*
[78] We could not find a comparable plan for Free Mobile.

According to these projections, while the average price per GB in 2017 is $0.45, it is estimated that by 2023, it will reach an estimated $0.24. As to the cost of offering the service through Wi-Fi, this would include an additional router and needed bandwidth. For estimation purposes, we assume those costs to be 45% of the cost of offering the same GB via cellular networks[79]. This means that the cost per Gigabyte offered by the site providing the service for free would be $0.20 in 2017, declining to $0.16 in 2023. By relying on the total free Wi-Fi traffic shown in table IV-8 and the average price per cellular Gigabyte minus the cost of provisioning free Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic (see table VI-9).

Table VI-9. France: Consumer Surplus of Free Wi-Fi Traffic (2018-2023)

	2018	2019	2020	2021	2022	2023
Total Free Traffic (in million Gigabytes per year)	568.58	694.44	861.77	985.09	1,186.44	1,499.73
Price per cellular gigabyte ($)	$ 0.41	$ 0.36	$ 0.33	$ 0.30	$ 0.27	$ 0.24
Cost per Wi-Fi provisioning ($)	$ 0.20	$ 0.19	$ 0.19	$ 0.18	$ 0.17	$ 0.16
Consumer surplus per Gigabyte ($)	$ 0.20	$ 0.17	$ 0.14	$ 0.12	$ 0.10	$ 0.08
Total Consumer surplus (in $ million)	$114	$118	$124	$118	$118	$121

Source: Telecom Advisory Services analysis

As indicated in table VI-9, consumer surplus of free Wi-Fi traffic in 2018 represents an estimated $ 114 million, reaching $ 121 million in 2023.

VI.3. Value of Residential Wi-Fi

The value of residential Wi-Fi is a combination of Internet access for home usage and avoidance of in-house wiring.

VI.3.1. Home Internet access for devices that lack an Ethernet port

A large portion of Internet access takes place at home. While some devices have the capability to hook-up to an Ethernet socket and then access the wireline network, others (smartphones, and tablets) do not. As mentioned in Chapter III, the underlying assumption of this analysis is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on a wireless network to access the Internet. As a consequence, estimating value of home access requires first to measure the traffic generated by these devices at home and then multiply it by the average price charged by cellular carriers. This will help estimating, as in the case above, the savings incurred by users at home to access the Internet through a combination of Wi-Fi and fixed broadband.

Based on our traffic model, the total traffic generated by smartphones and tablets in 2018 in France amounts to 6,777 million Gigabytes (equivalent to 340 movies streamed), reaching 49,582 million Gigabytes by 2023 (see table VI-10).

[79] This is relationship found in the case of the United States (see chapter IV).

Table VI-10. France: Total Mobile Internet Annual Traffic (2016-2023)
(In million Gigabytes)

	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	2,224	3,372	5,111	7,748	11,744	17,803	26,985	40,905
Tablets	861	1,198	1,666	2,317	3,224	4,484	6,238	8,677
Total	3,085	4,570	6,777	10,065	14,968	22,287	33,223	49,582

Source: Cisco; GSMA; analysis Telecom Advisory Services

A portion of this traffic is, as expected, generated while the subscriber is in his residence, relying on the Wi-Fi service. According to a Cisco study conducted in 2012[80], 43.12% of use time of devices that lack a wired port occurs at home. In the absence of French data on home use, we have relied on the US based estimate. Therefore, the portion of said traffic generated at home reached 2,922 million Gigabytes in 2018 and is expected to reach 21,378 million Gigabytes in 2023 (see table VI-11).

Table VI-11. France: Home Mobile Internet Traffic (2016-2023)
(In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	959	1,454	2,204	3,341	5,064	7,676	11,635	17,637
Tablets	371	516	718	999	1,390	1,934	2,690	3,741
Total	1,330	1,970	2,922	4,340	6,454	9,610	14,325	21,378

Source: Cisco; GSMA; analysis Telecom Advisory Services

If this traffic had to be transported by cellular networks, at the average price per GB estimated in the model reviewed in table VI-8 above, it would result in costs of $1.18 billion in 2018 and $5.12 billion in 2023.

VI.3.2. Avoidance of investment in in-house wiring

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in the average French residence reaches approximately €500 (or $575 per household)[81].

In order to estimate the benefit derived from wiring avoidance, the number of total Wi-Fi households in France is required. Strategy Analytics reported that in 2012, 71.6% of French households were equipped with Wi-Fi[82], out of total universe of broadband Internet households of 86%[83]. Considering that broadband households have reached 92% in 2017, we estimate Wi-Fi households to amount to 83% in 2018, reaching 93% by 2023.

Since 83% of French households currently have Wi-Fi, the avoidance cost of inside wiring for 22.56 million households results in savings of $ 12.97 billion. By 2023, with 93% of households having adopted Wi-Fi, the savings would reach $ 14.91 billion[84].

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[80] Cisco IBSG (2012)
[81] Interview with Roland Montagne, IDATE on August 1, 2018. The equivalent US number is $660.
[82] Burger, A. (2012) "Wi-Fi households to approach 800 million by 2016", *Telecompetitor*
[83] Statista. *Share of households with Internet access in France from 2007 to 2016*.
[84] This assumes that inside wiring costs will remain constant.

VI.4. Enterprise Wi-Fi

As stated in chapter III, the economic value of enterprise Wi-Fi is based on two sources:

- Business traffic routed through Wi-Fi access points rather than cellular networks;
- Avoidance of capital investment to deploy Ethernet wiring inside enterprise establishments to connect devices and peripherals.

VI.4.1. Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. In 2018, Cisco VNI and Telecom Advisory Services analysis estimates that total French business Internet traffic reached 6.14 billion GB, of which 2.70 billion are transported through Wi-Fi access points. Considering that the average price per GB transported by cellular is $0.41(per the analysis presented above), business savings from Wi-Fi would have reached $1,094 million, an addition to the producer surplus (the reduction in operating costs incurred by business establishments). By 2023, this benefit will reach $ 2,063 million (see table VI-12).

Table VI-12. France: Savings in business wireless traffic (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Total Annual traffic (Exabytes per month)	0.31	0.39	0.48	0.59	0.73	0.89	1.10	1.36
Share of Business Internet Traffic by Wi-Fi	42.00%	42.96%	43.93%	44.93%	45.95%	47.00%	48.07%	49.16%
Total Business Internet Traffic (million Gb)	4,046	4,988	6,149	7,580	9,344	11,519	14,200	17,506
Total Business Wi-Fi enterprise traffic (million Gb)	1,699	2,142	2,701	3,406	4,294	5,414	6,826	8,606
Average Price per Gb	$0.45	$0.45	$0.41	$0.36	$0.33	$0.30	$0.27	$0.24
Economic Impact (in million $)	$ 765	$ 964	$ 1,094	$ 1,242	$ 1,410	$ 1,601	$ 1,817	$ 2,063

Source: Cisco; analysis Telecom Advisory Services

IV.4.2. Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points, and multiply this value by a standard cost of deploying a CAT 6 network. The cost of deploying inside telecommunication wiring was calculated by multiplying the percent difference between a house ($660) and an office ($2,200) in the United States by the estimate for wiring a house in France (US$ 575), which results in US$ 1,340[85].

Assuming all 3,752,544 business establishments in France[86] are utilizing Wi-Fi which therefore allows them to save in wiring costs and that this number is expected to remain stable, the savings resulting from avoiding inside wiring amounts to $ 5.03 billion, which is expected to remain constant through 2023.

VI.5. Cellular off-loading

The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks.

[85] Interview with Roland Montagne, Director of Broadband Services, IDATE. The equivalent US number is $2,200.
[86] Source: https://www.statista.com/statistics/502717/number-of-enterprises-france-by-number-employees/

This analysis starts with the predicted incremental wireless data traffic generated between 2018 and 2023. According to the traffic forecast presented in table III-6 above, future monthly wireless data traffic in France amounts to 0.19 Exabytes per month in 2018 and will reach 1.39 Exabytes per month in 2023. Until 2020, when 5G deployment is expected to launch, this traffic should be handled through a combination of 3G and primarily 4G.

It is obvious that a cellular-only network does not economically handle all this traffic. So far, the offload coefficient in France approximates 65%, which is a composite of 20% outdoors and the remainder through indoor usage via Wi-Fi routers (the latter being assessed in terms of consumer surplus in the residential use section above)[87]. Due to their economic advantage relative to cellular base stations, carrier grade Wi-Fi deployment allows wireless operators to save both on CAPEX and OPEX. While the economic advantage of Wi-Fi off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are in general considerably less expensive than cellular network equipment with similar capacity. For example, a cellular pico-cell (needed to offer access via conventional cellular service) costs between $7,500 and $15,000[88], while a carrier-grade Wi-Fi access point requires an investment of $2,500[89]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table VI-13).

Table VI-13. Comparative Carrier Grade Wi-Fi and LTE Macro Cell CAPEX and OPEX

	Wi-Fi Site	LTE Macro Cell
New Site acquisition	$ 600	$ 150,000
Collocation	-	$ 50,000
Backhaul	$ 300	$ 5,000
Monthly site rental	$ 20	$ 1,000
Site maintenance/month	$ 10	$ 200

Source: LCC Wireless (2012)

As it can be seen, Wi-Fi has significant economic advantages at the unit level. However, site density requirements for Wi-Fi are much higher than for cellular. For example, in a dense urban environment with high traffic, for each cellular site, 23 Wi-Fi hotspots are required. The difference means that, from a Total Cost of Ownership (CAPEX and OPEX) standpoint, the factor that erodes some of Wi-Fi's economic advantage is OPEX, especially Wi-Fi site rental and backhaul costs. Along these lines, for the carrier-class Wi-Fi off-loading to materialize, site deployment needs to be managed on a case-by-case basis, by surgically placing sites primarily in high traffic areas.

In a prior report by this author[90], a simulation was presented to determine the economic advantage of relying on carrier-grade Wi-Fi sites to complement the deployment of LTE in the United States. To reiterate, according to Thanki (2012), achieving full LTE coverage in the United States relying on 2100 MHz to accommodate incremental wireless data traffic would require approximately 34,000 new base stations[91], representing a total capital investment of

[87] Interview with Roland Montagne, IDATE, August 1, 2018.
[88] "When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.
[89] Cisco Aironet 1552H Wireless Access Point.
[90] Katz, R. (2018). A 2017 *Assessment of the current and future economic value of unlicensed spectrum in the United States*. Washington, DC: Wi-Fi Forward.
[91] This model was adapted by the author from Ofcom, the UK regulator, to assess the effect of differing traffic levels on cell site numbers in urban areas in its consultation "Application of spectrum liberalization and trading to the mobile sector" (Ofcom, 2009).

$ 8.5 billion. On two simulation cases of off-loading in New York and San Diego, LCC Wireless assumed a CAPEX benefit of Wi-Fi off-loading ranging between 22.3 % and 44.7 %. When averaging these two estimates, the CAPEX reduction would amount to $2.76 billion. Even under the OPEX considerations mentioned above, the Total Cost of Ownership is lower for the Wi-Fi off-loading scenario (see table VI-14).

Table VI-14. Total Cost of Ownership of LTE only versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
Total Cost of Ownership	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) OPEX to CAPEX ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

According to the simulation run for the United States, presented in table VI-14, Wi-Fi carrier grade yields economic savings for a carrier of 18.71%.

Now, let's turn to the French environment. As of 2018, 4G coverage has reached 95%, and, according to GSMA intelligence, this number is not expected to increase in the future. Considering that 5G is not expected to launch before 2020, it is reasonable to assume that the 2018 CAPEX is benefitting from a share of the network infrastructure being deployed through Wi-Fi sites. In 2018, total CAPEX of French wireless operators is estimated by GSMA Intelligence to be $ 3,950 million. If this number already factors in the savings derived from deploying Wi-Fi sites, it would then mean that the CAPEX savings resulting from deploying carrier-grade Wi-Fi as a complement to cellular base stations for the rollout of LTE to accommodate traffic growth in 2018 in France would amount to $ 1,937 million[92]. This amount does not include the CAPEX saved by traffic off-loading to residential and business Wi-Fi networks[93]. In addition to the CAPEX driven savings, one would have to add the OPEX in order to estimate the total producer surplus. According to table III-15, each $1 billion in CAPEX savings triggers $2.82 billion in OPEX. As a result, total 2018 producer surplus in 2018 generated by Wi-Fi carrier grade rollout amounts to $ 7.40 billion.

Moving on to estimating the value in 2023, 5G deployment will increase the value of cellular off-loading. Given current announcements and trials, it is expected that French carriers will begin investing to deploy 5G in 2020 (see table VI-15).

Table VI-15. France: Deployment of 5G

	2020	2021	2022	2023	2024	2025
5G Coverage	1.27%	10.12%	22.78	33.61%	43.76%	48.73%

Source: GSMA Intelligence

Therefore, it is assumed that all the CAPEX invested in 2023 in France would be dedicated to 5G deployment. In this context, Wi-Fi becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands. To calculate the economic value of Wi-Fi in this context, we rely on the only known cost estimation of 5G to date: the one developed by Oughton and Frias (2016) for OFCOM

[92] (CAPEX without Wi-Fi) – (CAPEX without Wi-Fi * .329) = $ 3,950 million or $ 5,887 million – (5,887*.329) = $ 3,950 million
[93] See Cooper (2012).

in the United Kingdom. The authors' baseline case estimates a CAPEX of £42 billion, of which urban coverage investment amounts to £700 million, while suburban deployment demands £5.6 billion, and rural coverage £35.6 billion. We have used Oughton and Frias (2016) cost decomposition by zone of the UK and applied it to France, relying on a cost per POP metric by geography (see Table VI-16).

Table VI-16. 5G Investment in the United Kingdom vs. France

Geography	United Kingdom			France	
	Population Breakdown (%)	5G CAPEX (£ Billion)	5G CAPEX (%)	Population Breakdown (%)	5G CAPEX ($ Million)
Urban (cities>1 million)	29%	£0.7 ($0.948)	1.66%	64.5%	$ 1,019
Suburban	54%	£5.6 ($7.592)	13.33%	48%	$ 6,571
Rural	17%	£35.6 ($48.263)	84.76%	22.5%	$ 64,203
TOTAL	**100%**	**£41.9 ($56.803)**	**100%**	**100%**	**$71,792**

Sources: Oughton and Frias (2016); Trading Economics; World Bank; U.S. Census Bureau; Trulia; Telecom Advisory Services analysis

Considering, in accordance to table VI-16, that the total CAPEX required to deploy 5G in France would be $71,792, and that the incremental 5G coverage between 2022 and in 2023 would be 10.64%, it is assumed that the 5G CAPEX in that year will be $ 7,639 million. Reiterating again that this amount reflects the saving incurred by relying on Wi-Fi sites, and applying the same approach as used in 2018, would result in a total producer surplus (adding CAPEX and OPEX savings) of $ 14.31 billion in 2023.

VI.6. Locally manufactured Wi-Fi enabled equipment

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. It is assumed that the consumer surplus is roughly equal to consumer surplus (see Milgrom et al., 2011). Both consumer products and enterprise equipment are considered as part of the economic surplus generated by locally manufactured Wi-Fi enabled devices.

VI.6.1. Consumer products

As detailed in section III.3.5, we identified seven consumers products which are intrinsically linked to Wi-Fi: Wi-Fi enabled wireless speakers, home security systems, home networking systems (such Apple's HomePod, Amazon Echo, and Google Home), access points[94], external adapters[95], routers, and gateways. Our focus is to estimate economic surplus in France, based by revenues of French manufacturers for each product.

In the case of consumer access points, external adapters, routers and gateways, data indicates that French manufacturers hold some market share in access points, routers, and gateways (see table VI-17).

[94] Access points (APs) allow devices to connect to a wireless network.
[95] Wireless client device. It can be PCI adapter, which A PCI wireless adapter card is a device that is connected to a desktop computer's PCI bus to provide wireless capability to the desktop, a PC card, or a USB adapter.

Table VI-17. Consumer products: Global Market shares (2018)

Product	Market (in millions)	United States	United Kingdom	Germany	South Korea	France	Japan	China	Taiwa n	ROW
Access points	$ 11,631	0.2 %	0.0%	0.0%	0.0%	13.5%	0.0%	69.1%	7.7%	9.5
External adapters	$ 465.92	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	42.1%	9.7%	41.0%
Routers	$ 4,972.30	5.9%	0.0%	0.0%	0.0%	6.7%	0.0%	52.6%	15.5%	19.3%
Gateways	$ 6,389.25	6.6%	0.0%	0.0%	0.0%	29.0%	0.0%	38.1%	10.3%	16.0%

Sources: ABI Research; Telecom Advisory Services analysis

For example, Technicolor – formerly Thomson SARL – controls 13.5% of the access points market, 6.7% of the router market, and 29% of the gateway market[96].

For the other product lines, the estimates were based on a prorated of US market statistics. As a result, the market estimates for French consumer electronics are as follows (see table VI-18).

Table VI-18. France: Consumer Electronics market (in $ million, 2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Wireless speakers	$ 4,275	$ 5,734	$ 8,307	$ 8,991	$ 9,713	$ 10,449	$ 11,240	$ 12,054
Home security systems	$ 612	$ 628	$ 697	$ 714	$ 730	$ 743	$ 757	$ 768
Home networking equipment	$ 333	$ 467	$ 708	$ 791	$ 884	$ 982	$ 1,092	$ 1,210
Access points	$ 1,945	$ 2,131	$ 2,238	$ 2,315	$ 2,338	$ 2,302	$ 2,243	$ 2,279
External adapters	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Tablet	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Routers	$247	$ 313	$ 333	$ 346	$ 342	$ 329	$ 317	$ 317
Gateways	$ 1,795	$ 1,819	$ 1,851	$ 1,861	$ 1,842	$ 1,821	$ 1,784	$ 1,777
Total sales	$ 9,206	$ 11,094	$ 14,133	$ 15,017	$ 15,848	$ 16,626	$ 17,433	$ 18,406
Profit margins	42.87%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%
Producer surplus	$ 3,947	$ 4,927	$ 6,277	$ 6,669	$ 7,038	$ 7,384	$ 7,742	$ 8,174

Sources: ABI Research; Telecom Advisory Services analysis

As indicated in Table VI-18, of the total sales amounts, the profit margin estimated by CSI markets is 44.41%, which yields a producer surplus for these particular products in 2018 of $ 6,277 million. The high economic value of French consumer electronics relative to other countries is due to the prevalence of Technicolor as a major manufacturer of Wi-Fi enabled equipment. Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic surplus in 2018 would amount to $ 12.55 billion and would reach $ 16.35 billion in 2023.

VI.6.2. Enterprise products

In the case of enterprise Wi-Fi enabled products, France is not included among the main manufacturing countries (see table VI-19).

[96] ABI Research. *Wireless Connectivity Technology Segmentation Addressable Markets*, 1Q2018.

Table VI-19. Enterprise products: Global Market shares (2018)

Product	Market (in millions)	United States	China	ROW
Access points	$ 5,398	81.3 %	16.8 %	1.9 %
Controllers	$ 1,025	67.3 %	19.9 %	12.8 %

Sources: ABI Research; Telecom Advisory Services analysis

As a result, Wi-Fi enabled enterprise products was not included as a source of Wi-Fi economic value in France.

VI.7. Bridging the digital divide

The digital divide is defined as the gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory).

This analysis considers that Wi-Fi enabled ISPs would be one approach for addressing broadband demand existing in rural areas of France (we assume that half of the new broadband connections are provisioned by operators relying on Wi-Fi). Along these lines, it is assumed that the incremental penetration in broadband subscribers will have an impact on the economy according to a coefficient estimated through regression models that links the increase in broadband lines to economic growth (see table VI-20).

