# FINAL REPORT

## ASSESSMENT OF THE ECONOMIC VALUE OF UNLICENSED SPECTRUM IN THE UNITED STATES

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# AUTHOR

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## EXECUTIVE SUMMARY

For more than fifty years, ever since the publication of Coase's seminal paper (1959) on spectrum management, there has been a debate over the most effective way of allocating the frequency spectrum. One specific issue of the policy debate relates to the management of unlicensed spectrum, which covers the frequency bands for which no exclusive licenses are granted. While the debate has been useful so far in terms of highlighting the large range of beneficial effects of unlicensed spectrum - such as triggering technological innovation, complementing cellular networks, and the like - limited research quantifies its economic value. In the few studies that exist, researchers concur that the economic value generated by keeping a portion of the spectrum unlicensed is significant. However, the studies completed so far do not consistently measure the same areas of impact: some estimate residential Wi-Fi value (Thanki, 2009; Cooper, 2012) while others focus on Wi-Fi tablets (Milgrom et al, 2011); some mention Wireless Internet Service Providers that rely on Wi-Fi (Thanki, 2012), but their economic contribution is not quantified[1].

We recognize that valuing unlicensed spectrum is a difficult task since, contrary to licensed spectrum that supports a few homogeneous services, unlicensed bands are used by numerous heterogeneous devices and services (Bayrak, 2008). Furthermore, since many of the services that rely on unlicensed spectrum are not sold, it is difficult to estimate the consumers' willingness to pay as it has been done in the case of licensed spectrum (Hazlett, 2005). Finally, unlicensed spectrum is being used by technologies and services that are growing at a rate that renders obsolete any research completed two years ago: for example, Wi-Fi traffic in the United States is growing at 68% per annum, while Wi-Fi households, currently at 63%, are forecast to reach 86% by 2017. As such, estimates of value conducted in 2009 might not be relevant any more.

That said, if we were to add the different economic value estimates of all four studies completed so far (controlling for double counting and using the latest estimates), the resulting total economic value of unlicensed spectrum in the United States reaches $ 140.20 billion (see table A).

[1] The research evaluated in this report addresses only the studies focused on the United States. Additional similar work has been conducted in the United Kingdom by Indepen, Aegis and Ovum (2006), and Williamson et al (2013).

**Table A. United States: Prior Research on the Economic Value of Unlicensed Spectrum (in $ billions)**

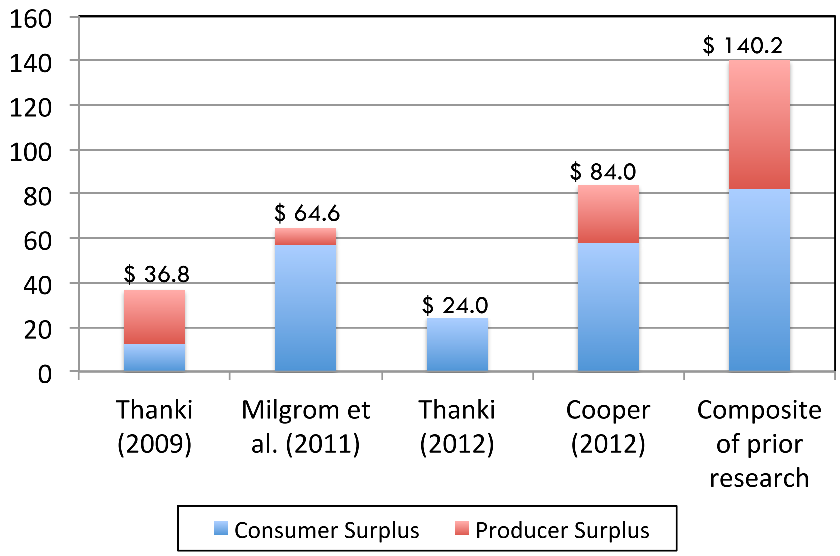
| | Effect | Thanki (2009) | Milgrom et al. (2011) | Thanki (2012) | Cooper (2012) | Composite |
|---|---|---|---|---|---|---|
| Wi-Fi Cellular Off-Loading | Consumer Surplus | N.A. | $ 25.0 | N.A. | $ 20.0 | $ 25.0 |
| | Producer Surplus | | N.A. | $ 8.5 | $ 26.0 | $ 26.0 |
| | Return to Speed | | $ 12.0 | N.A. | (*) | $ 12.0 |
| | New Business Revenue | | N.A. | N.A. | N.A. | N.A. |
| | Subtotal | | $ 37.0 | $ 8.5 | $ 46.0 | $ 63.0 |
| Residential Wi-Fi | | $4.3 - $ 12.6 | >$ 12.6 | $ 15.5 | $ 38 0 | $ 38.0 |
| Wi-Fi Only Tablets | Producer Surplus | N.A. | $ 7.5 | N.A. | N.A. | $ 7.5 |
| | Consumer surplus | | $ 7.5 | | N.A. | $ 7.5 |
| | Subtotal | | $ 15.0 | | N.A. | $ 15.0 |
| Hospital Wi-Fi | | $ 9-6 – $16.1 | N.A. | N.A. | (*) | $ 16.1 |
| Clothing RFID | | $ 2.0 - $ 8.1 | N.A. | N.A. | (*) | $ 8.1 |
| Wireless Internet Service Providers | | N.A. | N.A. | (*) | N.A. | N.A. |
| **Total** | | $ 16.0 - $ 36.8 | $ 64.6 | $24.0 | $ 84.0 | $ 140.2 |

(*) Referenced but not quantified
N.A. Not addressed
*Source: Compiled by TAS*

Despite this large number, all researchers mention in their studies that they may have underestimated these figures, which should be updated to capture the ever-increasing number of applications running on unlicensed bands.

The understandable limitations of the existing research on the economic value of unlicensed spectrum prompt the need to produce up-to-date, rigorously developed evidence to support the policy debate further. In this sense, the following study stands as a progression of analyses that were started by Thanki in 2009 and have been gradually extended and updated since (see figure A). It should be noted, however, that none of the prior studies claims their estimates represent the whole value of unlicensed spectrum.

**Figure A. Unlicensed Spectrum Economic Value in The United States: Prior Studies (in $ billions)**




Note: The composite constructed based on prior research does not account for economic growth that took place after the studies were completed.
*Source: Compiled by TAS*

This study first summarizes all economic benefits of unlicensed spectrum and formalizes a methodology for estimating its total economic value. Along those lines, unlicensed spectrum should be considered a critical production factor that generates value across four dimensions:

- Complementing wireline and cellular technologies, thereby enhancing their effectiveness;
- Providing an environment conducive to the development of alternative technologies, thus expanding consumer choice;
- Similarly, enabling the launch of innovative business models; and
- Expanding access to communications services beyond what is economically optimal by technologies operating in licensed bands

It should be mentioned, however, that these four dimensions could be interrelated and overlapping. For example, unlicensed spectrum can stimulate innovation resulting in new products and services, which could, in turn, contribute to the enhancement of existing wireline and cellular technologies, thereby increasing competition.

In addition to its intrinsic value, unlicensed spectrum generates "spill-over" value in other domains. In the first place, as pointed by Milgrom et al. (2011) unlicensed spectrum has a direct positive impact on the value of licensed bands. A reduction in the supply of licensed spectrum caused by maintaining or expanding unlicensed bands can yield an increase in the price per MHz of licensed spectrum. Beyond increasing the unit value of MHz as a result of restricted supply, the reduction of licensed spectrum bands acts as a stimulus for the development of technologies and services that complement licensed spectrum by increasing its capacity. Most importantly, technologies operating in unlicensed bands have the ability to off-load data traffic from cellular networks, which allows service providers to maximize revenues while controlling capital expenditures. In addition, by increasing broadband speed, traffic off-loading to Wi-Fi sites also raises broadband's consumer surplus. In fact, it has been argued that, considering the amount of traffic channeled through Wi-Fi, one could suggest the latter to be the preferred platform for data communications, while cellular networks become the off-loading technology (Garnett, 2011).

This study's approach to measuring the economic value focuses first on the surplus generated from the adoption of the technologies operating in the unlicensed network bands. The underlying premise is that the unlicensed spectrum resource generates a shift in both the demand and the supply curves (utilized to measure economic surplus) resulting from changes in the production function of services as well as the corresponding consumers' willingness to pay. On the supply side, the approach measures changes in the value of inputs in the production of wireless communications. The most obvious example is that of Wi-Fi, which positively contributes to wireless carriers' CAPEX and OPEX since they can control their spending while meeting demand for increased wireless traffic. From an economic theory standpoint, this allows the wireless industry to increase its output, yielding a marginal benefit that exceeds the marginal cost, resulting in a shift in the supply curve by a modification in the production costs. Additionally, since the demand curve is derived from the utility function, as consumers see the benefits of – and increasingly rely on - technologies enabled by unlicensed spectrum at a stable price, their willingness to pay will also increase, consequently shifting the demand curve. The sum of producer and consumer surplus represents the most important component of economic value creation.

However, beyond the concept of economic surplus, the study also measures any direct contribution of technologies, applications, and computer-mediated transactions that run on unlicensed spectrum bands to the nation's GDP. By quantifying their contribution to GDP, we consider the economic growth enabled by unlicensed spectrum. However, in measuring GDP contribution, we strictly consider only the revenues added "above and beyond" what would have occurred had the unassigned spectrum been licensed[2]. Table B presents the formalization of each value creation effect and underlying rationale.

[2] It should be mentioned that the "GDP contribution" metric might be subject to some distortions. For example, if the price of Wi-Fi service falls while quality remains stable, the imputed "contribution to GDP" decreases, while consumer welfare increases.