Table VI-20. France: GDP Contribution Resulting from reduction of the digital divide

	2016	2017	2018	2019	2020	2021	2022	2023
Incremental subscribers	997,000	820,643	844,987	870,053	895,863	922,438	949,802	977,978
Total broadband subscribers (million)	27.66	28.48	29.33	30.20	31.10	32.02	32.97	33.95
Households (million)	26.90	27.04	27.18	27.32	27.46	27.60	27.74	27.89
Incremental adoption broadband	3.71%	3.03%	3.11%	3.18%	3.26%	3.34%	3.42%	3.51%
Change in broadband penetration	102.82%	105.33%	107.90%	110.53%	113.23%	113.31%	113.39%	113.48%
Additional	3.60%	2.88%	2.88%	2.88%	2.88%	2.95%	3.02%	3.09%
Impact coefficient	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
GDP per capita	38,205	39,869	44,934	46,793	48,651	50,371	52,153	53,839
Population (million)	64.85	65.11	65.36	65.60	65.84	66.07	66.29	66.51
Indirect Impact on GDP (in $ billion)	7.14	5.98	6.77	7.07	7.38	7.85	8.35	8.85
Share that exist because Wi Fi	50%	50%	50%	50%	50%	50%	50%	50%
Indirect Impact on GDP (in $ billion)	3.572	2.991	3.384	3.537	3.691	3.926	4.175	4.427

Sources: WISPA (2017); Thomson and Garbacz (2008); Telecom Advisory Services analysis

Based on these calculations, Wi-Fi's contribution to GDP by reducing the digital divide in France would amount to $3.384 billion in 2018 and $4.427 billion in 2023.

VI.8. Wi-Fi return to speed

The return to speed is a benefit derived from the fact that Wi-Fi access is, in general considerably faster than cellular networks. In this context, research indicates that faster broadband speed has an impact on economic growth due to the increasing efficiency of a country's economy. In other words, faster broadband networks contribute to growth of a country's GDP. Along these lines, the objective in this case is to quantify the impact Wi-Fi technology has to the average speed of mobile devices in France.

We start by quantifying the speed differentials for France, which we calculate by subtracting the weighted average of Wi-Fi and cellular speeds (averaged according to traffic off-loading factors) from cellular speeds, and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (thus, if no off-loading were to occur; see table VI-21).

Table VI-21. France: Estimation of speed differential for total US traffic (in Mbps)

	2016	2017	2018	2019	2020	2021	2022	2023
Average speed of cellular networks	12.32	14.41	16.86	19.73	23.08	27.00	31.59	36.95
Average Wi-Fi speed	16.80	18.99	21.46	24.26	27.43	31.00	35.04	39.61
Average speed of weighted average of cellular and Wi-Fi traffic	13.49	15.42	17.72	20.45	23.67	27.43	31.90	37.16
Speed decrease (average speed of cellular/average weighted average speed)	-8.68%	-6.56%	-4.85%	-3.53%	-2.50%	-1.58%	-0.97%	-0.55%

Source: Cisco; TAS analysis

Having calculated the speed decrease percentage, we then apply this percentage to the coefficient derived from the model developed by Bohlin et al. (2011 and 2013) to gauge the potential impact on GDP if cellular networks transported all traffic (see table VI-22).

Table VI-22. Econometric model measuring the impact of broadband speed on GDP

Independent Variables	Coefficient
Average GDP growth (2008-2010)	0.577 *
Population density	-0.0441 *
Urban population	-0.0103 **
Labor force growth (%)	0.0492 *
Telecom revenue growth (%)	0.0492 *
Population growth (%)	-0.630 **
Average achieved downlink speed	-0.00214
Average achieved downlink speed squared	0.00142 *

*, ** Significant at 1% and 5% critical value respectively
Source: Rohman and Bohlin (2011)

As table VI-22 shows, by incorporating the elasticity of the coefficient of broadband speed and the square of the variable, the model assumes that the doubling of broadband speed causes a 0.3% increase in GDP growth. Our case shows the GDP impact on the **decrease** in speed. This is applied in turn to the French GDP at current prices (see table VI-23).

Table VI-23. France: Broadband speed impact on GDP

	2016	2017	2018	2019	2020	2021	2022	2023
Speed decrease (%)	-8.68%	-6.56%	-4.85%	-3.53%	-2.50%	-1.58%	-0.97%	-0.55%
Model coefficient	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%
Decrease in GDP per capita	-0.03%	-0.02%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%
GDP per capita (current prices)	38,205	39,869	44,934	46,793	48,651	50,371	52,153	53,839
Wi-Fi Traffic (% Total Traffic)	3.91%	3.57%	3.29%	3.07%	2.90%	2.52%	2.31%	2.20%
GDP Reduction (in $ millions, current prices)	-25.23	-18.21	-14.05	-9.96	-6.98	-3.98	-2.32	-1.31

Source: Cisco; TAS analysis

Table VI-23 indicates that if all cellular data traffic that is currently being off-loaded to Wi-Fi were to shift to cellular networks, the reduction in speed (in 2018 from an average 21.46 Mbps to 16.86) would have a $14.05 million impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data. In 2023, the amount would reach $1.31 million. Of note, the almost nil impact on GDP is due to the fact that the migration of all traffic to cellular would have a negligible impact on speed. By 2023, the forecast data based on Cisco Visual Networking Index assumes for France a "catch up" of cellular networks to the speed of Wi-Fi.

VI.9. Revenues of Wireless ISPs and Wi-Fi service providers

Wi-Fi off-loading can create new business opportunities for service providers offering wireless broadband services in public places (airports, hotels) for a fee. In addition to this segment, Wireless Internet Service Providers (WISPs) rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas. While some WISPs utilize licensed spectrum, the majority relies on unlicensed Wi-Fi spectrum.

The most straightforward way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in France. However, while there are a large number of Wi-Fi service providers present in the country, no statistics are available regarding their revenues. Subject matter experts estimate this to be a fairly fragmented market, with at least 50 providers considered to be "pure play" (which means their core business is the provision of Wi-Fi service)[97]. Beyond these 50 operators, there are several hundred companies that provide Wi-Fi services as a complement to other offerings, such as systems integration. Table VI-24 presents a compilation of some of the largest Wi-Fi service providers in France.

Table VI-24. France: Compilation of some of the largest Wi-Fi Service Providers

Company	Business focus
Qos Telecom	Public Wi-Fi operator specialized in offering Wi-Fi service in communities, public transportation and education
Osmozis	Supplier and operator of multi-service networks in European holiday centers. Company develops, manufactures, tests, installs and operates Wi-Fi networks and all associated connected devices solutions (revenues: US$ 9.2 million in 2016)
Groupe Inedys	Systems integrator, primarily focused in data center services and systems architecture development
Yziact	Systems integrator focused on management of systems infrastructure
S2F	Developer of IoT solutions
Nomotech/Nomosphere	Provider of Wi-Fi based service in regional rural areas (2,000 base stations)
Ozwillo	Association offering community applications and infrastructure

Source: Company web sites; interviews

In the absence of revenue statistics (the approach followed to estimate economic value in the United States), we have calculated Wi-Fi service provider revenues in France by prorating US Wi-Fi revenues based on the French GDP. Thus, it is estimated that the 2018 GDP contribution accounts for $489 million[98], and that it is expected to reach $ 1.60 billion by 2023.

[97] Interview with Jean-Christophe Budin, Wireless Business Line Director – Hubone, 7/30/18.

[98] Subject matter expert interviews have estimated revenues of French "pure play" Wi-Fi operators at US$ 230 million.

VI.10. Wi-Fi contribution to employment

The estimation of employment generated by Wi-Fi in France is calculated by relying on the total GDP contribution resulting from the effects analyzed above and using that as an input in the communications sector of an input-output matrix of the French economy. Table VI-25 presents the GDP contribution of each of the effects analyzed above.

Table VI-25. France: Total GDP Contribution of Wi-Fi (in $ billion)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$3.38	$3.54	$3.69	$3.93	$4.18	$4.43
Return to speed	$0.01	$0.00	$0.00	$0.00	$0.00	$0.00
Wi-Fi carriers	$0.49	$0.61	$0.76	$0.93	$1.27	$1.60
Total	$3.88	$4.15	$4.45	$4.86	$5.45	$6.03

Source: Telecom Advisory Services analysis

These inputs generate the following annual employment effects based on the I-O matrix for the French economy (table VI-26).

Table VI-26. France: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	22,881	35,456
Indirect jobs	5,468	8,473
Induced jobs	943	1,460
Total	29,292	45,389

Source: Telecom Advisory Services analysis

According to the contribution to the GDP, Wi-Fi is generating approximately 29,300 jobs in 2018 and is expected to increase by an annual 8.96% to 45,000 in 2023. Job estimates include direct jobs (those jobs created by Wi-Fi equipment manufacturers and distributors, as well as providers of Wi-Fi services), indirect jobs (those jobs created by suppliers to the Wi-Fi sector), and induced jobs (those jobs created by spending of direct and indirect workers).

The sector breakdown of 2018 employment is as follows (table VI-27).

Table VI-27. France: Sector Breakdown of Wi-Fi generated annual employment (2018)

Sector	Direct	Indirect	Induced	Total
Agriculture	0	0	64	64
Extractive industries	0	117	5	122
Manufacturing	0	427	27	454
Construction	0	266	0	266
Trade	0	467	467	934
Transportation	0	36	299	335
Communications	22,881	0	0	22,881
Financial Services	0	839	0	839
Business services	0	2,984	0	2,984
Other services	0	332	81	413
TOTAL	22,881	5,468	943	29,292

Source: Telecom Advisory Services analysis

VII. ECONOMIC VALUE OF WI-FI IN GERMANY

Wi-Fi technology is as developed in Germany as in the case of France. According to the iPass Wi-Fi Growth Map, there are currently 150,301 commercial hotspots and 21,455,333 community access points operating in the German territory[99]. However, when compared to France, Wi-Fi usage intensity appears to be much higher in Germany. According to OpenSignal[100], German wireless users spend 62.04% of their communications time connected to Wi-Fi networks rather than relying on their cellular data connection[101]. Along these lines, the intensive usage of Wi-Fi technology should have a significant impact on its social and economic benefits. This chapter presents first the summary of economic value estimates and then reviews each of the particular effects. The methodology reviewed in chapter III was utilized to calculate the economic value of Wi-Fi in Germany. Please refer to chapter III for detailed descriptions of each economic factor.

VII.1. Total economic value (2018 and 2023)

The total economic value of Wi-Fi in Germany in 2018 amounts to $ 94.00 billion, which is roughly equivalent to the GDP of the Slovak Republic[102]. This is comprised of $ 88.18 billion in economic surplus and $ 5.82 billion in contribution to the GDP (see table VII-1).

Table VII-1. Germany: Total Economic Value of Wi-Fi (2018) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 298	N.A.	$ 298	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 5,009	N.A.	$ 5,009	N.A.
	2.2. Inside wiring avoidance	$ 43,131	N.A.	$ 43,131	N.A.
	Subtotal	$ 48,140	N.A.	$ 48,140	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 4,205	$ 4,205	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 19,053	$ 19,053	N.A.
	Subtotal	N.A.	$ 23,258	$ 23,258	
4. Value of cellular off-loading		N.A.	$ 6,174	$ 6,174	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 5,157	$ 5,157	$ 10,314	N.A.
	5.2. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 5,157	$ 5,157	$ 10,314	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 3,575
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 1,548
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 697
TOTAL		$ 53,595	$ 34,589	$ 88,184	$ 5,820

Source: Telecom Advisory Services analysis

The key sources of Wi-Fi economic value are residential use ($ 48.14 billion in consumer surplus), followed by enterprise use ($23.26 billion) and cellular rerouting ($ 6.17 billion). Beyond this, the value of Wi-Fi enabled equipment (wireless speakers, security systems, etc.) has a significant impact in terms of economic surplus ($ 10.31 billion).

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99 Compared to 129,777 commercial and 23,536,080 community access points in France.
100 OpenSignal. *Global State of Mobile Networks* (August 2016).
101 Compared to 47.54% in France.
102 Source: International Monetary Fund (2017).

A 2023 forecast of the same value will reach $ 132.03 billion, composed of $ 124.30 billion in economic surplus, and $ 7.73 billion in GDP contribution (see table VII-2).

Table VII-2. Germany: Total Economic Value of Wi-Fi (2023) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 355	N.A.	$ 355	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 15,224	N.A.	$ 15,224	N.A.
	2.2. Inside wiring avoidance	$ 49,604	N.A.	$ 49,604	N.A.
	Subtotal	$ 64,828	N.A.	$ 64,828	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 7,301	$ 7,301	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 19,053	$ 19,053	N.A.
	Subtotal	N.A.	$ 26,354	$ 26,354	
4. Value of cellular off-loading		N.A.	$ 19,880	$ 19,880	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 6,444	$ 6,444	$ 12,888	N.A.
	5.3. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 6,444	$ 6,444	$ 12,888	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 4,803
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 581
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 2,345
TOTAL		$ 71,627	$ 52,678	$ 124,305	$ 7,729

Source: Telecom Advisory Services analysis

The relative importance of sources of economic value by 2023 remains the same as in 2018. Residential Wi-Fi usage remains the largest source of economic value ($64.82 billion), followed by enterprise use ($26.35 billion) and cellular carrier off-loading ($19.88 billion).

VII.2. Free Wi-Fi traffic

As described in chapter III, one dimension of Wi-Fi's economic value creation effects is derived from savings consumers receive by accessing the Internet through no cost sites (in retail shops, cafes, etc.) rather than relying on their cellular data plan. The following section presents the quantification of such benefit.

Total Internet traffic in Germany is growing at 26.6 %, while mobile Internet traffic has been growing close to 40% per annum, indicating a growing share of wireless (increasing from 4.10% to 5.28% in just three years) as indicated in Table VII-3.

Table VII-3. Germany: Internet Traffic (2016-2018) (In exabytes[103] per month)

	2016	2017	2018	CAGR
Total Internet	1.60	2.03	2.56	26.58 %
Wireless Internet	0.09	0.12	0.17	39.66 %

Source: Cisco; Telecom Advisory Services analysis

The growing adoption of wireless data-enabled devices (smartphones, tablets, PCs) combined with an increase in usage per device has driven overall traffic growth. The installed base of smartphones reached 78.69 million in 2018, while this number amounted to 22.24 million for

[103] 1 Exabyte equals 1,073,741,824 gigabytes.

tablets. On the other hand, the number of laptops is slightly declined from 48.60 in 2016 to 48.16 in 2018 (2016-18 CAGR: -0.46%[104]) due to tablet and, secondarily, smartphone substitution (see table VII-4).

Table VII-4. Germany: Device Installed Base and Penetration (2016-2018)

Device	Metrics	2016	2017	2018 (E)	CAGR
Smartphones	Units (in millions)	70.48	79.54	78.69	5.66 %
	Penetration (%)	85.94 %	96.76 %	95.54 %	5.44 %
Tablets	Units (in millions)	21.20	21.71	22.24	2.43 %
	Penetration (%)	25.85 %	26.42 %	27.00 %	2.21 %
Laptops	Units (in millions)	48.60	48.38	48.16	-0.46 %
	Penetration (%)	59.26 %	58.85 %	58.47 %	- 0.67 %

Sources: Cisco; GSMA Intelligence; Telecom Advisory Services analysis

Beyond the laptop to tablet substitution, the installed base of smartphones has shifted to 4G (LTE) network standards that provide faster speed of access and, consequently, stimulate more intense data usage. Looking forward, it is projected that the average speed of mobile devices by 2023 would have more than double from the current 14.21 Mbps to 34.04 Mbps[105].

Adding to the proliferation of devices, traffic per device has grown between 7.57% per annum for laptops and 36.0% for smartphones driven by increased applications and content availability (see table VII-5).

Table VII-5. Germany: Average Traffic Per Device (2016-2018)
(In Gigabytes per month)

	2016	2017	2018 (E)	CAGR
Smartphones	2.30	3.13	4.25	36.00 %
Tablets	6.10	7.90	10.24	26.60 %
Laptops	18.40	19.79	21.29	7.57 %

Source: Cisco VNI; Telecom Advisory Services analysis

It is interesting to note that in all three devices, traffic per device in the United States by 2018 is between 2.5 and 4 times higher than in Germany. That being said, the growth rate for traffic per smartphone in Germany is higher than in the United States, indicating a process of gradual convergence over time.

With the installed base and average data usage per device, total mobile Internet traffic in Germany was calculated for the next five years. We estimate a total traffic of 0.89 Exabytes per month in 2023. Projections regarding traffic growth from other sources vary, although they all agree directionally (see table VII-6).

Table VII-6. Germany: Mobile Internet Traffic (2018 and 2023)
(In million Exabytes per month)

	2018	2019	2020	2021	2022	2023	CAGR
Total Internet	2.56	3.25	4.11	5.20	6.58	8.33	26.58%
Mobile Internet	0.17	0.23	0.33	0.46	0.64	0.89	39.66%

Source: Cisco; Telecom Advisory Services analysis

[104] Note than the laptop installed base in the United States is still growing, albeit at only 3.90% (see chapter IV).
[105] Source: Cisco Visual Networking Index.

This growth has and will continue to put pressure on the public cellular networks to accommodate the traffic without incurring congestion while generating acceptable levels of revenue. This prompts the communications system to rely on Wi-Fi to handle a portion of the traffic. We will now estimate the portion of traffic that is off-loaded to Wi-Fi.

No public data exists on the portion of cellular traffic that is off-loaded to Wi-Fi sites in Germany. However, some data points provide a way of estimating this value. In 2010, Deutsche Telekom mentioned that it was offloading "a few percents (sic)" of its traffic, but that it was aiming to increase this value to 20%[106]. This projection appears to be quite conservative considering that as of 4Q2013, Deutsche Telekom had deployed in Germany 40,000 Wi-Fi base stations[107] but recent data indicates over 1,000,000 access points,[108]. On the other hand, by 3Q3015 Vodafone had reached 1,000,000 hotspots, partly as a result of their acquisition of Kabel Deutschland[109]. Finally, by 3Q2013 O2 had deployed only 3,000 Wi-Fi carrier grade base stations.[110] Based on the experience of other advanced countries, which has been validated by other market experts, it is estimated that the off-loading factor is 48% for smartphones and 42% for tablets and laptops[111].

By applying this off-loading factor to the total mobile data traffic, we project that total Wi-Fi traffic in Germany is currently 0.64 Exabytes per month in 2018, and reflecting a 19.05% growth rate (see table VII-7).

Table VII-7. Germany: Total Wi-Fi Traffic Per Device (2016-2018) (In Exabytes per month)

	2016	2017	2018(E)	CAGR
Smartphones	0.07	0.10	0.15	43.70 %
Tablets	0.05	0.07	0.09	36.50 %
Laptops	0.33	0.37	0.40	10.11%
Total	0.45	0.54	0.64	19.05 %

Source: Telecom Advisory Services analysis

The estimation of consumer surplus is conducted by multiplying the total Wi-Fi traffic from table VII-7 by the portion representing the "true free traffic" generated in public sites. Again, precise estimates for this value are non-existent for Germany. However, it has estimated that there are 1,251,240 open Wi-Fi networks in the country, 91,000 alone in Berlin[112]. Subject-matter experts interviewed have ranged the percent of free Wi-Fi traffic between 5% and 10%[113]. Considering that statistics for the United States indicate 4.32% of Wi-Fi traffic to be "free", we opted to stay within the conservative side, and utilize this value (see table VII-8).

[106] Donegan, M. (2010) "Deutsche Telekom joins rush to Wi-Fi off-load", *Heavy Reading*.
[107] Source: GSMA Intelligence.
[108] Interview with Christian Wagner, 7/24/2018.
[109] Source: GSMA Intelligence.
[110] Source: GSMA Intelligence.
[111] Interview with Claus Hetting.
[112] Source: Wiman (2018). *Mobile Open Wi-Fi Spots in Germany.*
[113] Source: Christian Wagner, 7/24/2018.

Table VII-8. Germany: Total Free Wi-Fi Traffic (2016-2018)

	2016	2017	2018(E)
Total Wi-Fi Traffic	0.45	0.54	0.64
Total Free Traffic (in Exabytes per month)	0.02	0.02	0.03
Total Free Traffic (in Exabytes per year)	0.24	0.28	0.33
Total Free Traffic (in million Gigabytes per year)	252.53	302.57	357.89

Source: Telecom Advisory Services analysis

We calculated consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we needed an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculated by averaging the most economic "dollar per GB" plan (so-called "unlimited") of two major wireless carriers providing service in Germany: Vodafone and O2[114] (see table VII-9).

Table VII-9. Germany: Average Price Per Gigabyte (2017)

Carrier	Market share	Plan	Price per Gb (Euros)
O2	36%	O2 Free XL: € 49.99/25 Gigabytes cap	€ 2.00
Vodafone	26%	Red XXL Rabatt für Selbständige: € 54.49/50 Gigabytes cap	€ 1.09
Average			€ 1.62

Note: The average is calculated by prorating every price per GB by the carrier's market share.
Source: Telecom Advisory Services analysis

Since the assessment of economic value is done in US dollars, the average price per GB is converted to $ 1.87. Historical data compiled for the US market allowed for projecting the future price per Gigabyte (see figure III-1 in chapter III).

According to these projections, while the average price per GB in 2017 is $ 1.87, it is estimated that by 2023, it will reach an estimated $1.00. As to the cost of offering the service through Wi-Fi, this would include an additional router and needed bandwidth. For estimation purposes, we assume those costs to be 45% of the cost of offering the same GB via cellular networks[115]. This means that the cost per Gigabyte offered by the site providing the service for free would be $0.85 in 2017, declining to $0.66 in 2023. By relying on the total free Wi-Fi traffic shown in table IV-8 and the average price per cellular Gigabyte minus the cost of provisioning free Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic (see table VII-10).

Table VII-10. Germany: Consumer Surplus of Free Wi-Fi Traffic (2018-2023)

	2018	2019	2020	2021	2022	2023
Total Free Traffic (in million Gigabytes per year)	357.89	434.21	533.68	663.48	832.81	1,054.15
Price per cellular gigabyte ($)	$ 1.68	$ 1.52	$ 1.36	$ 1.23	$ 1.11	$ 1.00
Cost per Wi-Fi provisioning ($)	$ 0.85	$ 0.81	$ 0.77	$ 0.73	$ 0.69	$ 0.66
Consumer surplus per Gigabyte ($)	$ 0.83	$ 0.71	$ 0.60	$ 0.50	$ 0.41	$ 0.34
Total Consumer surplus (in $ million)	$ 298	$ 307	$ 318	$ 331	$ 343	$ 355

Source: Telecom Advisory Services analysis

As indicated in table VII-10, consumer surplus of free Wi-Fi traffic in 2018 would reach an estimated $ 298 million and $ 355 million in 2023.

[114] T-Mobile's plan is unlimited and therefore it is not possible to estimate its price per GB.
[115] This is relationship found in the case of the United States (see chapter IV).

VII.3. Value of Residential Wi-Fi

The value of residential Wi-Fi is a combination of Internet access for home usage and avoidance of in-house wiring.

VII.3.1. Home Internet access for devices that lack an Ethernet port

As mentioned in Chapter III, the underlying assumption of this analysis is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on the cellular network to access the Internet. As a consequence, estimating value of home access requires first to measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers.

Based on our traffic model, the total traffic generated by these types of devices in 2018 in Germany amounts to 6,900 million Gigabytes, reaching 35,451 million Gigabytes by 2023 (see table VII-11).

Table VII-11. Germany: Total Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	2,062	2,931	4,166	5,922	8,418	11,967	17,011	24,182
Tablets	1,552	2,060	2,734	3,630	4,818	6,396	8,490	11,269
Total	3,614	4,991	6,900	9,552	13,236	18,363	25,501	35,451

Source: Cisco; GSMA; analysis Telecom Advisory Services

A portion of this traffic is, as expected, generated while the subscriber is in his residence, relying on the Wi-Fi service. As mentioned by a Deutsche Telekom executive, "At home, users disappear from the cellular network".[116] According to a Cisco study conducted in 2012[117], 43.12% of use time of devices that lack a wired port occurs at home. Interview of a subject-matter expert in Germany indicates this amount to be approximately 60%[118]. While we consider that the latter estimate is from Germany and that the time that has passed since the Cisco study has resulted in higher deployment of broadband access in the home, we opt to rely on the more conservative value of 43.12%. Therefore, the portion of said traffic generated at home reached 2,975 million Gigabytes in 2018 and is expected to amount for 15,285 million Gigabytes in 2023 (see table VII-12).

Table VII-12. Germany: Home Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	889	1,264	1,796	2,553	3,620	5,160	7,335	10,426
Tablets	669	888	1,179	1,565	2,077	2,758	3,660	4,859
Total	1,558	2,152	2,975	4,118	5,707	7,918	10,995	15,285

Source: Cisco; GSMA; analysis Telecom Advisory Services

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[116] Cited in Donegan, M. (2010) "Deutsche Telekom joins rush to Wi-Fi off-load", *Heavy Reading*.
[117] Cisco IBSG (2012)
[118] Interview with Christian Wagner. 7/25/2018.

If this traffic had to be transported by cellular networks, at the average price per GB estimated in the model of figure III-1 in chapter III, it would result in costs of $ 5.01 billion in 2018 and $15.22 billion in 2023.

VII.3.2. Avoidance of investment in in-house wiring

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in residence reaches approximately $1,390 per household[119].

In order to estimate the benefit derived from wiring avoidance, the number of total Wi-Fi households in Germany is required. Strategy Analytics reported that in 2012, 71.7% of German households were equipped with Wi-Fi[120], out of total universe of broadband Internet households of 95%[121]. Considering that broadband households have reached saturation (98% in 2017), growth could only exist within this universe. We estimate this to amount to 80% in 2018, reaching 93% by 2023.

Considering that 80% of German households currently have Wi-Fi[122], the avoidance cost of inside wiring for 39 million households, which in the absence of Wi-Fi yields a total cost of wiring of $43.13 billion. By 2023, with 93% of households having adopted Wi-Fi, the savings would have reached $49.60 billion[123].

VII.4. Enterprise Wi-Fi

As stated in chapter III, the economic value of enterprise Wi-Fi has two sources:

- Business traffic routed through Wi-Fi access points rather than cellular networks;
- Avoidance of capital investment to deploy Ethernet wiring inside enterprise establishments to connect devices and peripherals.

VII.4.1. Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. In 2018, Cisco VNI and Telecom Advisory Services analysis estimate that total German business Internet traffic will reach 5.90 billion GB, of which 2.50 are transported through Wi-Fi access points. Considering that the average price per GB transported by cellular is $1.68 (per the analysis presented above), savings from Wi-Fi would have reached $ 4.20 billion, an addition to the producer surplus. By 2023, this benefit will reach $ 7.30 billion (see table VII-13).

[119] Our sources indicate two price points for wiring a residence with CAT 5 wire in Germany: € 2,500 and € 1,200. We opted for the lower estimate, although it is important to note the significant difference with US prices (Germany: $ 1,390 at current exchange rate versus US: $ 660, as reported in chapter III).
[120] Burger, A. (2012) "Wi-Fi households to approach 800 million by 2016", *Telecompetitor*
[121] Statista. *Broadband Internet households in Germany*.
[122] Source: Watkins, David. *Broadband and Wi-Fi Households Global Forecast 2012*. Strategy Analytics
[123] This assumes that inside wiring costs will remain constant.

Table VII-13. Germany: Savings in business wireless traffic (2016-2023)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Share of Business Internet Traffic by Wi-Fi	40.00%	41.13%	42.30%	43.50%	44.73%	46.00%	47.30%	48.64%
Total Business Internet Traffic (million Gb)	4,059	4,895	5,904	7,121	8,589	10,359	12,495	15,070
Total Business Wi-Fi enterprise traffic (million Gb)	1,623	2,014	2,498	3,098	3,842	4,765	5,910	7,331
Average Price per Gb	$1.87	$1.87	$1.68	$1.52	$1.36	$1.23	$1.11	$1.00
Economic Impact (in million $)	$ 3,036	$ 3,765	$ 4,205	$ 4,695	$ 5,243	$ 5,855	$ 6,538	$ 7,301

Source: Cisco; analysis Telecom Advisory Services

VII.4.2. Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points, and multiply this value by a standard cost of deploying a CAT 6 network. The cost of deploying inside telecommunication wiring was calculated by multiplying the percent difference between a house ($660) and an office ($2,200) in the United States by the high-end estimate for wiring a house in Germany (US$ 2,875), which results in US$ 6,639.

Assuming all 2,863,925 business establishments in Germany [124] are utilizing Wi-Fi which therefore allows them to save in wiring costs and that number is expected to remain stable, the savings resulting from avoiding inside wiring amounts to $ 19,053 million, which is expected to remain constant through 2023.

VII.5. Cellular off-loading

The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks.

This analysis starts with the predicted incremental wireless data traffic generated between 2018 and 2023. According to the traffic forecast presented in table VII-6 above, future monthly wireless data traffic in Germany amounts to 0.17 Exabytes per month in 2018 and will reach 0.89 Exabytes per month in 2023. Until 2020, when 5G deployment is expected to launch, this traffic should be handled through a combination of 3G and primarily 4G.

It is obvious that a cellular-only network does not economically handle all this traffic. So far, the available statistics indicate that all three wireless carriers operating in Germany have, to different degrees, deployed an important number of carrier grade Wi-Fi sites[125]. Due to their relative economic advantage relative to cellular base stations, carrier grade Wi-Fi deployment allows wireless operators to save both on CAPEX and OPEX. While the economic advantage of Wi-Fi off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are considerably less expensive than cellular network equipment with similar capacity.

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[124] Source: Trading Economics.

[125] As presented above, by 4Q2013, T-Mobile had deployed in Germany 40,000 Wi-Fi base stations (source: GSMA), and some sources indicate that by 2018, the number has reached 100,000. On the other hand, by 3Q3015 Vodafone had reached 1,000,000 hot spots, partly as a result of their acquisition of Kabel Deutschland (sour: GSMA). Finally, according to GSMA Intelligence, O2 appears to lag the other two carriers (by 3Q2013 they had deployed only 3,000 Wi-Fi carrier grade base stations).

For example, a cellular pico-cell (needed to offer access via conventional cellular service) costs between $7,500 and $15,000[126], while a carrier-grade Wi-Fi access point requires an investment of $2,500[127]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table VII-14).

Table VII-14. Comparative Carrier Grade Wi-Fi and LTE Macro Cell CAPEX and OPEX

	Wi-Fi Site	LTE Macro Cell
New Site acquisition	$ 600	$ 150,000
Collocation	-	$ 50,000
Backhaul	$ 300	$ 5,000
Monthly site rental	$ 20	$ 1,000
Site maintenance/month	$ 10	$ 200

Source: LCC Wireless (2012)

As it can be seen, Wi-Fi has significant economic advantages at the unit level. However, we must add a caveat here. Site density requirements for Wi-Fi are much higher than for cellular. For example, in a dense urban environment with high traffic, for each cellular site, 23 Wi-Fi hotspots are required. The difference means that, from a Total Cost of Ownership (CAPEX and OPEX) standpoint, the driver that erodes some of the Wi-Fi economic advantage is OPEX, especially Wi-Fi site rental and backhaul costs. Along these lines, for the carrier-class Wi-Fi off-loading to materialize, site deployment needs to be managed on a case-by-case basis, by surgically placing sites primarily in high traffic areas.

In a prior report by this author[128], a simulation was presented to determine the economic advantage of relying on carrier-grade Wi-Fi sites to complement the deployment of LTE in the United States. According to Thanki (2012), achieving full LTE coverage in the United States relying on 2100 MHz to accommodate incremental wireless data traffic would require approximately 34,000 new base stations[129], representing a total capital investment of $ 8.5 billion. On two simulation cases of off-loading in New York and San Diego, LCC Wireless assumed a CAPEX benefit of Wi-Fi off-loading ranging between 22.3 % and 44.7 %. When averaging these two estimates, the CAPEX reduction would amount to $2.76 billion. Even under the OPEX considerations mentioned above, the Total Cost of Ownership remains lower under the Wi-Fi off-loading scenario (see table VII-15).

Table VII-15. Total Cost of Ownership of LTE only versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
Total Cost of Ownership	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) OPEX to CAPEX ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

126 "When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.
127 Cisco Aironet 1552H Wireless Access Point.
128 Katz, R. (2018). A 2017 *Assessment of the current and future economic value of unlicensed spectrum in the United States*. Washington, DC: Wi-Fi Forward.
129 This model was adapted by the author from Ofcom, the UK regulator, to assess the effect of differing traffic levels on cell site numbers in urban areas in its consultation "Application of spectrum liberalization and trading to the mobile sector" (Ofcom, 2009).

According to the simulation run for the United States, presented in table VII-15, Wi-Fi carrier grade yields economic savings for a carrier of 18.71%.

Now, let's turn to the German situation. As of 2018, 4G coverage has reached 95%, and, according to GSMA intelligence, this number is not expected to increase in the future. Considering that 5G is not expected to launch before 2020, it is reasonable to assume that the 2018 CAPEX is benefitting from a portion of the network infrastructure being deployed in terms of Wi-Fi sites. In 2018, total CAPEX of wireless operators is estimated by GSMA Intelligence to be $ 3,300 million. If this number already factors in the savings derived from deploying Wi-Fi sites, it would then mean that the CAPEX savings resulting from deploying carrier-grade Wi-Fi as a complement to cellular base stations for the rollout of LTE to accommodate traffic growth in 2018 in Germany would amount to $ 1,618 million[130]. This amount does not include the CAPEX saved by traffic off-loading to residential and business Wi-Fi networks[131]. In addition to the CAPEX driven savings, one would have to add the OPEX in order to understand total producer surplus. According to table IV-17, each $1 billion in CAPEX savings triggers $2.82 billion in OPEX. As a result, total 2018 producer surplus in 2018 triggered by Wi-Fi carrier grade rollout amounts to $ 6.17 billion.

Moving on to estimating the value in 2023, 5G deployment will increase the value of cellular re-routing. Given current announcements and trials, it is expected that German carriers will begin investing in 5G to deploy 5G in 2020 (see table VII-16).

Table VII-16. Germany: Deployment of 5G

	2020	2021	2022	2023
5G Coverage	19.90%	26.97%	37.31%	48.87%
CAPEX (in millions)	$ 3,247	- - -	- - -	- - -

Source: GSMA Intelligence

Therefore, it is assumed that all the CAPEX invested in 2023 in Germany would be dedicated to 5G deployment. In this context, Wi-Fi becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands. To calculate the economic value of Wi-Fi in this context, we rely on the only known cost estimation of 5G to date: the one developed by Oughton and Frias (2016) for OFCOM in the United Kingdom. The authors' baseline case estimates a CAPEX of £42 billion, of which urban coverage investment amounts only to £700 million, while suburban deployment demands £5.6 billion, and rural coverage £35.6 billion. We have used Oughton and Frias (2016) cost decomposition by zone of the UK and applied it to Germany, relying on a cost per POP metric (see Table VII-17).

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[130] CAPEX without Wi-Fi – (CAPEX without Wi-Fi * .329) = $ 3,295 million or
$ 4,910 million – 4,910*.329) = $ 3,295 million

[131] See Cooper (2012).

Table VII-17. Producer surplus of 5G in the United Kingdom vs. Germany

Geography	United Kingdom			Germany	
	Population Breakdown (%)	5G CAPEX (£ Billion)	5G CAPEX (%)	Population Breakdown (%)	5G CAPEX ($ Million)
Urban (cities>1 million)	29%	£0.7 ($0.948)	1.66%	28%	$ 1,109
Suburban	54%	£5.6 ($7.592)	13.33%	48%	$ 8,171
Rural	17%	£35.6 ($48.263)	84.76%	24%	$ 82,501
TOTAL	**100%**	**£41.9 ($56.803)**	**100%**	**100%**	**$91,781**

Sources: Trading Economics; World Bank; U.S. Census Bureau; Trulia; Telecom Advisory Services analysis

Considering that the total CAPEX required to deploy 5G in Germany would be $91,781, and that the incremental 5G coverage between 2022 and 2023 would be 11.6%, it is assumed that the 5G CAPEX in that year will be $ 10,610 million. Considering that this amount reflects the saving incurred by relying on Wi-Fi sites, and applying the same approach as used in 2018, would result in a total producer surplus (adding CAPEX and OPEX savings) of $ 19.88 billion.

VII.6. Locally manufactured Wi-Fi enabled equipment

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. It is assumed that the consumer surplus is roughly equal to consumer surplus (see Milgrom et al., 2011). Both consumer products and enterprise equipment are considered as part of the economic surplus generated by locally manufactured Wi-Fi enabled devices.

VII.6.1. Consumer products

As detailed in section III.3.5, we identified seven consumers products which are intrinsically linked to Wi-Fi: Wi-Fi enabled wireless speakers, home security systems, home networking systems (such Apple's HomePod, Amazon Echo, and Google Home), access points[132], external adapters[133], routers, and gateways. As conducted in the case of the United States, our focus is to estimate economic surplus in Germany, based by revenues of German manufacturers for each product.

In the case of access points, external adapters, routers and gateways, data indicates that the major global players are the US, Chinese, and Taiwanese manufacturers (see table VII-18).

Table VII-18. Consumer products: Global Market shares (2018)

Product	Market (in millions)	United States	United Kingdom	Germany	South Korea	France	Japan	China	Taiwan	ROW
Access points	$ 11,631	0.2 %	0.0%	0.0%	0.0%	13.5%	0.0%	69.1%	7.7%	9.5
External adapters	$ 465.92	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	42.1%	9.7%	41.0%
Routers	$ 4,972.30	5.9%	0.0%	0.0%	0.0%	6.7%	0.0%	52.6%	15.5%	19.3%
Gateways	$ 6,389.25	6.6%	0.0%	0.0%	0.0%	29.0%	0.0%	38.1%	10.3%	16.0%

Sources: ABI Research; Telecom Advisory Services analysis

132 Access points (APs) allow devices to connect to a wireless network.

133 Wireless client device. It can be PCI adapter, which A PCI wireless adapter card is a device that is connected to a desktop computer's PCI bus to provide wireless capability to the desktop, a PC card, or a USB adapter.

On the other hand, the markets for wireless speakers, home security systems, and home networking systems is served by firms like Behringer, Blaupunkt, Bosch, Audiotechnik, Telefunken, and Teufel for speakers, Visionic, and Abus for home security, AVM and Siemens, Elgato Systems for home networking systems. In the absence of market estimates, we opted to estimate the German market by prorating it against the US market for which statistics are abundant. As a result, the market estimates for Germany are as follows (see table VII-19).

Table VII-19. Germany: Consumer Electronics market (in $ million) (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Wireless speakers	$ 5,978	$ 7,773	$ 10,818	$ 11,216	$ 11,656	$ 12,277	$ 12,889	$ 13,509
Home security systems	$ 406	$ 402	$ 427	$ 418	$ 410	$ 408	$ 405	$ 402
Home networking equipment	$ 178	$ 247	$ 367	$ 401	$ 439	$ 488	$ 542	$ 600

Sources: Consumer Technology Association; Telecom Advisory Services analysis

Of these amounts, the prorated profit margin estimated by CSI markets is 44.41%, which yields a producer surplus for this particular product of $ 5,157 million. Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic surplus in 2018 would amount to $ 10.31 billion and would reach $ 12.89 billion in 2023.

VII.6.2. Enterprise products

In the case of enterprise Wi-Fi enabled products, Germany is not included among the main manufacturing countries (see table VII-20).

Table VII-20. Enterprise products: Global Market shares (2018)

Product	Market (in millions)	United States	China	ROW
Access points	$ 5,398	81.3 %	16.8 %	1.9 %
Controllers	$ 1,025	67.3 %	19.9 %	12.8 %

Sources: ABI Research; Telecom Advisory Services analysis

As a result, Wi-Fi enabled enterprise products was not included as a source of economic value.

VII.7. Bridging the digital divide

The digital divide is defined as the gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory).

This analysis assumes that Wi-Fi enabled ISPs would be the primary approach for addressing broadband demand in rural areas. Along these lines, it is assumed that the incremental penetration in broadband subscribers will have an impact on the economy according to a coefficient estimated through regression models that links the increase in broadband lines to economic growth (see table VII-21). Also we assume that half of the new broadband connections can be met by Wi-Fi enabled ISPs.

Table VII-21. Germany: GDP Contribution Resulting from reduction of the digital divide

	2016	2017	2018	2019	2020	2021	2022	2023
Incremental subscribers (million)	0.67	0.68	0.70	0.71	0.73	0.75	0.76	0.78
Incremental subscribers	670,178	684,357	699,283	714,535	730,119	746,044	762,315	778,942
Total broadband subscribers (million)	31.377	32.061	32.760	33.472	34.205	34.951	35.713	36.492
Households (million)	38.889	38.838	38.787	38.736	38.685	38.634	38.583	38.532
Adoption broadband	1.72%	1.76%	1.80%	1.84%	1.89%	1.93%	1.98%	2.02%
Change in broadband penetration	80.68%	82.55%	84.46%	86.42%	88.42%	88.46%	88.51%	88.56%
Additional	2.14%	2.13%	2.13%	2.13%	2.13%	2.18%	2.23%	2.28%
Impact coefficient	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
GDP per capita	$42,250	$44,550	$50,842	$53,276	$55,826	$58,375	$61,054	$63,728
Population (million)	82.014	82.204	82.366	82.489	82.566	82.591	82.574	82,531
Indirect Impact on GDP (in $ billion)	5.92	6.25	7.15	7.50	7.87	8.42	9.00	9.61
Share that exist because Wi Fi	50%	50%	50%	50%	50%	50%	50%	50%
Indirect Impact on GDP (in $ billion)	$ 2.96	$ 3.13	$ 3.58	$ 3.75	$ 3.94	$ 4.21	$ 4.50	$ 4.80

Sources: WISPA (2017); Thomson and Garbacz (2008); Telecom Advisory Services analysis

Based on these calculations, Wi-Fi's contribution to GDP by reducing the digital divide in Germany would amount to $3.58 billion in 2018 and $4.80 billion in 2023.