**Table B. Approaches to Measure Economic Value of Unlicensed Spectrum**

| | Economic Effect | Quantification | Rationale |
|---|---|---|---|
| Wi-Fi Cellular Off-Loading | Value of free Wi-Fi traffic offered in public sites | Consumer surplus | Price paid if traffic transported through the cellular network minus the price of paid Wi-Fi service equals the willingness to pay |
| | 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 |
| | 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 |
| | 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 |
| Residential Wi-Fi | Internet access for devices that lack a wired port (e.g. tablets, smartphones, game consoles) | Consumer surplus | Price to be paid if cellular network transports all traffic; this equals the willingness to pay |
| | Avoidance of investment in in-house wiring | Consumer surplus | Price to be paid if in-house wiring equals willingness to pay |
| Wireless Internet Service Providers | Aggregated revenues of 1,800 WISPs | GDP contribution | These revenues would not exist without the availability of unlicensed spectrum |
| Wi-Fi Only Tablets | Difference between retail price and manufacturing costs for a weighted average of tablet suppliers | Producer surplus | Availability of manufacturing and retail costs, as well as sales volume |
| | Difference between willingness to pay for entry level tablet and prices of iPad and Android products | Consumer surplus | Availability of willingness to pay data, retail pricing, and sales volume |
| Wireless Personal Area Networks | Sum of revenues of Bluetooth-enabled products | GDP Contribution | These revenues would not exist without the availability of unlicensed spectrum |
| | Sum of revenues of other WPAN standards (ZigBee, WirelessHART) | GDP Contribution | |
| RFID | RFID value in retailing | Consumer and producer surplus | Benefits to consumers and savings to producers resulting from RFID adoption |
| | RFID value in health care | | |

*Source: TAS analysis*

The compilation of effects outlined above indicates that the technologies operating in unlicensed spectrum bands in the United States generated a total economic value of $222 billion in 2013 and contributed $ 6.7 billion to the nation's GDP (see table C).

**Table C. United States: Summary of Economic Value of Unlicensed Spectrum (2013)**
**(in $ billions)**

| | Effect | Economic Value | | | GDP |
|---|---|---|---|---|---|
| | | Consumer Surplus | Producer Surplus | Total Surplus | |
| Wi-Fi Cellular Off-Loading | Value of free Wi-Fi traffic offered in public sites | $ 1.902 | N.A. | $ 1.902 | N.A. |
| | Benefit of total cost of ownership required to support future capacity requirement with Wi-Fi complementing cellular networks | N.A. | $ 10.700 | $ 10.700 | N.A. |
| | Contribution to GDP of increase of average mobile speed resulting from Wi-Fi off-loading | N.A. | N.A. | N.A. | $ 2.831 |
| | Sum of revenues of service providers offering paid Wi-Fi access in public places | N.A. | N.A. | N.A. | $ 0.271 |
| | Subtotal | $ 1.902 | $ 10.700 | $ 12.602 | $ 3.102 |
| Residential Wi-Fi | Internet access for devices that lack a wired port | $ 22.510 | N.A. | $ 22.510 | N.A. |
| | Avoidance of investment in in-house wiring | $ 13.570 | N.A. | $ 13.570 | N.A. |
| | Subtotal (*) | $ 36.080 | N.A. | $ 36.080 | N.A. |
| Wireless Internet Service Providers | Aggregated revenues of 1,800 WISPs | N.A. | N.A. | N.A. | $ 1.439 |
| Wi-Fi Only Tablets | Difference between retail price and manufacturing costs for a weighted average of tablet suppliers | N.A. | $ 34.885 | $ 34.885 | N.A. |
| | Difference between willingness to pay for entry level tablet and prices of iPad and Android products | $ 7.987 | N.A. | $ 7.987 | N.A. |
| | Subtotal | $ 7.987 | $ 34.885 | $ 42.872 | N.A. |
| Wireless Personal Area Networks | Sum of revenues of Bluetooth-enabled products | N.A. | N.A. | N.A. | $ 1.739 |
| | Sum of revenues of ZigBee-enabled products | N.A. | N.A. | N.A. | $ 0.267 |
| | Sum of revenues of WirelessHART-enabled products | N.A. | N.A. | N.A. | $ 0.160 |
| | Subtotal | N.A. | N.A. | N.A. | $ 2.166 |
| RFID | RFID Value in retailing | $ 26.26 | $ 68.58 | $ 94.84 | N.A. |
| | RFID Value in health care | $ 4.03 | $ 31.96 | $ 35.99 | N.A. |
| | Subtotal | $ 30.29 | $ 100.54 | $ 130.83 | N.A. |
| **TOTAL** | | $ 76.26 | $ 146.13 | $ 222.38 | $ 6.707 |

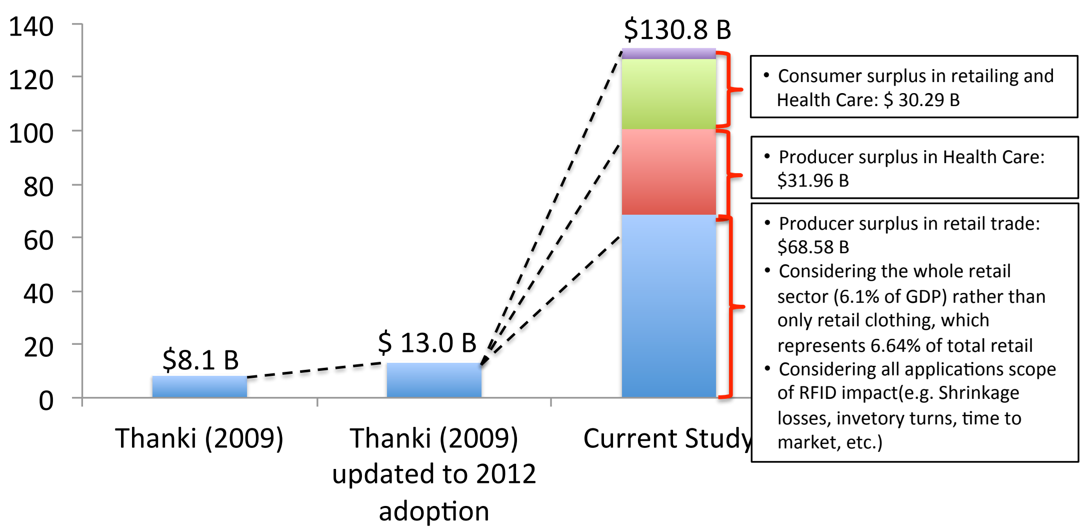
(*) A lower range in Residential Wi-Fi consumer surplus would amount to $ 31.9 billion
*Source: TAS analysis*

We recognize this number to be significantly higher (close to $ 82 billion more) than the composite generated by aggregating prior research (presented in Table A and Figure A), and, therefore, needs to be explained. The largest source of value ($130.83 billion) resides in the implementation of RFID in the Retail and Health Care industries (all data, sources and calculations of RFID value are included in chapter VIII). Thanki conducted the prior estimate of RFID economic value in 2009, focusing only on retail clothing (understandably so, since retail clothing was an adoption leader of RFID and there was already research on economic impact available at the time). The economic value estimated by Thanki in 2009 ranged between $2.1 and $8.1 billion. However, he recognized that the usage of RFID was “at its infancy”. In fact, his model assumed that RFID in retail clothing would reach 60% (high take up scenario) only in 2019.

Several things have happened since 2009. First, adoption of RFID in retail clothing has exceeded Thanki’s high uptake scenario (reaching 52% in 2012). If we were to consider only Thanki’s original industry (retail clothing), and the acceleration of RFID take-up, the economic value of this technology would increase approximately to $13 billion. Second, the blending of general-purpose networks and RFID has yielded new applications, which has led to their adoption in manufacturing plants, warehouses, and logistics chains. As a result, penetration has increased well beyond retail clothing, reaching the whole retail trade sector. According to a survey by Accenture, more than 50% of US retailers have already adopted RFID. Third, research on the economic value of RFID has greatly expanded since 2009 (Gorshe et al, 2012; Waller et al, 2011). For example, Thanki recognizes that his analysis does not consider the value that might be generated in preventing shrinkage, reducing inventory holdings, and using data for marketing purposes. In conclusion, three trends are at work that greatly enhance RFID economic value beyond the original estimate: more penetration in retail clothing, enhanced adoption in the retail sector as a whole, and more applications.

In addition, beyond retail trade, RFID adoption has expanded in the health care industries, a sector that was not originally considered by Thanki. The impact of all these changes is presented in figure B.

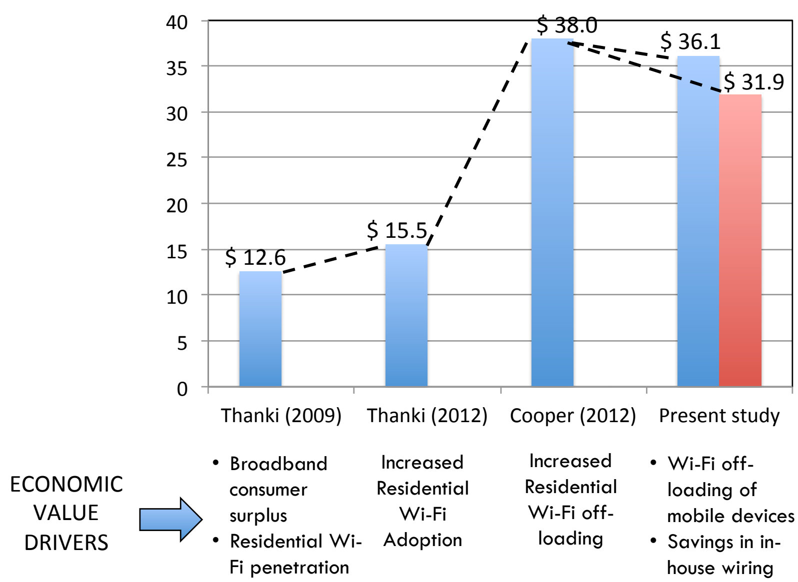
**Figure B. Economic Value of RFID: Thanki (2009) Versus Present Study (in $ billions)**




To sum up, implementing Radio Frequency Identification in two of the largest sectors of the US economy (retailing (6.1% of GDP) and health care (7.4% of GDP)) results in efficiencies that generate the largest portion of economic surplus ($ 130.83 billion). This estimate does not include all other areas impacted by RFID, such as manufacturing supply chain (Sarac et al., 2009) and livestock tracking.

Residential Wi-Fi also generates a sizable surplus. Thanki's original estimate (2009), based on the extrapolation of consumer surplus (Dutz et al., 2009) and 36% Wi-Fi adoption across households, was ranged between $4.3 billion and $12.6 billion. In 2012, Thanki updated his analysis based on increased Wi-Fi households and estimated its economic value at $15.5 billion. In the same year, Cooper (2012) provided a higher estimate (which he considers to be conservative) of $38 billion. This last author factors in not only the increase in Wi-Fi penetration but also the growth in cellular off-loading. Our approach differs from Thanki's and Cooper's. Rather than extrapolating from fixed broadband consumer surplus research, we quantify savings incurred by consumers as a result of deploying Wi-Fi in their residences (all data, sources and calculations are included in chapter IV). As of 2013, 63% of US households are equipped with Wi-Fi (versus only 36% when Thanki did his study), which has a net effect of providing free access for devices designed for wireless access (tablets, smartphones), generating annual transport savings of $22.5 billion. In addition, residential Wi-Fi services generate $13.6 billion in savings for households that do not require in-house wiring to interconnect PCs, printers, audio equipment, and the like. The sum of these estimates are two and a half times higher than Thanki's 2012 figures, and close to Cooper's (see figure C). To calibrate our results, we replicated Thanki's estimates, multiplying the total number of Wi-Fi households (72,450,000) by an assumed willingness to pay of $36.8 per household per month[3]. This yields a total surplus of $31.9 billion (considered to be a low bound estimate).

**Figure C. Economic Value of Residential Wi-Fi: Thanki (2009, 2012), Cooper (2012) Versus Present Study (in $ billions)**

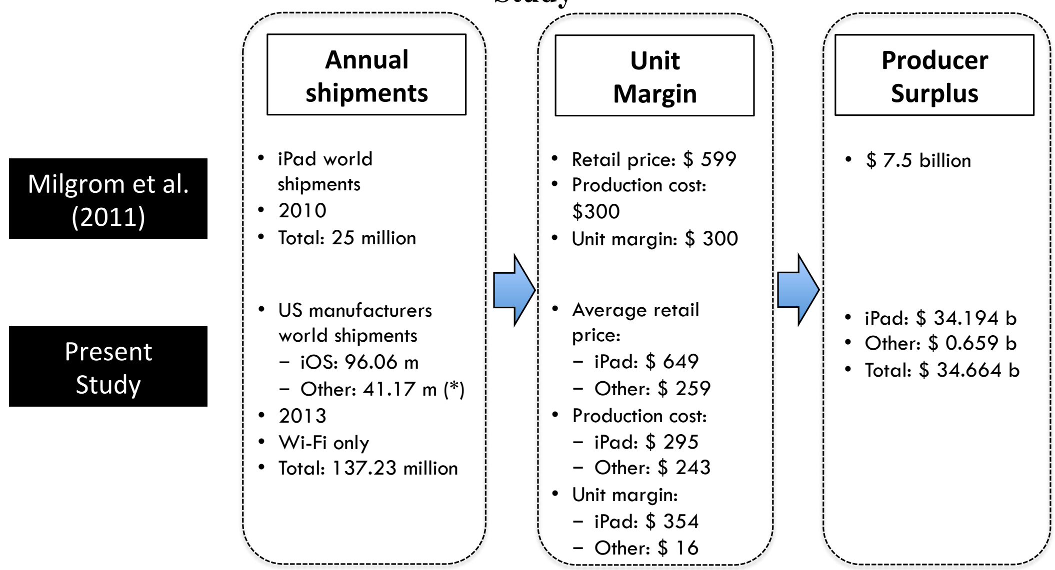



*Source: TAS analysis*

[3] Thanki estimates the average monthly consumer surplus to be $27.6, which represents 30% of the home broadband value. He also states that there is additional value not captured in his analysis (pp.35). Given the current Wi-Fi adoption and usage patterns, it is reasonable to assume that willingness to pay would amount to 40% of the value, which equals to $36.8 per month.

The producer surplus resulting from the adoption of tablets ($ 34.9 billion) is almost as high as the surplus of residential Wi-Fi and five times the surplus of the iPad as estimated by Milgrom et al. (2011) (all data, sources and calculations are included in chapter VI). While sales of tablets increased from 17.9 million in 2010 to approximately 220 million in 2013[4], the producer surplus per unit declined from $300 for the iPad in 2010 to an average per tablet (iOS or other) of $253 because Apple's competitors' tablet margins are substantially lower than the iPad (see figure D).

**Figure D. Producer Surplus of Wi-Fi Only Tablet: Milgrom et al. (2011) Versus Present Study**



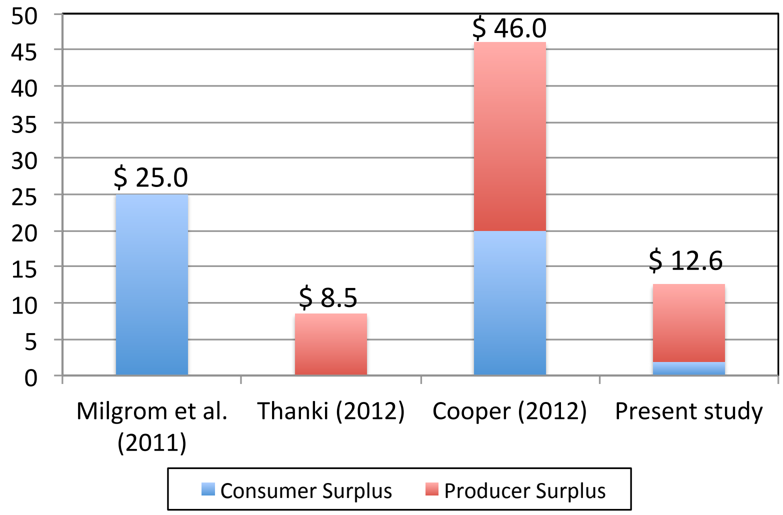

(*) Other: Google Nexus, Amazon Kindle Fire, HP Touchpad, etc.

*Source: TAS analysis*

Wi-Fi cellular off-loading also creates economic value (all data, sources and calculations are included in chapter III). This value includes the producer surplus generated by the operators' deployment of carrier-grade Wi-Fi sites to respond to the growth in wireless data traffic ($ 10.7 billion). This figure is higher than Thanki's 2012 $ 8.5 billion estimate due to the increase in the volume of Wi-Fi sites since the author conducted his analysis. Wi-Fi off-loading's second value-creation effect comes from the consumer surplus derived from the utilization of free Wi-Fi sites deployed in public locations ($ 1.9 billion). This is calculated as the cost of the total wireless traffic transported in free Wi-Fi sites (which is 3%) if the consumer would have to pay to a wireless carrier minus the price paid for Wi-Fi provisioned in public places. Our estimate is lower than Cooper's since we have a more conservative estimate of the annual benefit of off-loading for the carriers and because a portion of the consumer surplus assumed by Cooper (and Milgrom et al, 2011) has already been assigned to residential Wi-Fi (see figure E).

[4] This number was reduced to subtract shipments from manufacturers based overseas, and tablets with cellular connectivity, yielding a total of 137 million units for 2013.

**Figure E. Economic Value of Wi-Fi Off-Loading: Thanki (2012), Milgrom et al. (2012), Cooper (2012) Versus Present Study (in $ billions)**

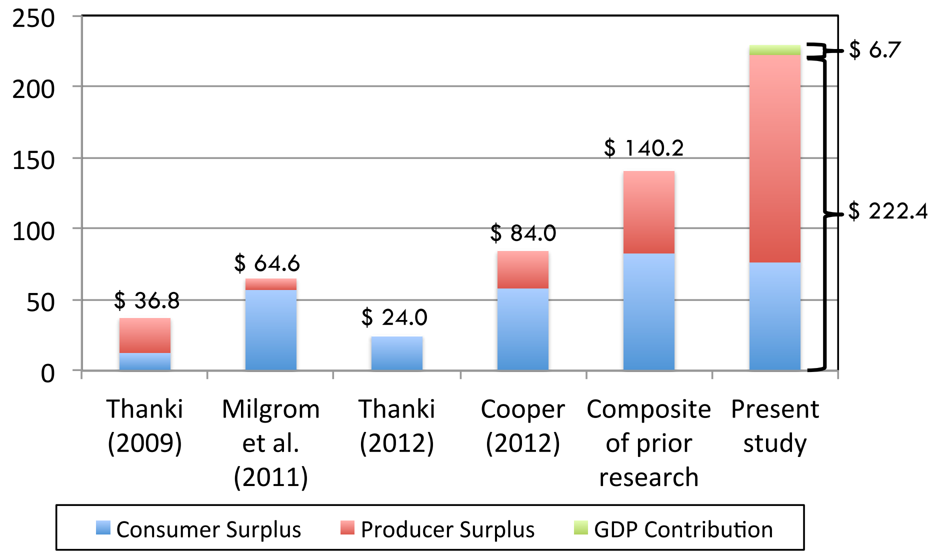



*Source: TAS analysis*

Finally, unlicensed spectrum fosters the development of new businesses generating revenues that directly contribute to the country GDP ($3.87 billion): companies offering paid Wi-Fi access in public places (e.g. Boingo), Wireless Internet Service Providers (WISPs), Bluetooth-enabled products (e.g. chipsets to enable hands-free wireless calling), ZigBee-enabled products (e.g. home automation), and WirelessHART (e.g. industrial monitoring systems). The spillover impact of faster-than-cellular broadband wireless connections resulting from Wi-Fi off-loading ($ 2.8 billion) also contributes to GDP.

To summarize, we believe that the aggregate economic surplus estimate of $222 billion and $6.7 billion in direct GDP contribution, while considerably higher than prior studies, is accurate since it captures the whole range of applications operating in unlicensed spectrum bands (figure F).

**Figure F. Unlicensed Spectrum Economic Value in the United States: Comparison with Prior Studies (in $ billions)**




*Source: TAS analysis*

Furthermore, this number is well above that one estimated by recent studies because it reflects a more detailed analysis of the multiple relatively heterogeneous applications and technologies that rely on unlicensed spectrum.