VII.8. Wi-Fi return to speed

The return to speed is a benefit derived from the fact that Wi-Fi access is, in general considerably faster than cellular networks. In this context, research indicates that faster broadband speed has an impact on economic growth due to the increasing efficiency of a country's economy. In other words, faster broadband networks contribute to growth of a country's GDP. Along these lines, the objective in this case is to quantify the impact Wi-Fi technology has to the average speed of mobile devices in Germany.

We start with the quantification of speed differentials for Germany, which we calculate by subtracting the weighted average of Wi-Fi and cellular speeds (averaged according to traffic off-loading factors) and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (see table VII-22).

Table VII-22. Germany: Estimation of speed differential for total US traffic (in Mbps)

	2016	2017	2018	2019	2020	2021	2022	2023
Average speed of cellular networks	10.02	11.93	14.21	16.92	20.15	24.00	28.58	34.04
Average Wi-Fi speed	21.60	23.92	26.50	29.35	32.50	36.00	39.87	44.16
Average speed of weighted average of cellular and Wi-Fi traffic	19.75	21.75	23.95	26.48	29.36	32.67	36.49	40.92
Speed decrease (average speed of cellular/average weighted average speed)	-49.28%	-45.15%	-40.68%	-36.09%	-31.36%	-26.54%	-21.68%	-16.82%

Source: Cisco; TAS analysis

Having calculated the speed decrease percentage, we then apply this percentage to the coefficient derived from the model developed by Bohlin et al. (2011 and 2013) to gauge the potential impact on GDP if cellular networks transported all traffic (see table VII-23).

Table VII-23. Econometric model measuring the impact of broadband speed on GDP

Independent Variables	Coefficient
Average GDP growth (2008-2010)	0.577 *
Population density	-0.0441 *
Urban population	-0.0103 **
Labor force growth (%)	0.0492 *
Telecom revenue growth (%)	0.0492 *
Population growth (%)	-0.630 **
Average achieved downlink speed	-0.00214
Average achieved downlink speed squared	0.00142 *

*, ** Significant at 1% and 5% critical value respectively
Source: Rohman and Bohlin (2011)

As table VII-23 shows, by incorporating the elasticity of the coefficient of broadband speed and the square of the variable, the model assumes that the doubling of broadband speed causes a 0.3% increase in GDP growth. Our case shows the GDP impact on the **decrease** in speed. This is applied in turn to the German GDP at current prices (see table VII-24).

Table VII-24. Germany: Broadband speed impact on GDP

	2016	2017	2018	2019	2020	2021	2022	2023
Speed decrease (%)	-49.28%	-45.15%	-40.68%	-36.09%	-31.36%	-26.54%	-21.68%	-16.82%
Model coefficient	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%
Decrease in GDP per cap.	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%
GDP per capita (current prices)	42,249.84	44,549.69	50,841.67	53,275.94	55,825.54	58,374.86	61,054.46	63,727.92
Wi-Fi Traffic (% Total Traffic)	38.23%	34.19%	30.30%	27.63%	25.59%	24.03%	22.83%	21.91%
GDP Reduction (in $ millions, current prices)	-1,959	-1,696	-1,548	-1,314	-1,110	-923	-749	-581

Source: Cisco; TAS analysis

Table VII-24 indicates that if all cellular data traffic that is currently being off-loaded to Wi-Fi were to shift to cellular networks, the reduction in speed (in 2018 from an average 26.50 Mbps to 14.21) would have a $1,548 million impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data. In 2023, the amount would reach $581 million. The reduction in economic value is explained by a gradual closing of the speed gap between cellular networks and Wi-Fi

VII.9. Revenues of Wireless ISPs and Wi-Fi service providers

Wi-Fi off-loading can create new business opportunities for service providers offering wireless broadband services in public places (airports, hotels) for a fee. In addition to this segment, Wireless Internet Service Providers (WISPs) rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas. While some WISPs utilize licensed spectrum, the majority relies on unlicensed Wi-Fi spectrum.

The most straightforward way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in Germany. However, while there are a large number of Wi-Fi service providers present in this space, no statistics are available regarding their revenues (as is the case with the United States). Table VII-25 presents a compilation of some of the largest Wi-Fi service providers.

Table VII-25. Germany: Compilation of some of the largest Wi-Fi Service Providers

Company	Business focus
Mywebspot	Offers Wi-Fi access to travelers
M3connect	25,000 access points, hospitality, retail, health care, transportation
Hoist Group	Hospitality and support to network operators, operating in 29 countries, including Germany
Airangel	Enterprise, hospitality
KraftCom	Hospitality
ABL Social Federation	Hospitality, retail, stadiums

Source: Company web sites; interviews

In the absence of revenue statistics (the approach followed to estimate economic value in the United States), we have calculated Wi-Fi revenues in Germany by prorating US Wi-Fi revenues based on the German GDP. Thus, it is estimated that the 2018 GDP contribution accounts for $697 million, and that it is expected to reach $ 2,345 million by 2023.

VII.10. Wi-Fi contribution to employment

The estimation of employment generated is calculated by relying on the total GDP contribution resulting from the effects analyzed above and using that as an input in the communications sector of an input-output matrix of the German economy. Table VII-26 presents the GDP contribution of each of the effects analyzed above.

Table VII-26. Germany: Total GDP Contribution of Wi-Fi (in $ billion)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$ 3.57	$ 3.75	$ 3.94	$ 4.21	$ 4.50	$ 4.80
Return to speed	$ 1.55	$ 1.31	$ 1.11	$ 0.92	$ 0.75	$ 0.58
Wi-Fi carriers	$ 0.70	$ 0.87	$ 1.09	$ 1.35	$ 1.86	$ 2.35
Total	$ 5.82	$ 5.93	$ 6.14	$ 6.48	$ 7.11	$ 7.73

Source: Telecom Advisory Services analysis

These inputs generate the following annual employment effects based on the I-O matrix for the German economy (table VII-27).

Table VII-27. Germany: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	53,435	70,949
Indirect jobs	8,596	11,414
Induced jobs	3,037	4,032
Total	65,068	86,395

Source: Telecom Advisory Services analysis

According to the contribution to the GDP, Wi-Fi is generating 65,068 jobs in 2018 and is expected to generate 86,395 in 2023. Job estimates include direct jobs (those jobs created by the specific Wi-Fi contribution), indirect jobs (those jobs created by suppliers to the Wi-Fi sector); induced jobs (those jobs created by spending of direct and indirect workers).

The sector breakdown of 2018 employment is as follows (table VII-28).

Table VII-28. Germany: Sector Breakdown of Wi-Fi generated annual employment

Sector	Direct	Indirect	Induced	Total
Agriculture	0	0	55	55
Extractive industries	0	403	2	405
Manufacturing	0	480	11	491
Construction	0	578	0	578
Trade	0	878	878	1,756
Transportation	0	98	1,617	1,715
Communications	53,435	0	0	53,435
Financial Services	0	934	0	934
Business services	0	4,482	0	4,482
Other services	0	743	474	1,217
TOTAL	53,435	8,596	3,037	65,068

Source: Telecom Advisory Services analysis

VIII. ECONOMIC VALUE OF WI-FI IN JAPAN

Wi-Fi technology in Japan exhibits a comparable development of community hotspots but a much larger deployment of commercial access points than Germany, a comparable European country. According to the iPass Wi-Fi Growth Map, there are currently 818,360 commercial hotspots and 21,373,940 community access points operating in the Japanese territory[134]. On the other hand, Wi-Fi usage intensity appears to be slightly lower in Japan than in Germany. According to OpenSignal[135], Japanese wireless users spend 58.54% of their communications time connected to Wi-Fi networks rather than relying on their cellular data connection[136]. Along these lines, the intensive usage of Wi-Fi technology should have a significant impact on its social and economic benefits. This chapter presents first the summary of economic value estimates and then reviews each of the particular effects.

The methodology reviewed in chapter III was utilized to calculate the economic value of Wi-Fi in Japan. This chapter presents first the summary of results and then reviews each of the particular effects. Please refer to chapter III for detailed descriptions of each economic factor.

VIII.1. Total economic value (2018 and 2023)

The total economic value of Wi-Fi in Japan in 2018 amounts to $ 171.46 billion, which is roughly equivalent to the GDP of the Qatar[137]. This is comprised of $ 163.63 billion in economic surplus and $ 7.83 billion in contribution to the GDP (see table VIII-1).

Table VIII-1. Japan: Total Economic Value of Wi-Fi (2018) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 1,440	N.A.	$ 1,440	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 28,476	N.A.	$ 28,476	N.A.
	2.2. Inside wiring avoidance	$ 41,080	N.A.	$ 41,080	N.A.
	Subtotal	$ 69,556	N.A.	$ 69,556	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 18,965	$ 18,965	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 38,234	$ 38,234	N.A.
	Subtotal	N.A.	$ 57,199	$ 57,199	N.A.
4. Value of cellular off-loading		N.A.	$ 20,910	$ 20,910	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 6,633	$ 6,633	$ 13,266	N.A.
	5.2. Locally manufactured enterprise devices	N.A.	$ 1,257	$ 1,257	N.A.
	Subtotal	$ 6,633	$ 7,890	$ 14,523	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 5,050
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 1,912
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 864
TOTAL		$ 77,629	$ 85,999	$ 163,628	$ 7,826

Source: Telecom Advisory Services analysis

[134] Compared to 150,301 commercial and 21,455,333 community access points in Germany.
[135] OpenSignal. *Global State of Mobile Networks* (August 2016).
[136] Compared to 62.04% in Germany.
[137] Source: International Monetary Fund (2017).

The key sources of Wi-Fi economic value are residential use ($ 69.56 billion in consumer surplus) and cellular rerouting ($ 20.91 billion). Beyond this, the value of Wi-Fi enabled equipment (wireless speakers, security systems, etc.) has a significant impact in terms of economic surplus ($ 13.27 billion).

A 2023 forecast of the same value will reach $ 247.53 billion, composed of $ 236.57 billion in economic surplus, and $ 10.96 billion in GDP contribution (see table VIII-2).

Table VIII-2. Japan: Total Economic Value of Wi-Fi (2023) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 2,027	N.A.	$ 2,027	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 70,237	N.A.	$ 70,237	N.A.
	2.2. Inside wiring avoidance	$ 46,219	N.A.	$ 46,219	N.A.
	Subtotal	$ 116,456	N.A.	$ 116,456	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 34,130	$ 34,130	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 38,234	$ 38,234	N.A.
	Subtotal	N.A.	$ 72,364	$ 72,364	
4. Value of cellular off-loading		N.A.	$ 29,021	$ 29,021	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 7,499	$ 7,499	$ 14,998	N.A.
	5.3Locally manufactured enterprise devices	N.A.	$ 1,705	$ 1,705	N.A.
	Subtotal	$ 7,499	$ 9,204	$ 16,703	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 6,250
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 2,033
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 2,678
TOTAL		$ 125,982	$ 110,589	$ 236,571	$ 10,961

Source: Telecom Advisory Services analysis

The relative importance of sources of economic value by 2023 remains the same as in 2018. Residential Wi-Fi usage remains the largest source of economic value ($116.46 billion), followed by enterprise use ($72.36 billion) and cellular carrier offloading ($29.02 billion).

VIII.2. Free Wi-Fi traffic

One dimension of Wi-Fi's economic value is derived from savings consumers receive by accessing the Internet through no cost sites (in retail shops, cafes, etc.) rather than relying on their cellular data plan. The following section presents the quantification of such benefit.

Total Internet traffic in Japan is growing at 29.40 %, while mobile Internet traffic has been growing a slightly lower rate (28.70%) per annum. As a result, mobile traffic remains stable at a 15% share of Internet traffic, as indicated in Table VIII-3.

Table VIII-3. Japan: Internet Traffic (2016-2018) (in exabytes[138] per month)

	2016	2017	2018	CAGR
Total Internet	3.50	4.53	5.86	29.40 %
Wireless Internet	0.54	0.69	0.89	28.70 %

Source: Cisco; Telecom Advisory Services analysis

The growing adoption of wireless data-enabled devices (smartphones, tablets, PCs) combined with an increase in usage per device has been propelling overall mobile Internet traffic growth in the country. The installed base of smartphones in Japan has reached 120.87 million in 2018. In the same year, the tablet installed base accounts for 19.51 million while the number of laptops has declined from 72.30 million in 2016 to 67.37 million in 2018 (2016-18 CAGR: -3.47%[139]) due to tablet and, secondarily, smartphone substitution (see table VIII-4).

Table VIII-4. Japan: Device Installed Base and Penetration (2016-2018)

Device	Metrics	2016	2017	2018 (E)	CAGR
Smartphones	Units (in millions)	108.10	114.30	120.87	5.74 %
	Penetration (%)	84.71 %	89.77 %	95.16 %	5.99 %
Tablets	Units (in millions)	19.10	19.52	19.51	2.20 %
	Penetration (%)	14.97 %	15.33 %	15.71 %	2.44 %
Laptops	Units (in millions)	72.30	69.79	67.37	-3.47 %
	Penetration (%)	56.65 %	54.81 %	53.04 %	- 3.24 %

Sources: Cisco; GSMA Intelligence; Telecom Advisory Services analysis

Beyond the laptop to tablet substitution, the installed base of smartphones has shifted to 4G (LTE) network standards that provide faster speed of access and, consequently, stimulate more intense data usage. Looking forward, it is projected that, with the launch of 5G, the average speed of mobile devices by 2023 would have doubled from the current 23.95 Mbps to 47.23 Mbps[140].

Adding to the proliferation of devices, traffic per device in Japan has grown between 17.18% per annum for laptops and 32.19% for tablets (see table VIII-5).

Table VIII-5. Japan: Average Traffic Per Device (2016-2018) (in Gigabytes per month)

	2016	2017	2018 (E)	CAGR
Smartphones	11.70	14.65	18.34	25.21%
Tablets	19.60	25.91	34.25	32.19%
Laptops	18.60	21.80	25.54	17.18%

Source: Cisco VNI; Telecom Advisory Services analysis

It is interesting to note that while traffic per smartphone and tablets is higher in Japan than in the United States, the reverse is the case for laptops where US traffic is twice that of Japan. On the other hand, the growth rate for traffic in both countries is fairly aligned.

With the installed base and average data usage per device, total mobile Internet traffic in Japan was calculated for the next five years. We estimate a total traffic of 3.15 Exabytes per month in

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[138] 1 Exabyte equals 1,073,741,824 gigabytes.

[139] Note than the laptop installed base in the United States is still growing, albeit at only 3.90% (see chapter IV).

[140] Source: Cisco Visual Networking Index.

2023. Projections regarding traffic growth from other sources vary, although they all agree directionally (see table VIII-6).

Table VIII-6. Japan: Mobile Internet Traffic (2018-2023)
(In million Exabytes per month)

	2018	2019	2020	2021	2022	2023	CAGR
Total Internet	5.86	7.58	9.81	12.70	16.43	21.27	29.40 %
Mobile Internet	0.89	1.15	1.48	1.90	2.45	3.15	38.70 %

Source: Cisco; Telecom Advisory Services analysis

This growth has and will continue to put pressure on the public cellular networks to accommodate the traffic without incurring congestion while generating acceptable levels of revenue. This prompts the communications system to rely on Wi-Fi to handle a portion of the traffic. We will now estimate the portion of traffic that is off-loaded to Wi-Fi in Japan.

As one of the most advanced global cellular markets, Japan was one of the first to suffer from heavy data congestion causing poor user experience, and sharply increasing network costs. In early 2010, Softbank CEO Masayoshi Son was one of the first to call for Wi-Fi to offload the data stress on mobile networks. Softbank became a pioneer in deploying Wi-Fi networks in Japan. By 2015, the carrier had installing over 1 million hotspots deployed, which resulted in 50% of total traffic generated by Softbank's customers being off-loaded to Wi-Fi. In March 2013, NTT Docomo had deployed 150,000 access points[141]. In 2012, KDDI, the third major Japanese cellular carrier, deployed 100,000 Wi-Fi access points to off-load cellular traffic.[142] Based on the available data, it is estimated that the off-loading factor for Japanese carriers is 60% for smartphones and 50% for tablets and laptops[143].

By applying this off-loading factor to the total mobile data traffic, we project that total Wi-Fi traffic in Japan is currently 2.38 Exabytes per month in 2018, and reflecting a 36.18% growth rate (see table VIII-7).

Table VIII-7. Japan: Total Wi-Fi Traffic Per Device (2016-2018)
(In Exabytes per month)

	2016	2017	2018(E)	CAGR
Smartphones	0.48	0.65	1.21	58.14%
Tablets	0.17	0.24	0.33	38.20%
Laptops	0.63	0.72	0.84	15.71%
Total	1.28	1.61	2.38	36.18%

Source: Telecom Advisory Services analysis

The estimation of consumer surplus is conducted by multiplying the total Wi-Fi traffic from table VIII-7 by the portion representing the "true free traffic" generated in public sites. While precise estimates for this value are non-existent for Japan, free Wi-Fi access points are quite prevalent in the country. Sources estimate there are 992,760 open Wi-Fi networks in the country, of which 515,000 are in Tokyo, and 248,000 in Yokohama[144]. Subject-matter experts interviewed have ranged the percent of free Wi-Fi traffic between 5% and 10%. Considering that statistics for the United States indicate 4.32% of Wi-Fi traffic to be "free", we opted to stay within the conservative side, and utilize the 5% value (see table VIII-8).

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[141] Ninagawa, T. and Hirama, K. Public Wi-Fi initiatives at NTT Docomo. *NTT Technical Review*, 2015.
[142] Ford, T. "KDDI to build 100,000 Wi-Fi network to offload cellular traffic", *RCR Wireless*, July 5, 2011.
[143] Interview with Claus Hetting.
[144] Source: Wiman (2018). *Mobile Open Wi-Fi Spots in Japan.*

Table VIII-8. Japan: Total Free Wi-Fi Traffic (2016-2018)

	2016	2017	2018(E)
Total Wi-Fi Traffic (in Exabytes per month)	1.28	1.61	2.38
Total Free Traffic (in Exabytes per month)	0.06	0.08	0.12
Total Free Traffic (in Exabytes per year)	0.77	0.97	1.43
Total Free Traffic (in million Gigabytes per year)	827.85	1040.45	1535.17

Source: Telecom Advisory Services analysis

We calculated consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we needed an estimate of the average price per GB of wireless data transmitted by wideband networks in Japan, which we calculated by averaging the most economic "dollar per GB" plan (so-called "unlimited") of the three major wireless carriers: KDDI, NTT Docomo, and Softbank (see table VIII-9).

Table VIII-9. Japan: Average Price Per Gigabyte (2017)

Carrier	Market share	Plan	Price per Gb (Yen)
KDDI	41 %	Data flat fee 30/30 (V) (30 GB)	¥ 266.67
NTT DOCOMO	39 %	Ultra Share pack 100 (100GB)	¥ 250.00
SoftBank	20 %	Ultra Giga	¥ 130.00
Average			¥ 233.02

Note: The average is calculated by prorating every price per GB by the carrier's market share.
Source: Telecom Advisory Services analysis

Since the assessment of economic value is done in US dollars, the average price per GB is converted to $ 2.11. Historical data compiled for the US market allowed for projecting the future price per Gigabyte (see figure III-1 in chapter III).

According to these projections, while the average price per GB in 2017 is $ 2.11, it is estimated that by 2023, it will reach an estimated $1.12. As to the cost of offering the service through Wi-Fi, this would include an additional router and needed bandwidth. For estimation purposes, we assume those costs to be 45% of the cost of offering the same GB via cellular networks[145]. This means that the cost per Gigabyte offered by the site providing the service for free would be $0.96 in 2017, declining to $0.74 in 2023. By relying on the total free Wi-Fi traffic shown in table VIII-8 and the average price per cellular Gigabyte minus the cost of provisioning free Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic (see table VIII-10).