In light of this value, and the technical characteristics of unlicensed spectrum, the economic rationale for licensing it does not apply. By definition, applications and services relying on low-power, low-propagation transmission, like Bluetooth, ZigBee, and RFID remain private goods, as one person's use of does not usually impact other users (Varian, 2013). Congestion in these cases is hardly a problem. In the case of Wi-Fi, some congestion issues arise, particularly in public places. However, these could be resolved by assigning more bands for unlicensed usage.

This last point leads to the question of whether the current assignment of unlicensed spectrum bands risks, in light of the explosive growth in usage, in becoming a bottleneck of future value creation. Indeed, our estimate of Internet traffic trends indicates that total Wi-Fi traffic in the United States is currently 0.67 Exabytes per month and will reach 5.97 Exabytes by 2017, reflecting a 68.0% growth rate. Wi-Fi households in the US, currently at 63%, are forecast to reach 86% by 2017[5]. According to IDC, tablet worldwide shipments, currently at 221 million, are estimated to reach 386 million by 2017. According to Gorsh et al, while 52% of retailers surveyed had already implemented or piloted RFID within their organization, 23 % are considering launching pilots in the near future[6]. All in all, there are currently 20,339 different unlicensed devices certified for use in the 2.4 GHz band alone, approximately three times the amount in any licensed band[7].

[5] Gillott, I. (2012). U.S. Home Broadband and Wi-Fi Usage Forecast 2012-2017. Austin, TX: iGR.

[6] Gorsh, M, Rollman, M, and Beverly, R. (2012) Item-level RFID: a competitive differentiator. Chicago, Illinois: Accenture.

[7] Wireless Innovation Alliance. Background on Unlicensed Spectrum.

In the context of accelerating adoption of applications operating in unlicensed spectrum, it would be relevant to ask the question whether there is enough spectrum space to accommodate the expected growth. Until 2008, roughly 955 MHz were allocated to unlicensed uses below 6 GHz (Hazlett et al., 2010), although only a small portion of this is in the beachfront spectrum (the 300 MHz to 3 GHz spectrum range). In 2010, the FCC allocated additional unused spectrum between broadcast TV channels. That said, the most used bands remain in the 900 MHz, 2.4 MHz, 5.2/5.3/5.8 GHz, 24 GHz, and above 60 GHz (Milgrom et al., 2011). In fact, the 2.4 GHz and 5GHz bands have become increasingly congested due to the intense Wi-Fi usage.

If future assignment of unlicensed spectrum is not fulfilled, it is plausible to consider that economic value creation would be at risk. This case is similar to the transition from 3G to 4G and the allocation of additional licensed spectrum for mobile broadband. Where do we see the effects that would be most at risk? Our quantification of the risk of not assigning additional unlicensed spectrum assumes that, beyond a certain point of network congestion, application or technology demand stops growing.

In the first place, let us address the so-called return to speed. At the current rate of traffic off-loading, the average speed of mobile traffic in the United States in 2013 was 10 Mbps[8]. Our analysis showed that, even when considering the increasing speed of LTE networks, if all the off-loaded traffic were to be conveyed through cellular networks, the speed would decline to 3.43 Mbps, with the consequent negative impact of $2.8 billion in GDP (see section III.3 for detailed calculations). Over five years, the impact would amount to $ 23.56 billion. The benefit derived from the additional speed resulting from off-loading is what we call the Wi-Fi return to speed. However, if we assume that, due to congestion, the average Wi-Fi speed does not increase to 17 Mbps, as Cisco projects, but stays at current levels (13.32 Mbps), the average speed of all mobile traffic would not change significantly from today, which means that $ 10.6 billion of the Wi-Fi speed return over the next five years would disappear.

Obviously, average speed could decline even further beyond the current level, with the consequent increase in value erosion. According to a study by Williamson et al. (2013), this scenario is highly likely. Once an 80-100 Mbps fiber link is deployed to a customer premise, the last mile is not the bottleneck any more, and the residential Wi-Fi becomes the congestion point. This is because there is a difference between the advertised speed in a typical Wi-Fi router (150 Mbps) and the delivered speed, which is below 70 Mbps[9]. Given that Wi-Fi shares available capacity across devices, if a typical Wi-Fi household is running multiple devices, the service will degrade and be substantially less than what could be handled by a fiber link.

A second area of negative impact under a scenario of limited unlicensed spectrum assignment is service degradation in public places (airports, convention halls, etc.). Research by Wagstaff (2009) and Van Bloem et al. (2011) indicates that in dense device environments, data overheads

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[8] This is calculated by prorating total mobile traffic by Wi-Fi and Cellular speeds according to off-loading factors (see appendix C).

[9] The difference is due in part to the need to assign part of the capacity to the data overheads. In addition, advertised speeds are based on tests that relying on large packets, while the average packet size is much smaller. Finally, range and attenuation are factors to be considered in the reduction of speed. Williamson et al. (2013) estimate that delivered speed is approximately 50% of the advertised.

that are generated to keep the connection running consume between 80% and 90% of capacity. In the context of increasing traffic volumes, Wi-Fi is becoming the contention point in public access networks. Some of this pressure could be alleviated by the upcoming Wi-Fi standard 802.11ac. While it is difficult to quantify the negative impact of this degradation, a large portion has been considered above in the reduction of the so-called Wi-Fi speed return. In addition, no additional assignment of unlicensed spectrum could result in the disappearance of the Wi-Fi service provider industry since, with lower service quality level, these operators could not compete with cellular service provider: an erosion of $271 million direct contribution to the GDP.

A third area of negative impact if additional unlicensed spectrum is not assigned could be an erosion of the benefit to carriers generated by cellular traffic off-loading. With high-density device environments being so prone to contention, if Wi-Fi does not benefit from additional spectrum, cellular carriers would experience service degradation when users roam into Wi-Fi. In other words, Wi-Fi's value of complementarity would be greatly diminished, reducing the $10.7 billion estimated producer surplus.

Following the evidence generated in this study, we conclude that any policies focused on this portion of the spectrum must preserve the value generated so far as well as the capacity to generate economic surplus in the future. Given the emerging body of evidence of congestion within the unlicensed spectrum bands and their estimated economic value, it would highly beneficial to pursue additional research linking up the study of congestion scenarios, the advantage of additional allocation and the risks of not proceeding along this path.

## I. INTRODUCTION

The debate over the most effective way of allocating frequency spectrum has been conducted over the past fifty years, in particular since the publication of Coase's seminal paper (1959) on spectrum management. A specific issue of the policy debate relates to the management of unlicensed spectrum, which covers the frequency bands for which no exclusive licenses are granted. Key policy questions addressed in this domain range from whether granting exclusive licenses would deter innovation to if setting spectrum for unlicensed uses would be costly in terms of reduced government revenues to be derived from auctioning frequency rights. Along these lines, research to date has produced a number of very important contributions in support of (Milgrom et al, 2011; Carter, 2003; Cooper, 2011; Bayrak, 2008; Marcus et al, 2013; Crawford, 2011; Benkler, 2012; Calabrese, 2013) and against (Hazlett et al., 2010a; Hazlett et al, 2010b, Nguyen et al, 2010; Bazelon, 2008) the allocation of spectrum for private use. That said, while the debate has highlighted the diverse beneficial effects of unlicensed spectrum - such as triggering technological innovation, complementing cellular networks, and the like - little research assesses the economic value of unlicensed spectrum, particularly the producer and consumer surplus derived from keeping a portion of the spectrum unassigned as well as its GDP contribution[10]. Part of the difficulty in assessing the value of unlicensed spectrum resides on the fact that, unlike licensed spectrum that is used for a few, homogeneous services, unlicensed bands provide the environment for the provision of several heterogeneous services and devices. Furthermore, given the recent history of some of those services, historical data on pricing and use is not readily available. Finally, given the complementarity between applications relying on unlicensed and licensed spectrum, value estimation of the unlicensed portion is non-trivial. Nevertheless, an evidence-based policy debate requires the rigorous quantification of economic value of the unlicensed spectrum.

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[11] and, consequently, were too conservative.

Two years later, Milgrom et al. (2011) supported Thanki's numbers, but also provided additional 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 faster data rates of mobile phones ($ 12 billion). Finally, they referenced other non-quantified benefits, such as the usage of Wi-Fi only devices and future applications such as Super Wi-Fi and Advanced Meter Infrastructure.

[10] 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).

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

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[12] (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 the 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 took place since 2009, and slightly reduced the Milgrom et al. off-loading consumer surplus estimate to $ 20 billion.

A compilation of the results produced by these four pieces of research reveals the limited available evidence generated to date in support of such a critical policy discussion (see table I-1).

**Table I-1. United States: Prior Research on Economic Value of Unlicensed Spectrum (in $ billions)**

| | Effect | Thanki (2009) | Milgrom et al. (2011) | Thanki (2012) | Cooper (2012) | Composite |
|---|---|---|---|---|---|---|
| Wi-Fi Cellular Off-Loading | Consumer Surplus | N.A. | $ 25.0 | N.A. | $ 20.0 | $ 25.0 |
| | Producer Surplus | | N.A. | $ 8.5 | $ 26.0 | $ 26.0 |
| | Return to Speed | | $ 12.0 | N.A. | (*) | $ 12.0 |
| | New Business Revenue | | N.A. | N.A. | N.A. | N.A. |
| | Subtotal | | $ 37.0 | $ 8.5 | $ 46.0 | $ 63.0 |
| Residential Wi-Fi | | $4.3 - $ 12.6 | >$ 12.6 | $ 15.5 | $ 38 0 | $ 38.0 |
| Wi-Fi Only Tablets | Producer Surplus | N.A. | $ 7.5 | N.A. | N.A. | $ 7.5 |
| | Consumer surplus | | $ 7.5 | | N.A. | $ 7.5 |
| | Subtotal | | $ 15.0 | | N.A. | $ 15.0 |
| Hospital Wi-Fi | | $ 9-6 – $16.1 | N.A. | N.A. | (*) | $ 16.1 |
| Clothing RFID | | $ 2.0 - $ 8.1 | N.A. | N.A. | (*) | $ 8.1 |
| Wireless Internet Service Providers | | N.A. | N.A. | (*) | N.A. | N.A. |
| Total | | $ 16.0 - $ 36.8 | $ 64.6 | $24.0 | $ 84.0 | $ 140.2 |

(*) Referenced but not quantified
N.A. Not addressed
*Source: TAS analysis*

The only consistent series of estimates, albeit reliant on different methodologies, is the one of residential Wi-Fi. Nevertheless, the growth in Wi-Fi household penetration is the central assumption driving an increase in economic value from a low-end estimate of $4.3 billion in 2009 to an estimate of $ 15.5 billion in 2012. A composite sum (which recognizes that there

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

could be some double-counting) of the latest estimates for each of the areas addressed would indicate a total economic value of $ 140.2 billion for unlicensed spectrum in the United States. We believe, however, that even this estimate could be subject to a number of forecasting limitations.

First, in a field that is evolving at such a high speed in terms of the rate of product innovation, consumer adoption, and technological substitution, a 2009 assessment of economic value could vastly underestimate present economic value.

Second, as pointed out by Milgrom et al. (2011), the range of unlicensed spectrum applications has vastly increased over time. In fact, by looking only at applications that currently rely on unlicensed spectrum, one could underestimate its value since some of the benefits cannot yet be foreseen. As an example, to be shown in chapter VI, one of the greatest benefits derived by unlicensed spectrum results from the diffusion of Wi-Fi only tablets. Apple introduced the first version of its iPad, the most successful tablet to date, in April 2010 (eight months after the publication of Thanki's study). By the time Milgrom et al. published their study (October 2011), global annual shipments of tablets reached 70 million. Two years later, this number exceeded 200 million.

Third, the assessment of economic value has, in many cases, been conducted at an extremely high level with the purpose of ranging orders of magnitude rather than stipulating value through a rigorous approach. As an example, the assessment of economic surplus derived from the Apple iPad (Milgrom et al 2011) considered that, in the absence of willingness-to-pay data, consumer surplus could be of the same magnitude of the product's producer surplus.[13]

The understandable limitations of extant research on the economic value of unlicensed spectrum raise the need to produce up-to-date evidence that brings additional support to the policy debate. This study commences with a summary of all economic benefits of unlicensed spectrum and formalizes the methodology for estimating total economic value. It then proceeds sequentially to assess the value of specific technologies that rely on unlicensed spectrum. For each technology, the economic value will be estimated by application or impact area. The last chapter dedicated to economic value estimation focuses on future uses of unlicensed spectrum. A final conclusion summarizes the evaluations of each technology, yielding a final value for specific metrics (economic value, GDP contribution, employment, consumer surplus). In this sense, the following study stands as a progression of analyses that were started by Thanki in 2009 and have gradually been extended and updated since.

[13] Milgrom et al. (2011) are cognizant of this limitation (calling it a "plausible first guess") and point out that assessing value in a rigorous fashion exceeds the purpose of their research.

## II. ESTIMATING ECONOMIC BENEFITS OF UNLICENSED SPECTRUM

This chapter presents the approach utilized to estimate the economic value of unlicensed spectrum. We begin by presenting the intrinsic and derived sources of value of unlicensed spectrum, which serves as a backdrop for reviewing prior value estimation research. Based on this review, we present the approach to be followed in the study.

### II.1. The intrinsic economic value of unlicensed spectrum

Unlicensed spectrum has fostered the establishment of standards that have enabled the development of numerous applications and devices (see table II-1):

**Table II-1. Standards and enabled complementary technologies**

| Standards | Frequency bands | Geographic Range | Data rate | Devices and applications |
|---|---|---|---|---|
| Wi-Fi (802.11b, 802.11g) | • 2.4 GHz<br>• 3.6 GHz<br>• 5 GHz | • indoor: 38 meters<br>• outdoor: 125 meters | • Up to 54 Mbps | • Computers<br>• Printers<br>• Mobile phones<br>• Tablets |
| Bluetooth (802.15.1) | • 2.4 GHz | • Short range indoors | • 1-3 Mbps | • Phone headsets<br>• PC networks<br>• Barcode scanners<br>• Credit card payment machines |
| ZigBee (802.15.4) | • 915 MHz | • 75 meters | • 250 Kbps | • Wireless light switches<br>• Electrical meters with in-home-displays<br>• Traffic management systems |
| WirelesHART (802.15.4) | • 2.4 GHz | • indoor: 60 -100 meters<br>• outdoor: 250 meters | • 250 Kbps | • Equipment and process monitoring<br>• Environmental monitoring, energy management<br>• Asset management, predictive maintenance, advanced diagnostics |
| WirelessHD | • 60 GHz | • 30 feet | • 28 Gbps | • High Definition consumer electronic devices |
| WiGig (802.11ad) | • 60 GHz | • 5 -10 meters | • 6 Gbps | • Smartphones<br>• Tablets<br>• Docking stations<br>• PCs & Peripherals<br>• TV & Peripherals<br>• Digital Cameras<br>• Camcorders |
| RFID | • 50-500 KHz<br>• 13.56 MHz<br>• 0.9 to 2.5 GHz | • Up to 29 inches | • Read-only: 8.75 kbps<br>• Active Read - Write: 3 kbps | • Asset tracking<br>• Livestock tracking, credit card payments<br>• Highway toll payments<br>• Supply chain management |

*Source: Compiled by TAS*

This section demonstrates how unlicensed spectrum should be considered a critical production factor to generate value across four dimensions:

- Complementing wireline and cellular technologies, thereby enhancing their effectiveness
- Developing alternative technologies, thus expanding consumer choice
- Supporting innovative business models
- Expanding access to communications services

### *II.1.1. The value of complementary technologies*

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

Wireless operators can also reduce their capital spending by complementing their cellular networks with carrier-grade Wi-Fi sites, which are considerably less expensive than cellular network equipment with similar capacity. In addition to reducing spending, wireless carriers can offer fast access service without a base station congestion challenge. Finally, cellular carriers derive benefits from avoiding CAPEX since a portion of traffic is off-loaded to residential Wi-Fi or business networks (Cooper, 2012).

As the list in table II-1 demonstrates, the list of devices and applications that complement and enhance the capability of fixed and wireless networks is fairly extensive. In most cases, fixed and wireless networks can deliver the value attached to specific applications only by coupling with the technology operating in unlicensed spectrum.

### *II.1.2. The value of alternative technologies*

In addition to complementing cellular networks, unlicensed spectrum can provide the environment needed for operating technologies that are substitutes to licensed uses, thereby providing consumers with a larger set of choices. By limiting power and relying on spectrum with low propagation, unlicensed bands avoid interference, rendering the need for property rights irrelevant. In fact, some of the most important innovations in wireless communications are intimately linked to Wi-Fi for gaining access.

Several communications platforms exist that depend on the availability of broadband services. For example, on *Skype*, the recommended download/upload speed for a high quality video call is 500 kbps and 2 Mbps for a group video call. *Webex*, a similar service predominantly seen in the professional context, has a bandwidth requirement of 3 Mbps for high quality videos. While fixed broadband can support these services, in either mobile (on the go) or nomadic settings, *Skype* or *Webex* increasingly rely on Wi-Fi connectivity for access.

Similarly, *Viber,* a platform that supports free messaging and voice/video calling primarily on smartphones, but also on PCs and tablets, can only be supported by LTE networks or faster technologies. Below 4G, latency, cell tower saturation and handovers handling have negatively impacted customer experience. In addition, given the bandwidth use required to support the service (50 Mb for approximately 200 minutes), Wi-Fi appears to be the most common form of access. A similar concept could be applied to *What's App*, a common platform used primarily on Wi-Fi networks to substitute text messaging.

### *II.1.3. The value of innovative business models*

By providing consumers with additional service choices, unlicensed spectrum also supports the development of innovative business models. The causality between unlicensed spectrum and innovation occurs at multiple levels. First, firms developing new applications in an unlicensed spectrum environment do not need approval from the operators of cellular networks. On the other hand, a firm that attempts to develop a product running on spectrum licensed to a set of exclusive holders faces a "coordination failure" barrier (Milgrom et al., 2011). Along those lines, if the product requires the acceptance and coordination of multiple license holders (say multiple cellular network operators), the innovator must negotiate with every one of them (unless it is willing to face the problem of restricting its market reach).

Second, even if the innovating firm restricts the number of cellular networks with which it negotiates, it still faces the complexities of reaching a financial agreement with the license holder. For example, despite its size and bargaining power, Apple spent a year and a half negotiating the initial marketing terms for the iPhone with AT&T[14].

Third, beyond the impact on time-to-market, small firms face an additional obstacle: spectrum exclusive license holders can impose a financial *hold-up* threat by raising the fraction of the potential revenues they would appropriate. This could reduce the incentive for small firms to launch new products.

The innovator greatly reduces all three of these obstacles when launching its product in an unlicensed spectrum environment. There is no need of prior agreement from license holders, no time-to market penalty, and no disincentives resulting from costly revenue splits. Finally, from a cost of entry standpoint, without licensing fees, required approvals, and the need for radio frequency engineering planning (Carpini, 2011), unlicensed spectrum results in extremely low set-up and deployment costs.

As a testament to the low innovation barriers in unlicensed spectrum environments, numerous applications launched in the past were developed leveraging unlicensed bands. These applications include wireless record players, transmission of radio signals over power lines, remote control operated devices, wireless microphones, garage door openers, telemetry systems, field disturbance sectors, auditory assistance devices, security alarms, and cordless phones. We

[14] Cohan, P. "Project Vogue: Inside Apple's iPhone deal with ATT", Forbes, 9/10/2013.

also count applications stores, and music streaming among the many innovative business models indirectly enabled by unlicensed spectrum[15].

While either fixed broadband or mobile broadband services can deliver these business models, technologies operating within unlicensed spectrum bands add additional convenience from the standpoint of nomadic mobility, speed of access, or affordability.