Table VIII-10. Japan: Consumer Surplus of Free Wi-Fi Traffic (2018-2023)

	2018	2019	2020	2021	2022	2023
Total Free Traffic (in million Gigabytes per year)	1,535	1,962	2,564	3,280	4,181	5,344
Price per cellular gigabyte ($)	$ 1.90	$ 1.71	$ 1.54	$ 1.38	$ 1.25	$ 1.12
Cost per Wi-Fi provisioning ($)	$ 0.96	$ 0.91	$ 0.87	$ 0.82	$ 0.78	$ 0.74
Consumer surplus per Gigabyte ($)	$ 0.94	$ 0.80	$ 0.67	$ 0.56	$ 0.46	$ 0.38
Total Consumer surplus (in $ million)	1,440	1,563	1,723	1,842	1,942	2,027

Source: Telecom Advisory Services analysis

As indicated in table VIII-10, consumer surplus of free Wi-Fi traffic in 2018 would reach an estimated $ 1.44 billion and $ 2.03 billion in 2023.

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[145] This is relationship found in the case of the United States (see chapter IV).

VIII.3. Value of Residential Wi-Fi

The value of residential Wi-Fi is a combination of Internet access for home usage and avoidance of in-house wiring.

VIII.3.1. Home Internet access for devices that lack an Ethernet port

As mentioned in Chapter III, the underlying assumption of this analysis is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on the cellular network to access the Internet. As a consequence, estimating value of home access requires first to measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers.

Based on our traffic model, the total traffic generated by these types of devices in 2018 in Japan amounts to 34,801 million Gigabytes, reaching 145,106 million Gigabytes by 2023 (see table VIII-11).

Table VIII-11. Japan: Total Mobile Internet Traffic (2016-2023) (in million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	15,177	20,094	26,602	35,220	46,629	61,733	81,730	108,205
Tablets	4,492	6,069	8,199	11,077	14,965	20,218	27,314	36,901
Total	19,669	26,163	34,801	46,297	61,594	81,951	109,044	145,106

Source: Cisco; GSMA; analysis Telecom Advisory Services

A portion of this traffic is, as expected, generated while the subscriber is in his residence, relying on the Wi-Fi service. According to a Cisco study conducted in the United States in 2012[146], 43.12% of use time of devices that lack a wired port occurs at home. Assuming that travel patterns have remained fairly stable since (e.g. time spent at work vs. home vs. public places), we chose to rely on this statistic for Japanese residential use for our Japan estimations. Therefore, the portion of said traffic generated at home reached 15,005 million Gigabytes in 2018 and is expected to amount to 62,566 million Gigabytes in 2023 (see table VIII-12).

Table VIII-12. Japan: Home Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	6,544	8,664	11,470	15,186	20,105	26,617	35,240	46,655
Tablets	1,937	2,617	3,535	4,776	6,453	8,718	11,777	15,911
Total	8,481	11,281	15,005	19,962	26,558	35,335	47,017	62,566

Source: Cisco; GSMA; analysis Telecom Advisory Services

If this traffic had to be transported by cellular networks, at the average price per GB estimated in the model of table VIII-9, it would result in costs of $ 28.48 billion in 2018 and $ 70.24 billion in 2023, savings to consumers that become consumer surplus.

VIII.3.2. Avoidance of investment in in-house wiring

[146] Cisco IBSG (2012)

Residential Wi-Fi allows consumers to avoid paying for wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in residence reaches approximately $1,390 per household[147].

In order to estimate the benefit derived from wiring avoidance, the number of total Wi-Fi households in Japan is required. Strategy Analytics reported that in 2012, 68.4% of Japanese households were equipped with Wi-Fi[148], out of total universe of broadband Internet households of 78%[149]. Considering that broadband households have reached 93% in 2018, we estimate Wi-Fi households to be 78% in 2018, reaching 88% by 2023.

Considering that 78% of Japanese households currently have Wi-Fi[150], the avoidance cost of inside wiring for 36.8 million households, which in the absence of Wi-Fi yields a total cost of wiring of $ 41.08 billion. By 2023, with 87% of households having adopted Wi-Fi, the savings would have reached $ 46.22 billion[151].

VIII.4. Enterprise Wi-Fi

As stated in chapter III, the economic value of enterprise Wi-Fi has two sources:

- Business traffic routed through Wi-Fi access points rather than cellular networks;
- Avoidance of capital investment to deploy Ethernet wiring inside enterprise establishments to connect devices and peripherals.

VIII.4.1. Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. In 2018, Cisco VNI and Telecom Advisory Services analysis estimate that total Japanese business Internet traffic will reach 1.91 billion GB, of which 9.99 billion GB are transported through Wi-Fi access points. Considering that the average price per GB transported by cellular is $1.90 (per the analysis presented above), savings from Wi-Fi would have reached $ 18.96 billion, an addition to the producer surplus. By 2023, this benefit will reach $ 34.13 billion (see table VIII-13).

Table VIII-13. Japan: Savings in business wireless traffic (2016-2023)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Share of Business Internet Traffic by Wi-Fi	50.00%	51.15%	52.32%	53.52%	54.74%	56.00%	57.28%	58.60%
Total Business Internet Traffic (million Gb)	12,808	15,641	19,101	23,327	28,487	34,789	42,485	51,884
Total Business Wi-Fi enterprise traffic (million Gb)	6,404	8,000	9,993	12,484	15,595	19,482	24,337	30,403
Average Price per Gb	$2.11	$2.11	$1.90	$1.71	$1.54	$1.38	$1.25	$1.12
Economic Impact (in million $)	$ 13,498	$ 16,862	$ 18,965	$ 21,330	$ 23,989	$ 26,981	$ 30,346	$ 34,130

Source: Cisco; analysis Telecom Advisory Services

[147] GDP adjusted estimate relative to the cost in Germany of $ 1,390. As a calibration, the cost of CAT6 cable in Japan is $22.7 for 15 meters, while the price of a switching hub for eight ports approximates $21.8. In addition, a consumer will have to pay for set-up and installation.
[148] Burger, A. (2012) "Wi-Fi households to approach 800 million by 2016", *Telecompetitor*
[149] Internet World Stats.
[150] Source: Watkins, David. *Broadband and Wi-Fi Households Global Forecast 2012*. Strategy Analytics
[151] This assumes that inside wiring costs will remain constant.

VIII.4.2. Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points, and multiply this value by a standard cost of deploying a CAT 6 network. The cost of deploying inside telecommunication wiring for an enterprise in Japan was calculated by prorating the cost estimated for Germany ($ 6,636), which results in $ 5,331 per establishment.

Assuming all 7,171,000 business establishments in Japan[152] are utilizing Wi-Fi which therefore allows them to save in wiring costs and that number is expected to remain stable, the 2018 savings resulting from avoiding inside wiring amounts to $ 38,234 million, which is expected to remain constant through 2023.

VIII.5. Cellular off-loading

The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks.

This analysis starts with the predicted incremental wireless data traffic generated between 2018 and 2023. According to the traffic forecast presented in table VIII-6 above, future monthly wireless data traffic in Japan amounts to 0.89 Exabytes per month in 2018 and will reach 3.15 Exabytes per month in 2023. Until 2020, when 5G is expected to launch, this traffic should be handled through a combination of 3G and primarily 4G.

As described before, the available statistics indicate that all three major wireless carriers operating in Japan have, to different degrees, deployed an important number of carrier grade Wi-Fi sites[153]. Due to their relative economic advantage relative to cellular base stations, carrier grade Wi-Fi deployment allows wireless operators to save both on CAPEX and OPEX. While the economic advantage of Wi-Fi off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are in general considerably less expensive than cellular network equipment with similar capacity. For example, a cellular pico-cell (needed to offer access via conventional cellular service) costs between $7,500 and $15,000[154], while a carrier-grade Wi-Fi access point requires an investment of $2,500[155]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table VIII-14).

[152] Source: Trading Economics.

[153] By 2015, Softbank had installing over 1 million hotspots deployed, which resulted in 50% of total traffic generated by Softbank's customers being off-loaded to Wi-Fi. In March 2013, NTT Docomo had deployed 150,000 access points[153]. In 2012, KDDI, the third major Japanese cellular carrier, deployed 100,000 Wi-Fi access points to off-load cellular traffic.

[154] "When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.

[155] Cisco Aironet 1552H Wireless Access Point.

Table VIII-14. Comparative Carrier Grade Wi-Fi and LTE Macro Cell CAPEX and OPEX

	Wi-Fi Site	LTE Macro Cell
New Site acquisition	$ 600	$ 150,000
Collocation	-	$ 50,000
Backhaul	$ 300	$ 5,000
Monthly site rental	$ 20	$ 1,000
Site maintenance/month	$ 10	$ 200

Source: LCC Wireless (2012)

As table VIII-14 shows, Wi-Fi has significant economic advantages at the unit level. However, we must add a caveat here. Site density requirements for Wi-Fi are much higher than for cellular. For example, in a dense urban environment with high traffic, for each cellular site, 23 Wi-Fi hotspots are required. The difference means that, from a Total Cost of Ownership (CAPEX and OPEX) standpoint, the driver that erodes some of the Wi-Fi economic advantage is OPEX, especially Wi-Fi site rental and backhaul costs. Along these lines, for the carrier-class Wi-Fi off-loading to materialize, site deployment needs to be managed on a case-by-case basis, by surgically placing sites primarily in high traffic areas.

In a prior report by this author[156], a simulation was presented to determine the economic advantage of relying on carrier-grade Wi-Fi sites to complement the deployment of LTE in the United States. According to Thanki (2012), achieving full LTE coverage in the United States relying on 2100 MHz to accommodate incremental wireless data traffic would require approximately 34,000 new base stations[157], representing a total capital investment of $ 8.5 billion. On two simulation cases of off-loading in New York and San Diego, LCC Wireless assumed a CAPEX benefit of Wi-Fi off-loading ranging between 22.3 % and 44.7 %. When averaging these two estimates, the CAPEX reduction would amount to $2.76 billion. Even under the OPEX considerations mentioned above, the Total Cost of Ownership remains lower under the Wi-Fi off-loading scenario (see table VIII-15).

Table VIII-15. Total Cost of Ownership of LTE only versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
Total Cost of Ownership	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) OPEX to CAPEX ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

According to the simulation run for the United States, presented in table VIII-15, Wi-Fi carrier grade yields economic savings for a carrier of 18.71%.

Now, let's turn to the Japanese situation to estimate the benefit incurred by local cellular carriers that have been aggressively deploying Wi-Fi access points. As of 2018, 4G coverage has reached 99%[158]. Considering that 5G is not expected to launch before 2020, it is reasonable to assume

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[156] Katz, R. (2018). A 2017 *Assessment of the current and future economic value of unlicensed spectrum in the United States*. Washington, DC: Wi-Fi Forward.
[157] This model was adapted by the author from Ofcom, the UK regulator, to assess the effect of differing traffic levels on cell site numbers in urban areas in its consultation "Application of spectrum liberalization and trading to the mobile sector" (Ofcom, 2009).
[158] Source: GSMA Intelligence.

that the 2018 CAPEX is benefitting from a portion of the network infrastructure being deployed in terms of Wi-Fi sites. In 2018, total CAPEX invested by all Japanese cellular operators is estimated by GSMA Intelligence to be $11,166 million. If this number already factors in the savings derived from deploying Wi-Fi sites, it would then mean that the CAPEX savings resulting from deploying carrier-grade Wi-Fi as a complement to cellular base stations for the rollout of LTE to accommodate traffic growth in 2018 in Japan would amount to $ 5.47 billion[159]. This amount does not include the CAPEX saved by traffic off-loading to residential and business Wi-Fi networks[160]. In addition to the CAPEX driven savings, one would have to add the OPEX in order to understand total producer surplus. According to table VIII-15, each $1 billion in CAPEX savings triggers $2.82 billion in OPEX. As a result, total 2018 producer surplus in 2018 triggered by Wi-Fi carrier grade rollout amounts to $ 20.91 billion.

Moving on to estimating the value in 2023, 5G deployment will increase the value of cellular off-loading. Given current announcements and trials, it is expected that Japanese carriers will launch 5G in 2020, and the planned total investment is $ 45.5 billion[161]. The total amount was spread through four years based on the progression of 5G coverage (see table VIII-16).

Table VIII-16. Japan: Deployment of 5G

	2020	2021	2022	2023
5G Coverage	16.90%	62.47%	96.52%	96.52%
CAPEX (in millions)	$ 7,690	$ 10,551	$ 10,551	$ 15,493

Source: GSMA Intelligence

It is assumed that all the CAPEX invested in 2023 in Japan would be dedicated to 5G deployment. In this context, Wi-Fi becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands.

Considering that the total CAPEX required to deploy 5G in Japan would be $45.50 billion, it is assumed that the 5G CAPEX in 2023 will be $ 15.49 billion. Considering that this amounts already factors in the saving incurred by relying on Wi-Fi sites, and applying the same approach as used in 2018, would result in a total producer surplus (adding CAPEX and OPEX savings) of $ 29.02 billion.

VIII.6. Locally manufactured Wi-Fi enabled equipment

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. It is assumed that the consumer surplus is roughly equal to consumer surplus (see Milgrom et al., 2011). Both consumer products and enterprise equipment are considered as part of the economic surplus generated by locally manufactured Wi-Fi enabled devices.

VIII.6.1. Consumer products

As detailed in section III.3.5, we identified seven consumers products which are intrinsically linked to Wi-Fi: Wi-Fi enabled wireless speakers, home security systems, home networking

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[159] CAPEX without Wi-Fi – (CAPEX without Wi-Fi * .329) = $ 11,166 million– (11,166*.329) = $ 5,475 million
[160] See Cooper (2012).
[161] Telecom Ramblings. *Japan's cellcos to invest over $45.5 billion in 5G*. June 8, 2017.

systems (such Apple's HomePod, Amazon Echo, and Google Home), access points[162], external adapters[163], routers, and gateways. As conducted in the case of the United States, our focus is to estimate economic surplus in Japan, based by revenues of Japanese manufacturers for each product.

In the case of access points, external adapters, routers and gateways, data indicates that the major global players are the US, Chinese, and Taiwanese manufacturers (see table VIII-18).

Table VIII-18. Consumer products: Global Market shares (2018)

Product	Market (in millions)	United States	United Kingdom	Germany	South Korea	France	Japan	China	Taiwan	ROW
Access points	$ 11,631	0.2 %	0.0%	0.0%	0.0%	13.5%	0.0%	69.1%	7.7%	9.5
External adapters	$ 465.92	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	42.1%	9.7%	41.0%
Routers	$ 4,972.30	5.9%	0.0%	0.0%	0.0%	6.7%	0.0%	52.6%	15.5%	19.3%
Gateways	$ 6,389.25	6.6%	0.0%	0.0%	0.0%	29.0%	0.0%	38.1%	10.3%	16.0%

Sources: ABI Research; Telecom Advisory Services analysis

Consequently, no benefit can be assigned to Japan.

On the other hand, the markets for wireless speakers, home security systems, and home networking systems is served by firms like Denon, Fostex, JVC, Onkyo, Panasonic, Pioneer, Sansui, Sony, TOA, and Yamaha for speakers, Tanaka, Fujicell, and Maspro for home security, and Toshiba, Panasonic, as well as Hitachi for home networking systems. In the absence of market estimates, we opted to estimate the Japanese market by prorating it against the US market for which statistics are abundant. As a result, the market estimates for Japan are as follows (see table VIII-19).

Table VIII-19. Japan: Consumer Electronics market (in $ million (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Wireless speakers	$ 8,583	$ 10,813	$ 14,101	$ 14,407	$ 14,604	$ 14,854	$ 15,380	$ 15,897
Home security systems	$ 453	$ 438	$ 439	$ 427	$ 411	$ 398	$ 392	$ 385
Home networking equipment	$ 209	$ 283	$ 396	$ 429	$ 462	$ 500	$ 550	$ 604

Sources: Consumer Technology Association; Telecom Advisory Services analysis

Of these amounts, the prorated profit margin estimated by CSI markets is 44.41%, which yields a 2018 producer surplus for this particular product of $ 6,633 million. Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic surplus in 2018 would amount to $ 13.27 billion and would reach $ 15.00 billion in 2023.

VIII.6.2. Enterprise products

A similar analysis as the one reviewed above was conducted for the two main enterprise Wi-Fi enabled pieces of equipment: access points and controllers (see table VIII-20).

[162] Access points (APs) allow devices to connect to a wireless network.
[163] Wireless client device. It can be PCI adapter, which A PCI wireless adapter card is a device that is connected to a desktop computer's PCI bus to provide wireless capability to the desktop, a PC card, or a USB adapter.

Table VIII-20. Japan: Economic Value of Wi-Fi enabled enterprise equipment (In $ million) (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Access points	1,113	1,141	1,223	1,281	1,416	1,485	1,544	1,633
Controllers	191	171	192	209	237	255	272	287
Total	1,304	1,312	1,415	1,490	1,654	1,741	1,815	1,920
Gross margin	42.87%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%	44.41%
Producer surplus (buy)	559	583	628	662	734	773	806	853
Producer surplus (sells)	559	583	628	662	734	773	806	853

Sources: ABI Research; CSI markets; Telecom Advisory Services analysis

VIII.7. Bridging the digital divide

The digital divide is defined as the gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory).

This analysis assumes that Wi-Fi enabled ISPs would be the primary approach for addressing broadband demand in rural areas. Along these lines, it is assumed that the incremental penetration in broadband subscribers will have an impact on the economy according to a coefficient estimated through regression models that links the increase in broadband lines to economic growth (see table VIII-21). Also we assume that half of the new broadband connections can be served by Wi-Fi enabled ISPs.

Table VIII-21. Japan: GDP Contribution Resulting from reduction of the digital divide

	2016	2017	2018	2019	2020	2021	2022	2023
Incremental subscribers (million)	1.16	0.99	1.02	1.04	1.07	1.10	1.12	1.15
Incremental subscribers	1,159,518	993,658	1,018,439	1,043,839	1,069,873	1,096,555	1,123,903	1,151,933
Total broadband subscribers (million)	39.842	40.836	41.854	42.898	43.968	45.064	46.188	47.340
Households (million)	46.995	47.077	47.159	47.240	47.322	47.405	47.487	47.569
Adoption broadband	2.47%	2.11%	2.16%	2.21%	2.26%	2.31%	2.37%	2.42%
Change in broadband penetration	84.78%	86.74%	88.75%	90.81%	92.91%	92.96%	93.02%	93.07%
Additional	2.91%	2.43%	2.43%	2.43%	2.43%	2.49%	2.54%	2.60%
Impact coefficient	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%
GDP per capita	38,983	38,440	40,849	42,522	43,755	45,060	46,491	48,036
Population (million)	127.616	127.335	127.020	126.675	126.302	125.903	125.477	125.027
Indirect Impact on GDP (in $ billion)	11.58	9.53	10.10	10.49	10.76	11.29	11.87	12.50
Share that exist because Wi Fi	50%	50%	50%	50%	50%	50%	50%	50%
Indirect Impact on GDP (in $ billion)	$ 5.79	$ 4.77	$ 5.05	$ 5.25	$ 5.38	$ 5.65	$ 5.94	$ 6.25

Sources: WISPA (2017); Thomson and Garbacz (2008); Telecom Advisory Services analysis

Based on these calculations, Wi-Fi's contribution to GDP by reducing the digital divide in Germany would amount to $5.05 billion in 2018 and $6.25 billion in 2023.

VIII.8. Wi-Fi return to speed

The return to speed is a benefit derived from the fact that Wi-Fi access is, in general considerably faster than cellular networks. In this context, research indicates that faster broadband speed has an impact on economic growth due to the increasing efficiency of a country's economy. In other words, faster broadband networks contribute to growth of a country's GDP. Along these lines, the objective in this case is to quantify the impact Wi-Fi technology has to the average speed of mobile devices in Japan.

We start with the quantification of speed differentials for Japan, which we calculate by subtracting the weighted average of Wi-Fi and cellular speeds (averaged according to traffic off-loading factors) and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (see table VIII-22).

Table VIII-22. Japan: Estimation of speed differential for total US traffic (in Mbps)

	2016	2017	2018	2019	2020	2021	2022	2023
Average speed of cellular networks	18.26	20.91	23.95	27.44	31.43	36.00	41.24	47.23
Average Wi-Fi speed	27.90	32.30	37.39	43.28	50.10	58.00	67.14	77.72
Average speed of weighted average of cellular and Wi-Fi traffic	25.05	28.88	33.73	38.95	45.05	52.02	60.05	69.34
Speed decrease (average speed of cellular/average weighted average speed)	-27.13%	-27.59%	-28.99%	-29.55%	-30.24%	-30.80%	-31.33%	-31.88%

Source: Cisco; TAS analysis

Having calculated the speed decrease percentage, we then apply this percentage to the coefficient derived from the model developed by Bohlin et al. (2011 and 2013) to gauge the potential impact on GDP if cellular networks transported all traffic (see table VIII-23).

Table VIII-23. Econometric model measuring the impact of broadband speed on GDP

Independent Variables	Coefficient
Average GDP growth (2008-2010)	0.577 *
Population density	-0.0441 *
Urban population	-0.0103 **
Labor force growth (%)	0.0492 *
Telecom revenue growth (%)	0.0492 *
Population growth (%)	-0.630 **
Average achieved downlink speed	-0.00214
Average achieved downlink speed squared	0.00142 *

*, ** Significant at 1% and 5% critical value respectively
Source: Rohman and Bohlin (2011)

As table VIII-23 shows, by incorporating the elasticity of the coefficient of broadband speed and the square of the variable, the model assumes that the doubling of broadband speed causes a 0.3% increase in GDP growth. Our case shows the GDP impact on the **decrease** in speed. This is applied in turn to the Japanese GDP at current prices (see table VIII-24).

Table VIII-24. Japan: Broadband speed impact on GDP

	2016	2017	2018	2019	2020	2021	2022	2023
Speed decrease (%)	-27.13%	-27.59%	-28.99%	-29.55%	-30.24%	-30.80%	-31.33%	-31.88%
Model coefficient	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%
Decrease in GDP per capita	-0.08%	-0.08%	-0.09%	-0.09%	-0.09%	-0.09%	-0.09%	-0.10%
GDP per capita (current prices)	38,983	38,439	40,849	42,522	43,755	45,060	46,491	48,036
Population (in millions)	127.616	127.334	127.020	126.675	126.302	125.903	125.478	125.027
GDP Reduction (in $ millions, current prices)	-1,658	-1,556	-1,912	-1,938	-1,996	-2,007	-2,014	-2,033

Source: Cisco; TAS analysis

Table VIII-24 indicates that if all cellular data traffic that is currently being off-loaded to Wi-Fi were to shift to cellular networks, the reduction in speed (in 2018 from an average 33.73 Mbps to 23.95) would have a $1.91 billion impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data. In 2023, the amount would reach $ 2.03 billion. The increase in economic value is explained by an increase in speed performance of Wi-Fi networks.

VIII.9. Revenues of Wireless ISPs and Wi-Fi service providers

Wi-Fi off-loading can create new business opportunities for service providers offering wireless broadband services in public places (airports, hotels) for a fee. In addition to this segment, Wireless Internet Service Providers (WISPs) rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas. While some WISPs utilize licensed spectrum, the majority relies on unlicensed Wi-Fi spectrum.

The most straightforward way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in Japan. However, while there are a large number of Wi-Fi service providers present in this space, no statistics are available regarding their revenues (as is the case with the United States). Table VIII-25 presents a compilation of some of the largest Wi-Fi service providers.

Table VIII-25. Japan: Compilation of some of the largest Wi-Fi Service Providers

Company	Business focus
Flet's Hikari Wi-Fi access	VSAT backhaul with Wi-Fi as a distribution technology
Tokyo speed Wi-Fi	Rental of mobile Wi-Fi access and translator device
Ninja Wi-Fi	Unlimited 4G and Wi-Fi router rental service
Lucky Wi-Fi	Mobile Wi-Fi router rental service
Wi2 300	Paid service at 200,000 access points at hotels, restaurants, cafes, shops and public spaces nationwide
BB Mobile point	Partner of Softbank

Source: Company web sites; interviews

In the absence of revenue statistics (the approach followed to estimate economic value in the United States), we have calculated Wi-Fi revenues in Japan by prorating US Wi-Fi revenues based on the Japanese GDP. Thus, it is estimated that the 2018 GDP contribution accounts for $ 864 million, and that it is expected to reach $ 2.68 billion by 2023.

VIII.10. Wi-Fi contribution to employment

The estimation of employment generated is calculated by relying on the total GDP contribution resulting from the effects analyzed above and using that as an input in the communications sector of an input-output matrix of the Japanese economy. Table VIII-26 presents the GDP contribution of each of the effects analyzed above.

Table VIII-26. Japan: Total GDP Contribution of Wi-Fi (in $ billion)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$5.05	$5.24	$5.38	$5.65	$5.94	$6.25
Return to speed	$1.91	$1.94	$2.00	$2.01	$2.01	$2.03
Wi-Fi carriers	$0.87	$1.07	$1.31	$1.58	$2.15	$2.68
Total	$7.83	$8.25	$8.69	$9.24	$10.10	$10.96

Source: Telecom Advisory Services analysis

These inputs generate the following annual employment effects based on the I-O matrix for the Japanese economy (table VIII-27).

Table VIII-27. Japan: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	38,165	53,449
Indirect jobs	8,600	12,044
Induced jobs	3,004	4,207
Total	49,769	69,700

Source: Telecom Advisory Services analysis

According to the contribution to the GDP, Wi-Fi is generating approximately 49,500 jobs in 2018 and is expected to generate 70,000 in 2023. Job estimates include direct jobs (those jobs created by the specific Wi-Fi contribution), indirect jobs (those jobs created by suppliers to the Wi-Fi sector); induced jobs (those jobs created by spending of direct and indirect workers).

The sector breakdown of 2018 employment is as follows (table VIII-28).

Table VIII-28. Japan: Sector Breakdown of Wi-Fi generated annual employment (2018)

Sector	Direct	Indirect	Induced	Total
Agriculture	0	0	13	13
Extractive industries	0	93	1	94
Manufacturing	0	1,428	102	1,530
Construction	0	284	0	284
Trade	0	1,556	1,556	3,112
Transportation	0	67	1,040	1,107
Communications	38,165	0	0	38,165
Financial Services	0	419	0	419
Business services	0	3,840	0	3,840
Other services	0	913	292	1,205
TOTAL	38,165	8,600	3,004	49,769

Source: Telecom Advisory Services analysis

IX. ECONOMIC VALUE OF WI-FI IN SOUTH KOREA

In one of the highest connected countries in the world, Wi-Fi technology in South Korea exhibits an extremely high Wi-Fi density. According to the iPass Wi-Fi Growth Map, there are currently 767,806 commercial hotspots and 14,535,255 community access points operating in the South Korean territory[164]. Hotspot density yields high Wi-Fi use. According to OpenSignal[165], South Korean wireless users spend 56.98% of their communications time connected to Wi-Fi networks rather than relying on their cellular data connection[166]. The intensive usage of Wi-Fi technology should have a significant impact on its social and economic benefits. This chapter presents first the summary of economic value estimates and then reviews each of the particular effects. The same methodology utilized to calculate the economic value of Wi-Fi in the other countries, outlined in chapter III, was used for South Korea. The following chapter presents first the summary of results and then reviews each of the particular effects. Please refer to chapter III for detailed descriptions of each economic factor.

IX.1. Total economic value (2018 and 2023)

The total economic value of Wi-Fi in South Korea in 2018 amounts to $ 67.59 billion, which is slightly under the GDP of the Dominican Republic[167]. The economic value is comprised of $ 66.73 billion in economic surplus and $ 0.86 billion in contribution to the GDP (see table IX-1).

Table IX-1. South Korea: Total Economic Value of Wi-Fi (2018) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 1,525	N.A.	$ 1,525	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 18,393	N.A.	$ 18,393	N.A.
	2.2. Inside wiring avoidance	$ 15,805	N.A.	$ 15,805	N.A.
	Subtotal	$ 34,198	N.A.	$ 34,198	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 10,721	$ 10,721	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 5,124	$ 5,124	N.A.
	Subtotal	N.A.	$ 15,845	$ 15,845	
4. Value of cellular off-loading		N.A.	$ 4,072	$ 4,072	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 5,546	$ 5,546	$ 11,092	N.A.
	5.2. Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 5,546	$ 5,546	$ 11,092	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 0
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 425
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 436
TOTAL		$ 41,269	$ 25,463	$ 66,732	$ 861

Source: Telecom Advisory Services analysis

The key sources of Wi-Fi economic value are residential use ($ 34.20 billion in consumer surplus) and cellular off-loading ($ 4.07 billion). Beyond this, the value of Wi-Fi enabled equipment (wireless speakers, security systems, tablets, etc.) has a significant impact in terms of economic surplus ($ 11.09 billion).

[164] Compared to 150,301 commercial and 21,455,333 community access points in Germany.
[165] OpenSignal. *Global State of Mobile Networks* (August 2016).
[166] Compared to 62.04% in Germany.
[167] Source: International Monetary Fund (2017).

A 2023 forecast of Wi-Fi economic value will reach $ 137.55 billion, composed of $ 135.84 billion in economic surplus, and $ 1.71 billion in GDP contribution (see table IX-2).

Table IX-2. South Korea: Total Economic Value of Wi-Fi (2023) (in US$ millions)

Effect	Component	Economic Surplus			GDP Contribution
		Consumer surplus	Producer surplus	Total	
1. Value of free Wi-Fi		$ 1,631	N.A.	$ 1,631	N.A.
2. Value of residential Wi-Fi	2.1. Home use	$ 54,685	N.A.	$ 54,685	N.A.
	2.2. Inside wiring avoidance	$ 17,963	N.A.	$ 17,963	N.A.
	Subtotal	$ 72,648	N.A.	$ 72,648	N.A.
3. Value of enterprise Wi-Fi	3.1. Wi-Fi business internet traffic	N.A.	$ 20,452	$ 20,452	N.A.
	3.2. Inside wiring avoidance	N.A.	$ 5,201	$ 5,201	N.A.
	Subtotal	N.A.	$ 25,653	$ 25,653	
4. Value of cellular off-loading		N.A.	$ 11,762	$ 11,762	N.A.
5. Value of locally manufactured Wi-Fi devices	5.1. Locally manufactured consumer devices	$ 12,073	$ 12,073	$ 24,146	N.A.
	5.3Locally manufactured enterprise devices	N.A.	$ 0	$ 0	N.A.
	Subtotal	$ 12,073	$ 12,073	$ 24,146	N.A.
6. Value of bridging the digital divide		N.A.	N.A.	N.A.	$ 0
7. Wi-Fi return to speed		N.A.	N.A.	N.A.	$ 760
8. Revenues of Wi-Fi carriers and WISPs		N.A.	N.A.	N.A.	$ 948
TOTAL		$ 86,352	$ 49,488	$ 135,840	$ 1,708

Source: Telecom Advisory Services analysis

The relative importance of sources of economic value by 2023 remains the same as in 2018. Residential Wi-Fi usage remains the largest source of economic value ($ 72.65 billion), followed by enterprise use ($ 25.65 billion) and cellular carrier off-loading ($ 11.76 billion).

IX.2. Free Wi-Fi traffic

One dimension of Wi-Fi's economic value is derived from savings consumers receive by accessing the Internet through no cost sites (in retail shops, cafes, etc.) rather than relying on their cellular data plan. The following section presents the quantification of such benefit.

Total Internet traffic in South Korea is growing at an annual rate of 17.76 %, while mobile Internet traffic has been growing at close to 37 % per annum, indicating a growing share of wireless (increasing from 7.35 % to 9.95 % in three years) as indicated in Table IX-3.

Table IX-3. South Korea: Internet Traffic (2016-2018) (In exabytes[168] per month)

	2016	2017	2018	CAGR
Total Internet	3.40	4.00	4.72	17.76 %
Wireless Internet	0.25	0.34	0.47	36.74 %

Source: Cisco; Telecom Advisory Services analysis

The growing adoption of wireless data-enabled devices (smartphones, tablets, PCs) combined with an increase in usage per device has driven overall traffic growth. The installed base of smartphones reached 50.78 million in 2018, while this number amounted to 7.63 million for tablets. On the other hand, the number of laptops has slightly declined from 19.90 million in 2016

[168] 1 Exabyte equals 1,073,741,824 gigabytes.

to 19.07 million in 2018 (2016-18 CAGR: -2.10%[169]) due to tablet and, secondarily, smartphone substitution (see table IX-4).

Table IX-4. South Korea: Device Installed Base and Penetration (2016-2018)

Device	Metrics	2016	2017	2018 (E)	CAGR
Smartphones	Units (in millions)	47.30	49.01	50.78	3.62 %
	Penetration (%)	92.95 %	95.96 %	99.09 %	3.31 %
Tablets	Units (in millions)	7.40	7.52	7.63	1.57 %
	Penetration (%)	14.54 %	14.72 %	14.90 %	1.27 %
Laptops	Units (in millions)	19.90	19.48	19.07	- 2.10 %
	Penetration (%)	39.11 %	38.15 %	37.22 %	- 2.39 %

Sources: Cisco; GSMA Intelligence; Telecom Advisory Services analysis

Beyond the laptop to tablet substitution, the installed base of smartphones has shifted to 4G (LTE) network standards that provide faster speed of access and, consequently, stimulate more intense data usage. Looking forward, it is projected that the average speed of mobile devices by 2023, under 5G technology conditions, would have increased significantly from the current 35.21 Mbps to 51.05 Mbps[170].

Adding to the proliferation of devices, traffic per device has grown between 4.56% per annum for laptops and 34.80% for smartphones driven by increased applications and content availability (see table IX-5).

Table IX-5. South Korea: Average Traffic Per Device (2016-2018)
(In Gigabytes per month)

	2016	2017	2018 (E)	CAGR
Smartphones	13.30	17.93	24.17	34.80%
Tablets	17.10	21.34	26.62	24.77%
Laptops	122.20	127.77	133.59	4.56%

Source: Cisco VNI; Telecom Advisory Services analysis

It is interesting to note in 2018 that traffic per device in South Korea greatly exceeds that of the other countries under study, with the exception of tablets, where it stands second to Japan (see table IX-6).

Table IX- 6. Average Traffic Per Device (2018)
(In Gigabytes per month)

	France	Germany	Japan	South Korea	United Kingdom	United States
Smartphones	7.87	4.25	18.34	24.17	7.24	17.98
Tablets	7.76	10.24	34.25	26.62	21.81	18.78
Laptops	32.97	21.29	25.54	133.59	55.34	55.76

Source: Cisco VNI; Telecom Advisory Services analysis

With time series of the installed base and average data usage per device, total mobile Internet traffic in South Korea was calculated for the next five years. We estimate a total traffic of 2.24 Exabytes per month in 2023, which is approximately 7,000 times the entire US Library of Congress. [171] Projections regarding future traffic growth vary, although they all agree directionally (see table IX-7).

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169 Note than the laptop installed base in the United States is still growing, albeit at only 3.90% (see chapter IV).
170 Source: Cisco Visual Networking Index.
171 Fishrer, T. "Terabytes, Gigabytes, and Petabytes: How big are they", *Lifewire*, May 10, 2018.

Table IX-7. South Korea: Mobile Internet Traffic (2018-2023)
(In million Exabytes per month)

	2018	2019	2020	2021	2022	2023	CAGR
Total Internet	4.72	5.55	6.54	7.70	9.07	4.72	17.76%
Mobile Internet	0.47	0.64	0.88	1.20	1.64	2.24	36.74 %

Source: Cisco; Telecom Advisory Services analysis

This growth has and will continue to put pressure on the public cellular networks to accommodate the traffic without incurring congestion while generating acceptable levels of revenue. This situation prompts the communications system to rely on Wi-Fi to handle a portion of the traffic. We will now estimate the portion of traffic that is off-loaded to Wi-Fi.

There are 438,746 Wi-Fi hotspots operated by South Korean Mobile Network Operators[172]. Research on Wi-Fi offloading in South Korea indicated already a 65% offloading rate in 2012[173]. However, the Cisco Visual Networking Index team reported that in 2016, the introduction of cellular unlimited plans led to a deceleration of mobile offload into Wi-Fi[174]. It is unclear as of yet what the ultimate result is going to be, particularly since, as pointed out above, South Korea is a Wi-Fi access point dense environment. Thus, to reflect a conservative assessment, we decided to rely on a 60% offloading rate.

By applying this off-loading factor to the total mobile data traffic, we project that total Wi-Fi traffic in South Korea is currently 1.93 Exabytes per month in 2018 (see table IX-8).

Table IX-8. South Korea: Total Wi-Fi Traffic Per Device (2016-2018)
(In Exabytes per month)

	2016	2017	2018(E)
Smartphones	0.34	0.49	0.68
Tablets	0.06	0.07	0.09
Laptops	1.06	1.11	1.16
Total	1.46	1.67	1.93

Source: Telecom Advisory Services analysis

The estimation of consumer surplus is conducted by multiplying the total Wi-Fi traffic from table IX-8 by the proportion representing the "true free traffic" generated in public sites (retail stores, cafes, public squares, community sites). Precise estimates for this value are non-existent for South Korea. However, it has been estimated that in 2018 there are 1,208,070 open Wi-Fi networks in the country, 724,000 alone in Seoul, and 323,000 in Incheon[175]. Additionally, subject-matter experts interviewed for South Korea have ranged the percent of free Wi-Fi traffic between 5% and 10%[176], while statistics for the United States indicate 4.32% of Wi-Fi traffic to be "free". Based on these data points, we opted to quantify the portion of offloaded traffic going to truly free sites in South Korea to be approximately 5% (see table IX-9).

172 iPass Wi-Fi Growth Map.
173 Lee, K, Lee, J, Yi, Y, Rhee, I., and Chong, S. "Mobile data offloading: How much can Wi-Fi deliver?" *IEEE/ACM Transactions on Networking* (Volume 21, Issue 2, April 2013).
174 Sumits, A. *Top five surprises from the 2017 Mobile VNI study*, February 7, 2017.
175 Source: Wiman (2018). *Mobile Open Wi-Fi Spots in South Korea.*
176 Source: Christian Wagner, 7/24/2018.

Table IX-9. South Korea: Total Free Wi-Fi Traffic (2016-2018)

	2016	2017	2018(E)
Total Wi-Fi Traffic	5.00%	5.00%	5.00%
Total Free Traffic (in Exabytes per month)	0.07	0.08	0.10
Total Free Traffic (in Exabytes per year)	0.88	1.00	1.16
Total Free Traffic (in million Gigabytes per year)	941.85	1,073.57	1,241.73

Source: Telecom Advisory Services analysis

We calculated consumer surplus by multiplying the total free traffic by the difference between what the consumer would have to pay if s/he were to utilize a wireless carrier and the cost of offering free Wi-Fi (incurred by the retailer or public site). To do so, we needed an estimate of the average price per GB of wireless data transmitted by wideband networks, which we calculated by averaging the most economic "dollar per GB" plan of two major wireless carriers providing service in South Korea: SK Telecom and LG Uplus (see table IX-10).

Table IX-10. South Korea: Average Price Per Gigabyte (2017)

Carrier	Market share	Plan	Price per Gb (Won)
SK Telecom	48%	Data global Pack 103 (up to 25 MB at 4G speeds, and then at reduced speed)	3237.14
LG Uplus	20%	Data Special D (data and dedicated data for video portal for 40GB per month, and then at reduced speed)	2750.00
Average			3,094.70

Note: The average is calculated by prorating every price per GB by the carrier's market share.
Source: Telecom Advisory Services analysis

Since the assessment of Wi-Fi economic value is done in US dollars, the average price per GB in Won was converted to $ 2.76. Historical data on pricing trends compiled for the US market allowed for projecting the future price per Gigabyte for South Korea (see figure III-1 in chapter III).

According to these projections, while the average price per GB in 2017 was $ 2.76, it is estimated that by 2023, it will reach an estimated $1.47. As to the cost of offering the service through free Wi-Fi networks, this would include an additional router and needed bandwidth. For estimation purposes, we assume those costs to be 45% of the cost of offering the same GB via cellular networks[177]. This means that the cost per Gigabyte offered by the site providing the service for free would be $1.26 in 2017, declining to $0.97 in 2023. By relying on the total free Wi-Fi traffic shown in table IX-9 and the average price per cellular gigabyte minus the cost of provisioning free Wi-Fi service, we calculated the consumer surplus of free Wi-Fi traffic (see table IX-11).