### *II.1.4. The value of expanding access to communications services*

In addition to the applications discussed above, technologies operating in unlicensed spectrum can bridge the broadband coverage digital divide. According to a report from the NTIA and the FCC, in 2011 there were 26.2 million US citizens living within 9.2 million households (or 6.99%) unserved by fixed broadband services. As expected, the majority of these households were located in rural and isolated areas of the country. While the FCC report does not track broadband over cellular coverage, the National Broadband Map indicates that 3.2 million households (34% of the unserved number mentioned above) can only gain access to broadband services provided by the so-called Wireless Internet Service Providers (WISPs), which typically operate on unlicensed or lightly licensed spectrum in the 3.65 GHz band.

Further developments in the areas of spectrum sensing, dynamic spectrum access, and geolocation techniques (Stevenson et al., 2009) could improve the quality of wireless service based on unlicensed spectrum technologies. For example, as reported by Burger (2011), a new version of the Wi-Fi standard, 802.11af, sometimes called “Super Wi-Fi”, can substantially extend the geographic range of conventional 802.11 standard and provide cost-efficient access in rural settings.

## II.2. The derived value of unlicensed spectrum

In addition to its intrinsic value, unlicensed spectrum generates “spill-over” value in other domains. In the first place, unlicensed spectrum has a direct positive impact on the value of licensed bands. For example, Milgrom et al. (2011) argue that a reduction in the supply of licensed spectrum caused by keeping or expanding the unlicensed bands can yield an increase in the price per MHz of licensed bands. Assuming that aggregate demand is relatively inelastic, scarcity could yield a price increase. In that sense, less available spectrum will not necessarily result in lower revenues for the government.

Beyond the unit value of MHz as a result of restricted supply, the reduction of licensed spectrum bands stimulates the development of technologies and services that complement such bands by enhancing the supply of capacity, thereby raising their intrinsic value per MHz. Most importantly, technologies operating in unlicensed bands have the ability to off-load data traffic from cellular networks, which allows service providers to maximize revenues while controlling capital expenditures. In addition, network off-loading also raises broadband’s consumer surplus. Effects such as higher download speeds increase consumer surplus (as indicated by research

[15] See also the recent launch of consumer wireless service providers running on unlicensed spectrum offering unlimited service at a fraction of the price charged by cellular carriers’ plans.

conducted among both consumers (Roston et al, 2010; Dutz et al, 2009) and enterprises (Grimes et al, 2009; Ospina, 2011).

Finally, by providing an environment for the development of alternative wireless communications platforms, unlicensed spectrum becomes a primary vehicle for increasing consumer choice of services.

### II.3. A theoretical approach to measuring economic value of unlicensed spectrum

An attempt to measure rigorously the economic value of unlicensed spectrum requires the formalization of an approach that can integrate the various economic gains, be it consumer or producer benefits, as well as their net direct contributions to the GDP. The following section first reviews the approach used by prior research to estimate economic value. Based on the review of prior research, it outlines the framework that this study will follow.

#### *II.3.1. Prior theoretical frameworks to measure economic value of unlicensed spectrum*

In the first attempt to estimate economic value of unlicensed spectrum, Thanki (2009) selected applications and relied both on consumer and producer surplus (see table II-2).

**Table II-2. Theoretical Underpinnings of Thanki (2009) Assessment of Annual Economic Value of Unlicensed Spectrum in the United States (in $ billions)**

| Example | Consumer Surplus | Producer Surplus |
|---|---|---|
| Residential Wi-Fi | $ 4.3 - $ 12.6 | N.A. |
| Wi-Fi in hospitals | (*) | $ 9.6 - $ 16.1 |
| RFID in retail clothing | $ 2.0 - $ 8.1 (**) | |

(*) Mentioned in the study but not quantified
(**) Estimates cannot differentiate between pure efficiency gains (producer surplus) and benefits to consumers
*Source: Thanki (2009)*

In his study, Thanki (2009) also ascertains that if the effect of a technology "cannot be directly attributed to either consumer or producer surplus, (it) cannot be regarded as an economic gain."

The Milgrom et al. (2011) approach is also implicitly based on the concept of economic surplus. Beyond reiterating Thanki's 2009 estimates, their quantification of value derived from three applications is based on the assessment of consumer and producer surplus (see table II-3).

**Table II-3. Theoretical Underpinnings of Milgrom et al (2011) Assessment of Annual Economic Value of Unlicensed Spectrum in the United States (in $ billions)**

| Example | Consumer Surplus | Producer Surplus |
|---|---|---|
| iPad | $ 7.5 | $ 7.5 |
| Wi-Fi Cellular off-loading | $ 25 | N.A. |
| Speed effect (*) | $ 12 | N.A. |

(*) Alternative way of measuring off-loading consumer surplus
*Source: Milgrom et al. (2011)*

In his 2012 paper, Thanki again relies on the economic surplus framework, restating his residential Wi-Fi statement and adding an estimate of producer surplus for cellular off-loading: the cost saved by carriers by off-loading a portion of wireless data traffic to Wi-Fi hot-spots (see table II-4).

**Table II-4. Theoretical Underpinnings of Thanki (2012) Assessment of Annual Economic Value of Unlicensed Spectrum in the United States (in $ billions)**

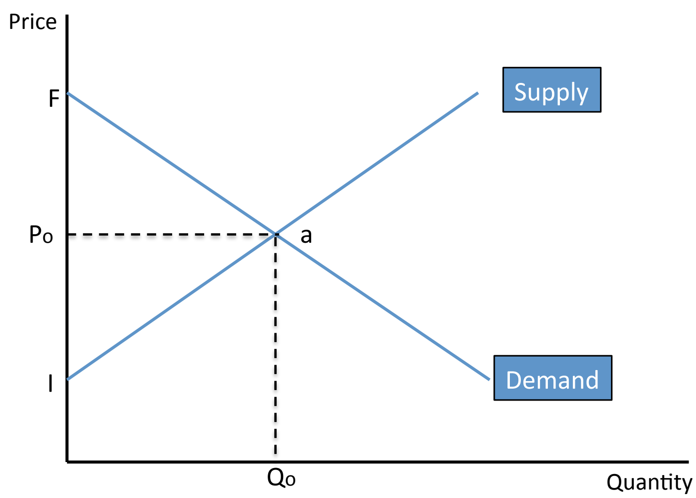
| Example | Consumer Surplus | Producer Surplus |
|---|---|---|
| Residential Wi-Fi | $ 15.5 | N.A. |
| Wi-Fi Cellular off-loading | N.A. | $ 8.5 |

*Source: Thanki (2012)*

Cooper (2012) also follows the same theoretical framework.

The methodology implicitly relied on in determining the economic impact of unlicensed spectrum in all four studies is based on the economic surplus approach (see figure II-1).

**Figure II-1. Measurement of Economic Surplus**



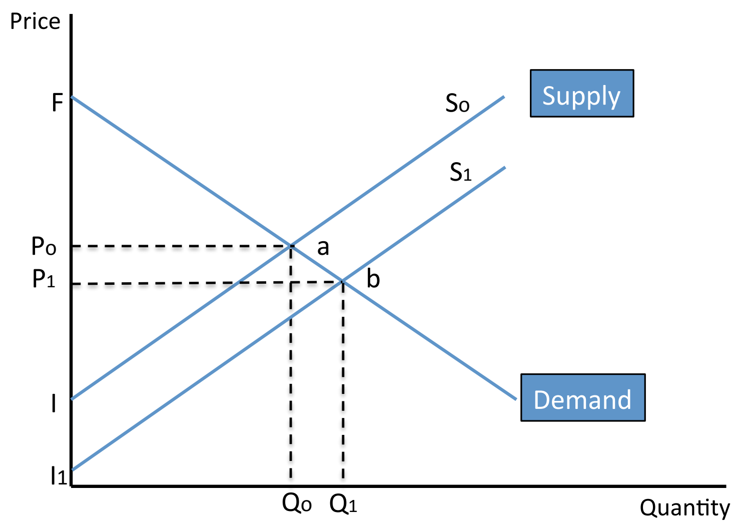

The concept of economic surplus is based on the difference between the value of units consumed and produced up to the equilibrium price and quantity, allowing for the estimation of consumer surplus (area of F, Po, a) and producer surplus (area of Po, I, a).[16] Consumer surplus measures the total amount 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, in our context, is essentially the economic profit they earn from providing the service. The total surplus is contained in the area F, I, a.

[16] Following Alston (1990), we acknowledge that this approach ignores effects of changes in other product and factor markets; for example, unlicensed spectrum increases the economic value of technologies operating in licensed bands.

***II.3.2. Our approach to measuring economic value of unlicensed spectrum:***

Our approach to measuring economic value focuses first on the surplus generated after the adoption of the technologies operating in the unlicensed network bands.[17] The underlying assumption of this approach is that the unlicensed spectrum resource generates a shift both in the demand and supply curves resulting from changes in the production function of services as well as the corresponding willingness to pay. On the supply side, the approach measures changes in the value of inputs in the production of wireless communications. The most obvious example is whether Wi-Fi enabled by unlicensed spectrum represents a positive contribution to wireless carriers' CAPEX and OPEX insofar as they can control their spending while meeting demand for increased wireless traffic. From an economic theory standpoint, the wireless industry can then increase its output, yielding a marginal benefit exceeding the marginal cost. This results in a shift in the supply curve by a modification in the production costs (see figure II-2).

**Figure II-2. Measurement of Economic Surplus Resulting From a Supply Shift**

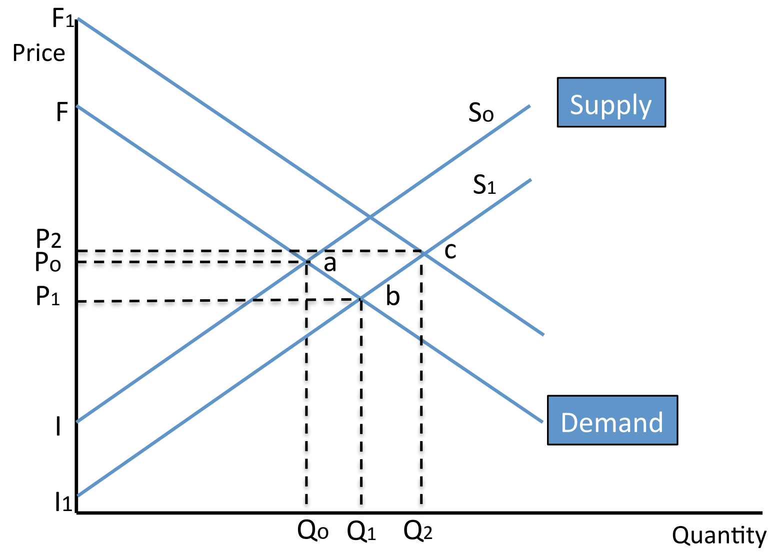



The development and adoption of technologies operating within unlicensed spectrum bands causes the shift in the supply curve, yielding a new equilibrium price and quantity. Under this condition, producer surplus is represented by the triangle F, b, P1, and consumer surplus by the area within P1, b, I1.

Additionally, since the demand curve is derived from the utility function, higher benefit to the consumer derived from the reliance on technologies enabled by unlicensed spectrum at a stable price will yield an increase in the willingness to pay, and consequently a shift in the demand curve (see figure II-3).

[17] See a similar approach used by Mensah and Wohlgenant (2010) to estimate the economic surplus of adoption of soybean technology.

**Figure II-3. Measurement of Economic Surplus Resulting From a Supply and Demand Shift**




Under these conditions, total economic value is now represented by the area I1, c, F1, representing both changes in consumer and producer surplus.

To quantify incremental surplus derived from the adoption of technologies operating in the unlicensed spectrum bands, we itemize the number of technologies and applications intricately linked to this environment. However, we complement the concept of economic surplus with an assessment of the direct contribution of the technologies and applications 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. On the one hand, we focus on consumer and producer surplus, but, on the other hand, we consider the new economic growth enabled by unlicensed spectrum. In measuring the GDP direct contribution, we strictly consider the revenues added "above and beyond" what would have occurred had the unassigned spectrum been licensed. Along those lines, if unit costs are available, we do not include them in the GDP contribution, but rather include them in a metric of producer surplus.

The assignment of each effect and underlying rationale is included in table II-5.

**Table II-5. Approaches to Measuring Economic Value of Unlicensed Spectrum**

| | Economic Effect | Quantification | Rationale |
|---|---|---|---|
| Wi-Fi Cellular Off-Loading | Value of free Wi-Fi traffic offered in public sites | Consumer surplus | Price paid if traffic transported through the cellular network minus the price of paid Wi-Fi service equals the willingness to pay |
| | Total cost of ownership (cumulative CAPEX and OPEX) necessary 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 |
| | Contribution to GDP from the increase in average mobile speed resulting from Wi-Fi off-loading | GDP contribution | While speed increase could be considered consumer surplus, recent research asserts a spill-over in terms of economic efficiency |
| | 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 |
| Residential Wi-Fi | Internet access for devices that lack a wired port (e.g. tablets, smartphones, game consoles) | Consumer surplus | Price to be paid if transported through the cellular network; this equals the willingness to pay |
| | Avoidance of investment in in-house wiring | Consumer surplus | Price to be paid for in-house wiring equals willingness to pay |
| Wireless Internet Service Providers | Aggregated revenues of 1,800 WISPs | GDP contribution | These revenues would not exist without the availability of unlicensed spectrum |
| Wi-Fi Only Tablets | Difference between retail price and manufacturing costs for a weighted average of tablet suppliers | Producer surplus | Availability of manufacturing and retail costs as well as sales volume |
| | Difference between willingness to pay for entry level tablet and prices of iPad and Android products | Consumer surplus | Availability of willingness to pay data, retail pricing, and sales volume |
| Wireless Personal Area Networks | Sum of revenues of Bluetooth-enabled products | GDP Contribution | These revenues would not exist without the availability of unlicensed spectrum |
| | Sum of revenues of other WPAN standards (ZigBee, WirelessHART) | GDP Contribution | |
| RFID | RFID value in Retailing | Consumer and producer surplus | Benefits to consumers and savings to producers resulting from RFID adoption |
| | RFID value in Health Care | | |

*Source: TAS analysis*

In the following chapters, we will proceed by estimating economic value according to the approaches described above.

## III. THE VALUE OF Wi-Fi FOR CELLULAR OFF-LOADING

Wi-Fi is already transporting the majority of the mobile Internet traffic. Global analysts estimate that 40% of network off-loading occurs via public and private Wi-Fi facilities[18]. Cisco estimates that the global average for daily data consumption is four times higher over Wi-Fi than over cellular networks, averaging 55 MB and 13 MB per day, respectively.[19] As expected, the United States is well ahead of this trend. For example, based on a sample of 200,000 US users, Mobidia estimates that, as of January 2012, 88% of smartphone users were active Wi-Fi users, with a traffic off-loading factor of 63.4%.[20]

While the value of cellular off-loading is based on the congestion relief for licensed spectrum owners that comes from the additional spectrum (Bazelon, 2008), end users also see value in off-loading to private and public Wi-Fi since it allows them to gain access to the Internet without, in many instances, incurring transport costs (e.g. not paying the carrier). In addition, consumers can benefit from longer battery life[21] and faster access speeds (Cui et al, 2013).

Thus, as a complement to cellular networks, Wi-Fi reduces the cost of mobile broadband access, allows service providers to decrease the capital required to support exploding data traffic, and provides Internet access with generally faster access speeds than either 3G or even 4G. In addition, Wi-Fi allows for the provision of paid Internet access services (such as paid services at public sites such as airports).

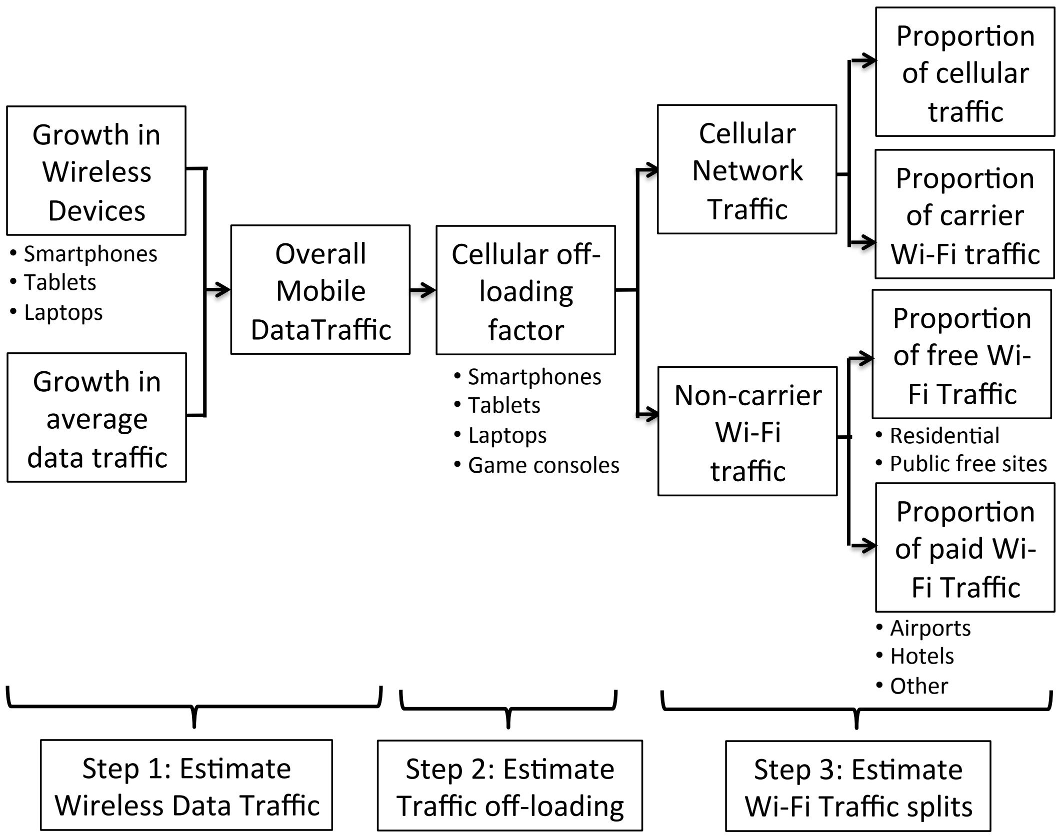
To estimate the economic value of Wi-Fi for cellular off-loading, we will focus on four areas:

- Consumer surplus: the difference between the consumer's willingness to pay and the price paid for the service; along these lines, if a consumer accesses the Internet in a public hot-spot for free, surplus would equate to the monetary value he would pay to a cellular operator for gaining equal access; we do not include in this estimate the economic value associated with residential Wi-Fi (Thanki, 2009), which will be addressed in a subsequent section.
- Producer surplus: in light of the explosive growth in data traffic, wireless carriers operating in licensed bands deploy Wi-Fi facilities 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.
- 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 efficiency and innovation.
- New business models: Wi-Fi allows for the entry of service providers of paid Internet access in public places (such as Boingo and iPass); they generate new revenues that would not exist if unlicensed spectrum bands were not available.

[18] Sources: Cisco (38.5%); Juniper Research (40%).
[19] Cisco (2013).
[20] Informa (2012). "Understanding today's smartphone user: demystifying data usage trends on cellular & Wi-Fi networks".
[21] Lee et al. (2010) estimated that Wi-Fi off-loading saves 55% of battery power.

Each of these four domains will be explored in turn. In order to quantify the economic value in each area, it is necessary to understand first how mobile data traffic flows between cellular and Wi-Fi networks in the United States. The estimation of cellular off-loading patterns required for quantifying its economic value proceeds along three steps (see figure III-1).

**Figure III-1. Methodology for Estimating Off-Loading Traffic**




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 sites. 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.

**III.1. Estimating mobile data traffic:**

Mobile data traffic in the United States has been growing at 59% per annum. Table III-1 presents historical data as measured by several analysts.