Table IX-11. South Korea: Consumer Surplus of Free Wi-Fi Traffic (2018-2023)

	2018	2019	2020	2021	2022	2023
Total Free Traffic (in million Gigabytes per year)	1241.73	1460.61	1745.71	2121.59	2620.29	3284.84
Price per cellular gigabyte ($)	$ 2.48	$ 2.24	$ 2.01	$ 1.81	$ 1.63	$ 1.47
Cost per Wi-Fi provisioning ($)	$ 1.26	$ 1.19	$ 1.13	$ 1.08	$ 1.02	$ 0.97
Consumer surplus per Gigabyte ($)	$ 1.23	$ 1.04	$ 0.88	$ 0.74	$ 0.61	$ 0.50
Total Consumer surplus (in $ million)	$ 1,525	$ 1,523	$ 1,535	$ 1,560	$ 1,594	$ 1,631

Source: Telecom Advisory Services analysis

177 This is relationship found in the case of the United States (see chapter IV).

As indicated in table IX-11, consumer surplus of free Wi-Fi traffic in 2018 would amount to an estimated $ 1.53 billion and reach $ 1.63 billion in 2023.

IX.3. Value of Residential Wi-Fi

The value of residential Wi-Fi is a combination of Internet access for home usage and avoidance of in-house wiring.

IX.3.1. Home Internet access for devices that lack an Ethernet port

As mentioned in Chapter III, the underlying assumption of this quantification of economic value is that in the absence of Wi-Fi, users of devices lacking an Ethernet port would have to depend on the cellular network to access the Internet. As a consequence, estimating value of home access requires first to measure the traffic generated by these devices at home and then would multiply it by the average price charged by cellular carriers.

Based on our traffic model, the total traffic generated by these types of devices in 2018 in South Korea amounts to 17,167 million Gigabytes, reaching 86,280 million Gigabytes by 2023 (see table IX-12).

Table IX-12. South Korea: Total Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	7,549	10,544	14,728	20,573	28,736	40,138	56,064	78,309
Tablets	1,518	1,924	2,439	3,090	3,916	4,963	6,290	7,971
Total	9,067	12,468	17,167	23,663	32,652	45,101	62,354	86,280

Source: Cisco; GSMA; analysis Telecom Advisory Services

A portion of this traffic is, as expected, generated while the subscriber is in his residence, relying on the Wi-Fi service. According to a Cisco study conducted in the United States in 2012[178], 43.12% of use time of devices that lack a wired port occurs at home. Since the Cisco study has resulted in higher deployment of broadband access in the home, we opt to rely on the more conservative value of 43.12%. Therefore, the portion of said traffic generated at home reached 7,402 million Gigabytes in 2018 and is expected to amount to 37,202 million Gigabytes in 2023 (see table IX-13).

Table IX-13. South Korea: Home Mobile Internet Traffic (2016-2023) (In million Gigabytes)

Total Annual traffic	2016	2017	2018	2019	2020	2021	2022	2023
Smartphones	3,255	4,546	6,351	8,870	12,390	17,306	24,173	33,765
Tablets	654	830	1,051	1,332	1,689	2,140	2,712	3,437
Total	3,909	5,376	7,402	10,202	14,079	19,446	26,885	37,202

Source: Cisco; GSMA; analysis Telecom Advisory Services

If this traffic had to be transported by cellular networks, at the average price per GB estimated in Table IX-13, it would result in costs of $ 18.39 million in 2018 and $ 54.69 million in 2023.

[178] Cisco IBSG (2012)

IX.3.2. Avoidance of investment in in-house wiring

Residential Wi-Fi allows consumers to avoid paying for Ethernet wiring to connect all home devices (printers, laptops, storage units, etc.). The average cost of deploying inside wiring in a South Korean residence reaches approximately $896 per household[179].

In order to estimate the benefit derived from wiring avoidance, the number of total Wi-Fi households in South Korea is required. Strategy Analytics reported that in 2012, 80.3% of South Korean households were equipped with Wi-Fi[180], out of total universe of broadband Internet households of 95.8%[181]. Considering that broadband households have reached saturation (99.2% in 2017[182]), growth could only exist within this universe. We estimate this to amount to 90% in 2018, reaching 100% by 2023.

Recognizing that 90% of South Korean households currently have Wi-Fi[183], the avoidance cost of inside wiring for 17.64 million households, which in the absence of Wi-Fi yields a total cost of wiring of $ 15.80 billion. By 2023, with 100% of households having adopted Wi-Fi, the savings would have reached $ 17.96 billion[184].

IX.4. Enterprise Wi-Fi

As stated in chapter III, the economic value of enterprise Wi-Fi has two sources:

- Business traffic routed through Wi-Fi access points rather than cellular networks;
- Avoidance of capital investment to deploy Ethernet wiring inside enterprise establishments to connect devices and peripherals.

IX.4.1. Savings in wireless business traffic

Wi-Fi enterprise savings result from wireless traffic that is routed through Wi-Fi access points. In 2018, Cisco VNI and Telecom Advisory Services analysis estimate that total South Korean business Internet traffic will reach 8.82 billion GB, of which 4.31 billion GB are transported through Wi-Fi access points. Considering that the average price per GB transported by cellular is $2.48 (per the analysis presented above), savings from Wi-Fi would have reached $ 10.72 billion, an addition to the producer surplus. By 2023, this benefit will reach $ 20.45 billion (see table IX-14).

[179] Calculated as GDP prorated value of Germany's price points for wiring a residence with CAT 5 wire in Germany: € 1,200. (Germany: $ 1,390 at current exchange rate).
[180] Burger, A. (2012) "Wi-Fi households to approach 800 million by 2016", *Telecompetitor.*
[181] Source: International Telecommunications Union.
[182] Ramirez, E. "Nearly 100% of households in South Korea now have Internet access thanks to seniors" *Forbes*, January 31, 2017.
[183] Source: Watkins, David. *Broadband and Wi-Fi Households Global Forecast 2012*. Strategy Analytics
[184] This assumes that inside wiring costs will remain constant.

Table IX-14. South Korea: Savings in business wireless traffic (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Total Annual traffic (Exabytes per month)	0.68	0.85	1.05	1.30	1.61	1.99	0.68	0.85
Share of Business Internet Traffic by Wi-Fi	47.00%	47.96%	48.94%	49.94%	50.96%	52.00%	53.06%	54.15%
Total Business Internet Traffic (million Gb)	5,747	7,118	8,816	10,919	13,524	16,750	20,747	25,696
Total Business Wi-Fi enterprise traffic (million Gb)	2,701	3,414	4,314	5,453	6,892	8,710	11,009	13,913
Average Price per Gb	$2.76	$2.76	$2.48	$2.24	$2.01	$1.81	$1.63	$1.47
Economic Impact (in million $)	$ 7,454	$ 9,422	$ 10,721	$ 12,199	$ 13,881	$ 15,795	$ 17,974	$ 20,452

Source: Cisco; analysis Telecom Advisory Services

IX.4.2. Avoidance in enterprise building inside wiring

Similar to residential Wi-Fi savings due to capital investment avoidance in inside wiring, we assume that the total number of business establishments are equipped with Wi-Fi access points, and multiply this value by a standard cost of deploying a CAT 6 network ($4,277)[185].

Assuming all 1,197,789 business establishments in South Korea[186] are utilizing Wi-Fi which therefore allows them to save in wiring costs and that number is expected to remain stable, the savings resulting from avoiding inside wiring amounts to $ 5.12 billion, reaching $ 5.20 billion in 2023.

IX.5. Cellular off-loading

The value of cellular off-loading relates to the total cost of ownership required to accommodate future capacity requirements using Wi-Fi to complement cellular networks.

This analysis starts with the predicted incremental wireless data traffic generated between 2018 and 2023. According to the traffic forecast presented in table IX-6 above, future monthly wireless data traffic in South Korea amounts to 0.47 Exabytes per month in 2018 and will reach 2.24 Exabytes per month in 2023. Until 2020, when 5G deployment is expected to launch, this traffic should be handled through a combination of 3G and primarily 4G.

It is obvious that a cellular-only network does not economically handle all this traffic. As mentioned above, 60% of the cellular traffic in South Korea is currently being off-loaded to Wi-Fi access points. Due to their relative economic advantage relative to cellular base stations, carrier grade Wi-Fi deployment allows wireless operators to save both on CAPEX and OPEX. While the economic advantage of Wi-Fi off-loading varies substantially by topography and size of the urban environment, carrier-grade Wi-Fi sites are considerably less expensive than cellular network equipment with similar capacity. For example, a cellular pico-cell (needed to offer access via conventional cellular service) costs between $7,500 and $15,000[187], while a carrier-grade Wi-Fi access point requires an investment of $2,500[188]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table IX-15).

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[185] Calculated by prorating the cost of wiring a business establishment in Germany: $ 6,636.
[186] Source: Trading Economics.
[187] "When Femtocells become Picocells", the 3G4G Blog and Ubiquisys.
[188] Cisco Aironet 1552H Wireless Access Point.

Table IX-15. Comparative Carrier Grade Wi-Fi and LTE Macro Cell CAPEX and OPEX

	Wi-Fi Site	LTE Macro Cell
New Site acquisition	$ 600	$ 150,000
Collocation	-	$ 50,000
Backhaul	$ 300	$ 5,000
Monthly site rental	$ 20	$ 1,000
Site maintenance/month	$ 10	$ 200

Source: LCC Wireless (2012)

As it can be seen in table IX-15, Wi-Fi has significant economic advantages at the unit level. However, we must add a caveat here. Site density requirements for Wi-Fi are much higher than for cellular. For example, in a dense urban environment with high traffic, for each cellular site, 23 Wi-Fi hotspots are required. The difference means that, from a Total Cost of Ownership (CAPEX and OPEX) standpoint, the driver that erodes some of the Wi-Fi economic advantage is OPEX, especially Wi-Fi site rental and backhaul costs. Along these lines, for the carrier-class Wi-Fi off-loading to materialize, site deployment needs to be managed on a case-by-case basis, by surgically placing sites primarily in high traffic areas.

In a prior report by this author[189], a simulation was presented to determine the economic advantage of relying on carrier-grade Wi-Fi sites to complement the deployment of LTE in the United States. According to Thanki (2012), achieving full LTE coverage in the United States relying on 2100 MHz to accommodate incremental wireless data traffic would require approximately 34,000 new base stations[190], representing a total capital investment of $ 8.5 billion. On two simulation cases of off-loading in New York and San Diego, LCC Wireless assumed a CAPEX benefit of Wi-Fi off-loading ranging between 22.3 % and 44.7 %. When averaging these two estimates, the CAPEX reduction would amount to $2.76 billion. Even under the OPEX considerations mentioned above, the Total Cost of Ownership remains lower under the Wi-Fi off-loading scenario (see table IX-16).

Table IX-16. Total Cost of Ownership of LTE only versus LTE+ Wi-Fi Off-Load

	LTE Only	LTE + Wi-Fi Off-Loading	Delta %/$
Total CAPEX	$ 8.5 billion	$ 5.7 billion	32.9 %/$ 2.8 billion
Total OPEX (*)	$ 48.7 billion	$ 40.8 billion	16.2 %/ $ 7.9 billion
Total Cost of Ownership	$ 57.2 billion	$ 46.5 billion	18.71 %/$ 10.7 billion

(*) OPEX to CAPEX ratios assumed from LCC San Diego case
Source: LCC Wireless (2012); Thanki (2012); TAS analysis

According to the simulation run for the United States, presented in table IX-16, Wi-Fi carrier grade yields economic savings for a carrier of 18.71%.

Now, let's turn to the South Korean situation. Ever since 2011, 4G coverage has reached 100%. GSMA Intelligence estimates that 5G will be launched in 2019, one year ahead than in other advanced nations. In this context, it is reasonable to assume that the 2018 CAPEX is still benefitting from a portion of the network infrastructure being deployed through Wi-Fi access

[189] Katz, R. (2018). A 2017 *Assessment of the current and future economic value of unlicensed spectrum in the United States*. Washington, DC: Wi-Fi Forward.
[190] This model was adapted by the author from Ofcom, the UK regulator, to assess the effect of differing traffic levels on cell site numbers in urban areas in its consultation "Application of spectrum liberalization and trading to the mobile sector" (Ofcom, 2009).

points. Total 2018 CAPEX of South Korean wireless operators is estimated by GSMA Intelligence to be $ 3,239 million. If this number already factors in the savings derived from deploying Wi-Fi sites, it would then mean that the CAPEX savings resulting from deploying carrier-grade Wi-Fi as a complement to cellular base stations for the rollout of LTE to accommodate traffic growth in 2018 would amount to $ 2,173 million. This amount does not include the CAPEX saved by traffic off-loading to residential and business Wi-Fi networks[191]. In addition to the CAPEX driven savings, one would have to add the OPEX in order to understand total producer surplus. According to the ratio CAPEX to OPEX presented in table VI-15, each $1 billion in CAPEX savings triggers $3.01 billion in OPEX. As a result, total 2018 producer surplus in 2018 triggered by Wi-Fi carrier grade rollout amounts to $ 4.07 billion.

Moving on to estimating the value of off-loading, 5G deployment planned total investment by South Korean wireless carriers is $ 9.36 billion[192]. We estimate that, based on the GSMA coverage statistics, the amount will be spread through five years based on the progression of 5G coverage (see table IX-17).

Table IX-17. South Korea: Deployment of 5G (2019-2023)

	2019	2020	2021	2022	2023
5G Coverage	61.27 %	64.15 %	82.01 %	82.30 %	82.52 %

Source: GSMA Intelligence

Since the South Korean 5G investment appears to be front-loaded, estimating Wi-Fi's economic value for 2023 would minimize it. Therefore, rather than considering only the 2023 incremental CAPEX required to extend 0.22% of coverage, we decided to base the calculations on the total investment of $ 9.36 billion. In this context, Wi-Fi becomes a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands.

Considering that the total investment of $ 9.36 billion already factors in the savings incurred by relying on Wi-Fi sites, and applying the same approach as used for 2018, the total producer surplus attributed to Wi-Fi as a result of 5G deployment (adding CAPEX and OPEX savings) would be $ 11.76 billion.

IX.6. Locally manufactured Wi-Fi enabled equipment

The difference between market prices and locally manufactured costs of Wi-Fi enabled products represents the manufacturer's margin and, consequently, producer surplus. It is assumed that the consumer surplus is roughly equal to consumer surplus (see Milgrom et al., 2011). Both consumer products and enterprise equipment are considered as part of the economic surplus generated by locally manufactured Wi-Fi enabled devices.

IX.6.1. Consumer products

As detailed in section III.3.5, we identified seven consumers products which are intrinsically linked to Wi-Fi: Wi-Fi enabled wireless speakers, home security systems, home networking

[191] See Cooper (2012).
[192] Tomas, J.P. "Korean carriers to invest more than $9 billion in 5G this year". *RCR Wireless News*, January 2, 2018.

systems (such Apple's HomePod, Amazon Echo, and Google Home), access points[193], external adapters[194], routers, and gateways. As conducted in the case of the United States, our focus is to estimate economic surplus in South Korea, based by revenues of South Korean manufacturers for each product[195].

In the case of access points, external adapters, routers and gateways, data indicates that the major global players are the US, Chinese, and Taiwanese manufacturers (see table IX-18).

Table IX-18. Consumer products: Global Market shares (2018)

Product	Market (in millions)	United States	United Kingdom	Germany	South Korea	France	Japan	China	Taiwan	ROW
Access points	$ 11,631	0.2 %	0.0%	0.0%	0.0%	13.5%	0.0%	69.1%	7.7%	9.5
External adapters	$ 465.92	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	42.1%	9.7%	41.0%
Routers	$ 4,972.30	5.9%	0.0%	0.0%	0.0%	6.7%	0.0%	52.6%	15.5%	19.3%
Gateways	$ 6,389.25	6.6%	0.0%	0.0%	0.0%	29.0%	0.0%	38.1%	10.3%	16.0%

Sources: ABI Research; Telecom Advisory Services analysis

On the other hand, the markets for wireless speakers, home security systems, and home networking systems is served by firms like Harman (a Samsung company) for speakers. In the absence of reliable market estimates, we opted to build a composite estimate combining Harman revenues with the export volumes of the Korean Electronics Association for the category of household devices (which includes both security systems and home networking equipment. As a result, the market estimates for South Korea are as follows (see table IX-19).

Table IX-19. South Korea: Consumer Electronics Production (in $ million) (2016-2023)

	2016	2017	2018	2019	2020	2021	2022	2023
Wireless speakers	$ 7,200	$ 7,920	$ 8,712	$ 9,583	$ 10,542	$ 11,596	$ 12,755	$ 14,031
Home security and networking systems	$ 2,293	$ 2,943	$ 3,777	$ 4,848	$ 6,222	$ 7,986	$ 10,250	$ 13,156
Total	$ 9,493	$ 10,863	$ 12,489	$ 14,431	$ 16,764	$ 19,582	$ 23,005	$ 27,186

Sources: Consumer Technology Association; Telecom Advisory Services analysis

Of these amounts, the prorated profit margin estimated by CSI markets is 44.41%, which yields a producer surplus for this particular product of $ 5.55 billion. Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic surplus in 2018 would amount to $ 11.09 billion and would reach $ 24.15 billion in 2023.

IX.6.2. Enterprise products

In the case of enterprise Wi-Fi enabled products, South Korea is not included among the main manufacturing countries (see table IX-20).

Table IX-20. Enterprise products: Global Market shares (2018)

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[193] Access points (APs) allow devices to connect to a wireless network.

[194] Wireless client device. It can be PCI adapter, which A PCI wireless adapter card is a device that is connected to a desktop computer's PCI bus to provide wireless capability to the desktop, a PC card, or a USB adapter.

[195] Economic value derived from Wi-Fi enabled tablets was not considered in this case due to the lack of data on manufacturer's margins and consumer willingness to pay data.

Product	Market (in millions)	United States	China	ROW
Access points	$ 5,398	81.3 %	16.8 %	1.9 %
Controllers	$ 1,025	67.3 %	19.9 %	12.8 %

Sources: ABI Research; Telecom Advisory Services analysis

As a result, Wi-Fi enabled enterprise products was not included as a source of economic value.

IX.7. Bridging the digital divide

The digital divide is defined as the gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory). Considering that broadband households have reached saturation (99.2% in 2017[196]), it is assumed that Wi-Fi cannot address any lingering digital divide unserved territories. The Wi-Fi contribution to GDP will be factored in the next two sections.

IX.8. Wi-Fi return to speed

The return to speed is a benefit derived from the fact that Wi-Fi access is, in general considerably faster than cellular networks. In this context, research indicates that faster broadband speed has an impact on economic growth due to the increasing efficiency of a country's economy. In other words, faster broadband networks contribute to growth of a country's GDP. Along these lines, the objective in this case is to quantify the impact Wi-Fi technology has to the average speed of mobile devices in South Korea.

We start with the quantification of speed differentials for South Korea, which we calculate by subtracting the weighted average of Wi-Fi and cellular speeds (averaged according to traffic off-loading factors) and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (see table IX-21).

Table IX-21. South Korea: Estimation of speed differential for total US traffic (in Mbps)

	2016	2017	2018	2019	2020	2021	2022	2023
Average speed of cellular networks	30.34	32.69	35.21	37.92	40.85	44.00	47.39	51.05
Average Wi-Fi speed	37.20	41.33	45.93	51.03	56.70	63.00	70.00	77.78
Average speed of weighted average of cellular and Wi-Fi traffic	36.20	39.86	43.83	48.14	52.82	57.93	63.50	69.61
Speed decrease (average speed of cellular/average weighted average speed)	-16.17%	-17.99%	-19.67%	-21.22%	-22.67%	-24.04%	-25.37%	-26.66%

Source: Cisco; TAS analysis

Having calculated the speed decrease percentage, we then apply this percentage to the coefficient derived from the model developed by Bohlin et al. (2011 and 2013) to gauge the potential impact on GDP if cellular networks transported all traffic (see table IX-22).

[196] Ramirez, E. "Nearly 100% of households in South Korea now have Internet access thanks to seniors" *Forbes*, January 31, 2017.

Table IX-22. Econometric model measuring the impact of broadband speed on GDP

Independent Variables	Coefficient
Average GDP growth (2008-2010)	0.577 *
Population density	-0.0441 *
Urban population	-0.0103 **
Labor force growth (%)	0.0492 *
Telecom revenue growth (%)	0.0492 *
Population growth (%)	-0.630 **
Average achieved downlink speed	-0.00214
Average achieved downlink speed squared	0.00142 *

*, ** Significant at 1% and 5% critical value respectively
Source: Rohman and Bohlin (2011)

As table IX-22 shows, by incorporating the elasticity of the coefficient of broadband speed and the square of the variable, the model assumes that the doubling of broadband speed causes a 0.3% increase in GDP growth. Our case shows the GDP impact on the **decrease** in speed. This is applied in turn to the South Korean GDP at current prices (see table IX-23).

Table IX-23. South Korea: Broadband speed impact on GDP

	2016	2017	2018	2019	2020	2021	2022	2023
Speed decrease (%)	-16.17%	-17.99%	-19.67%	-21.22%	-22.67%	-24.04%	-25.37%	-26.66%
Model coefficient	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%
Decrease in GDP per capita	-0.05%	-0.05%	-0.06%	-0.06%	-0.07%	-0.07%	-0.08%	-0.08%
GDP per capita (current prices)	27,534.84	29,891.26	32,774.54	34,268.86	35,787.84	37,429.55	39,142.76	40,867.46
GDP Reduction (in $ millions, current prices)	-315	-365	-425	-472	-525	-590	-667	-760

Source: Cisco; TAS analysis

Table IX-23 indicates that if all cellular data traffic that is currently being off-loaded to Wi-Fi were to shift to cellular networks, the reduction in speed (in 2018 from an average 43.83 Mbps to 35.21 Mbps) would have a $425 million impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data. In 2023, the amount would reach $760 million. The increase in economic value is explained by a gradual augmentation of the speed gap between cellular networks and Wi-Fi.

IX.9. Revenues of Wireless ISPs and Wi-Fi service providers

Wi-Fi off-loading can create new business opportunities for service providers offering wireless broadband services in public places (airports, hotels) for a fee. In addition to this segment, Wireless Internet Service Providers (WISPs) rely primarily on unlicensed spectrum to offer broadband accessibility in rural areas. While some WISPs utilize licensed spectrum, the majority relies on unlicensed Wi-Fi spectrum.

The most straightforward way of estimating the economic value of Wi-Fi in this domain is to add up the revenues of all firms operating in this space in South Korea. However, while there are a large number of Wi-Fi service providers present in this space, no statistics are available regarding their revenues (as is the case with the United States).

In the absence of revenue statistics (the approach followed to estimate economic value in the United States), we have calculated Wi-Fi revenues in South Korea by prorating US Wi-Fi revenues based on the South Korean GDP. Thus, it is estimated that the 2018 GDP contribution accounts for $436 million, and that it is expected to reach $ 948 million by 2023.

IX.10. Wi-Fi contribution to employment

The estimation of employment generated is calculated by relying on the total GDP contribution resulting from the effects analyzed above and using that as an input in the communications sector of an input-output matrix of the South Korean economy. Table IX-24 presents the GDP contribution of each of the effects analyzed above.

Table IX-24. South Korea: Total GDP Contribution of Wi-Fi (in $ million)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Return to speed	$ 424.65	$ 471.73	$ 525.25	$ 589.71	$ 667.25	$ 759.67
Wi-Fi carriers	$436.42	$436.42	$436.42	$541.05	$747.46	$948.10
Total	$861.07	$908.15	$961.67	$1,130.76	$1,414.71	$1,707.77

Source: Telecom Advisory Services analysis

These inputs generate the following annual employment effects based on the I-O matrix for the South Korean economy (table IX-25).

Table IX-25. South Korea: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	5,325	10,560
Indirect jobs	4,473	8,871
Induced jobs	1,878	3,724
Total	11,676	23,155

Source: Telecom Advisory Services analysis

According to the contribution to the GDP, Wi-Fi is generating approximately 11,500 jobs in 2018 and is expected to grow at an annual rate of 14.68%, generating 23,000 in 2023. Job estimates include direct jobs (those jobs created by the specific Wi-Fi contribution), indirect jobs (those jobs created by suppliers to the Wi-Fi sector); induced jobs (those jobs created by spending of direct and indirect workers).

The sector breakdown of 2018 employment is as follows (table IX-26).

Table IX-26. South Korea: Sector Breakdown of Wi-Fi generated annual employment

Sector	Direct	Indirect	Induced	Total
Agriculture	0	0	152	152
Extractive industries	0	90	1	91
Manufacturing	0	426	37	463
Construction	0	40	0	40
Trade	0	1,398	1,398	2,796
Transportation	0	32	160	192
Communications	5,325	0	0	5,325
Financial Services	0	315	0	315
Business services	0	2,005	0	2,005
Other services	0	167	130	297
TOTAL	5,325	4,473	1,878	11,676

Source: Telecom Advisory Services analysis

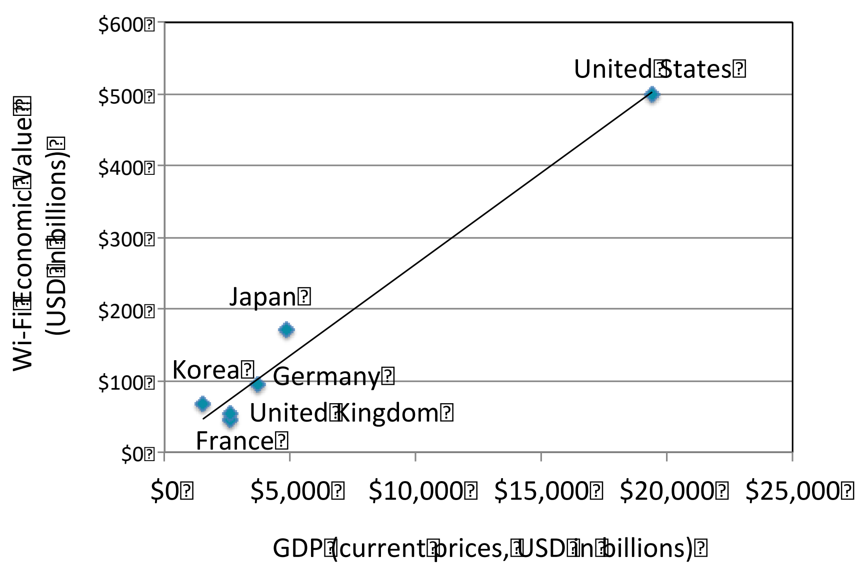
X. GLOBAL ECONOMIC VALUE OF Wi-Fi

Having quantified the economic value of Wi-Fi for the United States, the United Kingdom, Germany, France, Japan and South Korea, we now generate a high level estimation of the economic value for the remaining countries of the world. Rather than calculating the economic value for each country (an approach that would be impractical), we use the leading indicators methodology. This methodology consists in selecting indicators existing for both groups (the six advanced nations and the rest of world) and rely on them for the interpolation. The two indicators selected for this purpose are:

- Total GDP: the underlying assumption is that there is a direct link between the level of development of a given country and the economic value of Wi-Fi in that country;
- Human Development Index (constructed by the United Nations Development Program): this indicator introduces a variable that controls for a country's level of urbanization, literacy, and other social factors.

As a starting point, we validated the starting assumption that a country's economy is directly correlated with the economic value of Wi-Fi (see figure X-1).

Figure X-1. GDP vs. Wi-Fi Economic Value



Source: IMF; Telecom Advisory Services analysis

This correlation supports the use of GDP as lead indicator. As the table X-1 indicates, the six countries under study represent 43.44% of the world GDP.

Table X-1. World Distribution of GDP

Groups	GDP	Percent
Six countries studied (US, UK, Germany, France, Japan, South Korea)	34,693	43.44%
Rest of the World	45,171	56.56%
Total	79,865	100 %

Source: International Monetary Fund

With the initial assumption of a correlation between GDP and economic value, we then calculate a first estimate. We then discount these results by the level of social development measured by the UN Human Development Index (HDI). The average world HDI, normalized by GDP, is 0.839, while the average for the six countries under study is 0.915, and 0.78 for the remaining countries of the world (see table X-2).

Table X-2. Human Development Index: Six Advanced Countries vs. Rest of World

Groups	HDI
Six countries studied (US, UK, Germany, France, Japan, South Korea)	0.915
Rest of the World estimation	0.780
Total	0.836

Source: United Nations

These values are then used to discount the original GDP-based economic value estimates for the "rest of the world". The discount factor is calculated by dividing the "rest of the world" HDI (0.780) by the six countries under study HDI (0.915). This allows calculating the Wi-Fi economic value for the "rest of the world", and adding it to the six countries under study, estimating the economic value for the whole world (see table X-3).

Table X-3. Global Wi-Fi Economic Value (in billions US$)

	2018			2023		
	Economic surplus	GDP Contribution	Total	Economic surplus	GDP Contribution	Total
Six advanced Countries	$ 890.78	$ 40.07	$ 930.85	$ 1,582.94	$ 62.40	$ 1,645.34
Rest of World estimation	$ 989.19	$ 44.50	$ 1,033.69	$ 1,757.81	$ 69.29	$ 1,827.10
Total Global Value	$ 1,879.97	$ 84.57	$ 1,964.54	$ 3,340.75	$ 131.69	$ 3,472.44

Source: Telecom Advisory Services

To sum up, the "rest of the world" estimation represents an amount of Wi-Fi economic value that is fairly close to the six advanced countries under study. Wi-Fi world economic value in 2018 amounts to $ 1.96 trillion and is expected to reach to $ 3.472 trillion by 2023.

The GDP contribution of the "rest of the world" estimation allows the estimation of employment. By conducting a similar methodology of GDP prorating with a control for the Human Development Index, we developed an estimate of Wi-Fi GDP contribution (see table X-4).

Table X-4. Rest of World: Total GDP Contribution of Wi-Fi (in $ billion)

	2018	2019	2020	2021	2022	2023
Bridging the digital divide	$ 21.55	$ 23.45	$ 25.39	$ 28.36	$ 31.64	$ 35.39
Return to speed	$ 14.88	$ 14.59	$ 14.09	$ 13.47	$ 13.11	$ 12.80
Wi-Fi carriers	$ 8.06	$ 9.30	$ 11.07	$ 13.19	$ 17.24	$ 21.10
Total	$ 44.49	$ 47.34	$ 50.55	$ 55.02	$ 61.99	$ 69.29

Source: Telecom Advisory Services analysis

With these estimates, total annual employment generation for the rest of the world was estimated (see table X-5).

Table X-5. Rest of World: Wi-Fi generated Annual Employment

	2018	2023
Direct jobs	240,817	359,505
Indirect jobs	65,429	103,905
Induced jobs	17,788	27,842
Total	324,034	491,252

Source: Telecom Advisory Services analysis

Total, global job contribution of Wi-Fi in 2018 is 616,000 jobs; by 2023 Wi-Fi will be generating 934,000 jobs worldwide (see table X-6).

Table X-6. Global: Wi-Fi generated Annual Employment

	2018			2023		
	Six advanced countries	Rest of the World	Global	Six advanced countries	Rest of the World	Global
Direct jobs	216,860	240,817	457,677	323,741	359,505	683,246
Indirect jobs	58,920	65,429	124,349	93,568	103,905	197,473
Induced jobs	16,018	17,788	33,806	25,072	27,842	52,914
Total	291,798	324,034	615,832	442,381	491,252	933,633

Source: Telecom Advisory Services analysis

It should be noted that, since the estimates for the rest of the world were based on a prorating methodology reflecting the advanced country effects, the result might underestimate total employment effects in the developing world.

XI. CONCLUSION

This study was predicated on the fact that Wi-Fi technology has taken a prominent position in the wireless ecosystem, with enormous importance in everyday life. As of today, most laptops, tablets, smartphones, security cameras, smart TVs, printers, scanners, home appliances, and even cars, increasingly utilize Wi-Fi. Already in 2016, Wi-Fi was installed in 800 million households around the world and wireless users in some of the largest countries around the world spent more time connected to Wi-Fi than to cellular networks.

A detailed analysis focused on key developed markets beyond the United States was conducted to identify the economic value of Wi-Fi in those markets. The specific markets, besides the United States, are: United Kingdom, France, Germany, Japan, and South Korea. Included in this study are effects ranging from Wi-Fi usage in free sites, residences, and businesses, to savings to cellular carriers through traffic offloading, profits of Wi-Fi enabled equipment manufacturing, and benefit from faster network throughput. The study concludes that the 2018 economic value of Wi-Fi for the six countries is nearly $1 trillion. The country with the highest Wi-Fi economic value creation is the United States ($499.09 billion), followed by Japan ($171.46 billion), Germany ($ 94.00 billion), South Korea ($67.59 billion), the United Kingdom ($54.48 billion), and France ($44.23 billion).

The most important sources of economic value are the use of Wi-Fi by consumers in their homes and the usage of Wi-Fi for enterprise communications. That said, the production side of the economy also benefits from Wi-Fi in terms of the profits received by manufacturers of equipment (access points, controllers, routers, gateways, smart speakers, home security systems, and the like) and the savings incurred by the cellular carriers that rely on the technology to offload traffic from their networks. Finally, Wi-Fi also generates economic value through social contributions: the technology represents a useful application to tackle the digital divide in rural and isolated geographies, while also providing an important platform for free internet access.

Beyond estimates of the economic value in each of the six advanced nations, the study generated an extrapolation for the rest of the world that relied on two macro-indicators: GDP and the United Nations Human Development Index. When including the rest of the world, the global economic value associated to Wi-Fi in 2018 amounts to $1.96 trillion, and is expected to reach $ 3.47 trillion by 2023, a compound annual growth rate of 12%.

The study also provided an estimate of job creation by relaying on Input / Output analysis. Job creation estimates include direct jobs (those jobs created by manufacturing of Wi-Fi enabled equipment and operating Wi-Fi infrastructure), indirect jobs (those jobs created by suppliers to the Wi-Fi equipment manufacturing sector and operators), and induced jobs (those jobs created by spending of direct and indirect workers).

By conducting a similar methodology of GDP prorating, with a control for the Human Development Index, we developed an estimate of employment creation for the "rest of the world". According to this, global employment benefitting from Wi-Fi in 2018 amounts to 616,000 jobs and is expected to reach nearly one million jobs by 2023 (934,000).

Based on this evidence, Wi-Fi technology should be recognized as one of the dominant economic engines of the digital ecosystem. Governments around the world should develop the right incentives to stimulate the social and economic benefits of Wi-Fi. This includes assigning enough spectrum to avoid congestion, promoting the development of start-ups that rely on Wi-Fi to create new applications, and rely on the technology to address the digital divide barrier.

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GLOSSARY

Complementary technology: A complementary technology is a resource that, due to its intrinsic strengths, compensates for the limitations of another (example: Wi-Fi can enhance the effectiveness of devices that use licensed spectrum, such as smartphones

Consumer surplus: consumer surplus measures the total amount consumers would be willing to pay to have the service compared to what they actually pay.

Digital divide: The gap between those who have ready access to computers and the Internet, and those who do not. Digital divide could be based on race, gender, educational attainment, and income. In this work the divide under consideration refers to geography (rural and isolated areas of a given country versus the rest of the national territory).

Economic surplus: The concept of economic surplus is based on the difference between the value of units consumed and produced up to the equilibrium price and quantity, allowing for the estimation of consumer surplus and producer surplus.

Factor of production: Factors of production is an economic term that describes the inputs that are used in the production of goods or services in order to make an economic profit. The factors of production include land, labor, and capital. In this work Wi-Fi is also considered to be an input in production of communications services.

Free Wi-Fi traffic: traffic generated by a consumer when s/he accesses the Internet in a public hotspot for free (e.g. coffee shop, retailer). In this case, consumer surplus would equate to the monetary value the consumer would pay to a cellular operator for gaining similar access.

Input/output tables: a quantitative economic technique that represents the interdependencies between different branches of a national economy or different regional economies. In this work, input-output matrices are used to model the impact on output and employment of additional telecommunications spending resulting from the contribution to GDP of Wi-Fi.

Inside wiring: Ethernet wiring to connect data devices within a residence or office building. Wiring could be of different standards such CAT5, CAT6, or CAT7.

Producer surplus: producer surplus measures the consumers pay for a given product compared to the total manufacturing and distribution costs, which is essentially the economic profit they earn from providing the service.

Return to speed: Since Wi-Fi accessibility allows, in general, faster access to the Internet than cellular networks do, higher speeds have a positive contribution on the economy in terms of increased overall efficiency and innovation. The contribution is measured in terms of economic growth.

Traffic off-loading: In light of the explosive growth in data traffic, wireless carriers operating in licensed bands deploy Wi-Fi access points to reduce both capital and operating expenses, while dealing with congestion challenges.

United Nations Human Development Index: The Human Development Index (HDI) is a composite statistic (composite index) of life expectancy, education, and per capita income indicators, which are used to rank countries into four tiers of human development. A country scores higher HDI when the lifespan is higher, the education level is higher, and the GDP per capita is higher.

APPENDIX: WI-FI VALUE AND 5G

Estimating Wi-Fi off-loading value is a difficult task, complicated by the fast-moving pace of innovation and other industries' reliance on Wi-Fi, such as cellular networks. The deployment of 5G is expected within the two to five year window, so it will impact the off-loading economic value for 2023. Wi-Fi is a key enabler of 5G services. The upcoming flexible, radio-neutral 5G environment will be intrinsically supported by the next wave of 802.11 Wi-Fi standards (802.11n/ac, 802.11ax, WiGig), and short-range wireless technologies operating in unlicensed bands.

The investment in rolling 5G in a given country is a pre-condition to estimate the contribution of Wi-Fi to its deployment. Not all countries have defined the capital required. The most developed public estimate is the one prepared by Oughton and Frias (2016) for OFCOM in the United Kingdom ($56.94 billion[197]). In South Korea, the wireless operators have made an announcement of the expected investment ($9,36 billion[198]), while Japanese carriers have announced an investment of $45.5 billion[199]. Not all figures are comparable: the UK estimate includes all geographies (both urban, suburban, and rural); the South Korean estimate was announced as a single year investment and probably does not cover the whole territory, while the Japanese figure appears to represent a multi-year CAPEX.

To determine the 2023 value it is necessary to first estimate the CAPEX on that single year. This was calculated by prorating the GSMA 5G coverage change for a single year. For example, considering the GSMA estimate of 5G coverage change between 2021 and 2022 for Japan (34.05 percentage points), the total 5G spend for Japan ($45.5 billion) was multiplied by 34.45%. Therefore, the 5G CAPEX in 2023 in Japan would be $ 15,493 million.

It is assumed that the estimate already factors in the Wi-Fi benefit. Thus, in order to estimate Wi-Fi's contribution, it is required to estimate what the CAPEX would be without Wi-Fi:

$$\text{CAPEX without Wi-Fi} - \$15{,}493 \text{ million} = \text{Wi-Fi economic value} \qquad (1)$$

Relying on the LTE only to LTE+Wi-Fi CAPEX ratio calculated for the US (32.9% reduction)[200] we developed the following model:

$$((\text{CAPEX LTE w/ Wi-Fi})/1-0.329) - (\text{CAPEX w/Wi-Fi}) = \text{Wi-Fi Economic value} \qquad (2)$$

or,

$$(\$\,15{,}493/(1-0.329)) - \$\,15{,}493 = \text{Wi-Fi CAPEX savings} \qquad (3)$$

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197 Oughton, E. & Frias, Z. (2016). Exploring the cost, coverage and rollout implications of 5G in Britain. Engineering and Physical Sciences Research Council. Retrieved from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577965/Exploring_the_Cost_Coverage_and_Rollout_Implications_of_5G_in_Britain_-_Oughton_and_Frias_report_for_the_NIC.pdf

198 Tomas, J.P. "Korean carriers to invest more than $9 billion in 5G this year". *RCR Wireless News*, January 2, 2018.

199 Telecom Ramblings. *Japan's cellcos to invest over $45.5 billion in 5G*. June 8, 2017.

200 LCC Wireless (2012). Madden, J. *Reaching a Balance between Macro, Small cells, and Carrier Wi-Fi*. Mobile Experts LLC.

Then, by using the OPEX to CAPEX savings for the LTE+ Wi-Fi simulation,

(Wi-Fi CAPEX savings *7.9)/2.8 = Wi-Fi OPEX savings (4)

Wi-Fi economic value = CAPEX savings + OPEX savings (5)

This approach had to be adapted for each country based on the data available. In the case of unavailable data (for example, the United States), we used the OFCOM model to calculate a CAPEX per POP for each geography and applied to the new country based on population distribution.