**Table III-1. United States: Wireless Internet Traffic (2010-2013) (in petabytes per month)**

| | 2010 | 2011 | 2012 | 2013 | CAGR |
|---|---|---|---|---|---|
| Cisco | 81.92 | 122.88 | 204.80 | 327.68 | 59% |
| Strategy Analytics | 257.5 | 451.3 | 744.0 | 1,165.9 | 65.4% |
| GSMA (*) | 83.35 | 115.66 | 184.72 | 329.88 | 58% |

(*) Calculated by TAS based on data from GSMA Intelligence
*Source: Cisco; Compiled by TAS*

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 reached 192.7 million in 2013, while this number amounted to 62 million for tablets. On the other hand, the number of laptops remains relatively stable at 241 million (2010-13 CAGR: 0.8%) due to tablet and, secondarily, smartphone substitution (see table III-2).

**Table III-2. United States: Device Installed Base and Penetration (2009-2013)**

| | | 2010 | 2011 | 2012 | 2013 | CAGR |
|---|---|---|---|---|---|---|
| Total Smartphones | Units (in millions) | 112.89 | 139.34 | 172.00 | 192.75 | 19.5% |
| | Penetration (%) | 36.00% | 44.07% | 53.96% | 59.99% | 18.6% |
| Tablets | Units (in millions) | 26.41 | 35.01 | 46.41 | 61.53 | 32.6% |
| | Penetration (%) | 8.42% | 11.07% | 14.56% | 19.15% | 31.5% |
| Laptops | Units (in millions) | 235.18 | 237.16 | 239.08 | 240.99 | 0.8% |
| | Penetration (%) | 75.00% | 75.00% | 75.00% | 75.00% | 0.0% |
| Devices per user | | 1.19 | 1.30 | 1.44 | 1.67 | 8.9% |

*Sources: Parks Associates; Cisco; Deloitte; TAS 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. Data also shows that as connected devices increasingly penetrate the subscriber base, the number of "devices per user" increases commensurately: from 1.19 in 2010 to 1.67 in 2013.[22]

Adding to the proliferation of devices, traffic per device has grown between 26.5% and 53.8% per annum driven by increased applications and content availability (see table III-3).

**Table III-3. United States: Average Traffic Per Device (in Gigabytes per month)**

| | 2010 | 2011 | 2012 | 2013 | CAGR |
|---|---|---|---|---|---|
| Smartphones | 0.28 | 0.40 | 0.56 | 0.80 | 41.6% |
| Portable Game Consoles | 0.24 | 0.31 | 0.39 | 0.50 | 28.1% |
| Tablets | 1.74 | 2.68 | 4.12 | 6.33 | 53.8% |
| Laptops | 1.43 | 2.08 | 2.44 | 2.88 | 26.5% |

*Source: Cisco (2013)*

[22] Credit Suisse (6 February 2011) estimates that the number of devices per unique user in the United States will climb from 1.2 in 2009 to 3.9 in 2015, as consumers add mobile broadband enabled laptops, tablets and connected devices to their device collections.

With the installed base and average data usage per device, total wireless Internet traffic in the United States can be calculated for the next five years. Our numbers estimate a total traffic of 1,238.4 million Gigabytes in 2013, reflecting a growth rate of 64.6% per annum. Projections regarding traffic growth from other sources vary, although they agree directionally (see table III-4).

**Table III-4. United States: Mobile Internet Traffic (2013-2017)**
**(in million Gigabytes per month)**

| | 2013 | 2014 | 2015 | 2016 | 2017 | CAGR |
|---|---|---|---|---|---|---|
| This study | 1,238.5 | 1,864.9 | 2,989.2 | 5,083.2 | 9,090.6 | 64.6% |
| Cisco (*) | 737.3 | 1,353.2 | 2,514.6 | 4,728.3 | 8,990.6 | 86.9% |
| Ericsson (**) | 1,238.5 | 1,857.7 | 2,786.5 | 4,179.8 | 6,269.7 | 50.0% |

(*) Includes tablets; smartphones and also comprises feature phones.
(**) Ericsson estimates that mobile data traffic is expected to grow with a CAGR of around 50 percent (2012-2018). Using the estimated TAS baseline from 2013, the value for 2017 is calculated.
*Source: compiled by TAS*

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.

## III.2. Estimating cellular network off-loading traffic

By relying on network off-loading statistics, the overall wireless data traffic numbers calculated above will now be divided between on- and off- cellular networks. Traffic statistics for network off-loading vary, although they all highlight the fact that Wi-Fi captures a majority of global network traffic (see table III-5).

**Table III-5. Network Off-Loading Statistics**

| Country | Date | Type of Traffic | Wi-Fi Off-Loading Factor | Method of measurement | Author(s) |
|---|---|---|---|---|---|
| Korea | 2/2010 | iPhone users over 3G | 65 % | Trace-driven simulation | Lee et al. (2010) |
| Canada, Germany, Japan, South Korea, UK and US | 4/2013 | Android LTE smartphones | 73 % | Data collected by Mobidia My Data Manager installed in thousands of devices | Roberts (2013) |
| Japan | 12/2012 | Mobile data devices | 43 % | KDDI traffic monitoring | KDDI as reported by GSMA |
| United States | 1/2012 | Smartphone app users | 63.4% | Panel of 200,000 users | Mobidia |
| China | 2012 | Wireless data traffic | 72 % | China Mobile traffic statistics | China Mobile as reported by GSMA |
| United States | 2017 | Mobile Data Traffic | 66 % | | Cisco VNI |
| World | 2013 | Mobile Data Traffic | 38.5 % | | Cisco VNI |
| World | 2017 | Mobile Data Traffic | 46.1 % | | Cisco VNI |
| World | 2013 | Mobile Data Traffic | 40 % | Forecasting models | Juniper Research |
| World | 2017 | Mobile Data Traffic | 60 % | Forecasting models | Juniper Research |

*Source: TAS compilation*

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 III-6).

**Table III-6. United States: Wireless Device Off-Loading Factors (2012-2017)**

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| Smartphones | 59 % | 60 % | 61 % | 62 % | 63 % | 64 % |
| Tablets | 77 % | 77 % | 77 % | 78 % | 78 % | 78 % |
| Laptops | 47 % | 50 % | 54 % | 58 % | 62 % | 66 % |

*Source: Cisco; Mobidia; 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 0.67 Exabytes and will reach 5.97 Exabytes by 2017, reflecting a 68.0% growth rate (see table III-7).

**Table III-7. United States: Total Wi-Fi Traffic Per Device (2012-2017) (in Exabytes per month)**

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | CAGR |
|---|---|---|---|---|---|---|---|
| Smartphones | 0.05 | 0.08 | 0.13 | 0.21 | 0.34 | 0.54 | 58.7% |
| Tablets | 0.14 | 0.28 | 0.57 | 1.16 | 2.37 | 4.82 | 103.8% |
| Laptops | 0.26 | 0.30 | 0.36 | 0.43 | 0.51 | 0.61 | 19.0% |
| Total | 0.45 | 0.67 | 1.07 | 1.80 | 3.22 | 5.97 | 68.0% |

*Source: TAS analysis*

Cellular traffic off-loading (or mobile off-loading) allows for the routing of traffic from mobile devices to Wi-Fi spots and the telecommunications network through fixed transmission. Per Cui et al., (2013), cellular network off-loading occurs at four network points: 1) private Wi-Fi (owned by users at home), 2) public paid Wi-Fi (hot-spots at airports, hotels, etc.), 3) public free Wi-Fi sites (coffee-shops, places of work and study), and 4) carrier-class Wi-Fi (network off-loading points owned by carriers, deployed to alleviate congestion and reduce network CAPEX). Based on this information, the following sections will calculate both consumer and producer surplus.

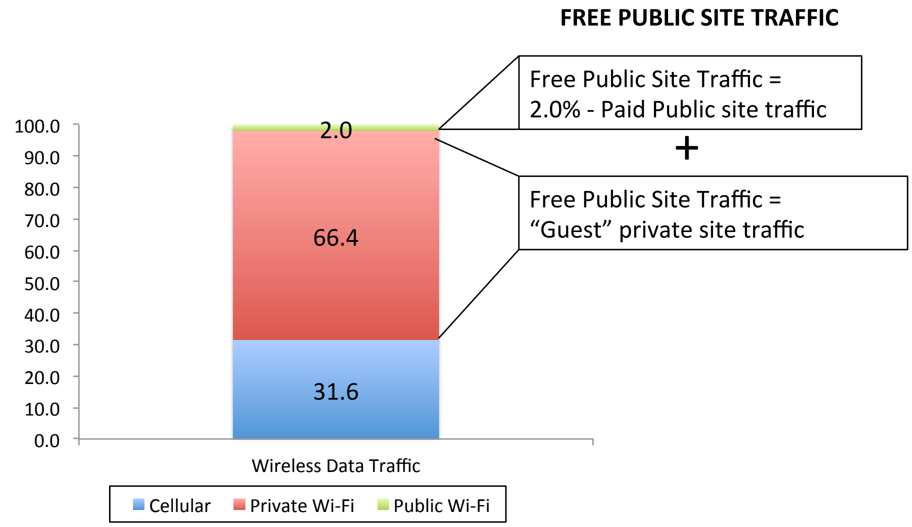
## III.3. Estimating consumer surplus of free public access[23]

In the world's most advanced Wi-Fi markets, such as the US and UK, the vast majority of users today perceive data usage over Wi-Fi to be free. Reacting to consumer preference and perceptions, major retailers, such as Starbucks or McDonald's, have switched their entire hot-spot footprints to a free-to-end-user model.

As stated above, the consumer surplus of Wi-Fi comes from the utilization of free sites offered at airports, hotel lobbies (courtesy access), free extension of private sites (guest access points), and municipal facilities in public places.[24] The volume of Wi-Fi traffic transported through this type of facility is contingent upon free public hot-spot density. Based on the latest statistics generated by Mobidia's monitoring of 200,000 users in the United States, 2% of total US Android smartphone Wi-Fi traffic in January 2013 relied on "public managed networks." This category comprises all public venues, such as hotels, airports, franchised restaurants and coffee shops, and retail chains. However, a portion of this traffic is paid, and therefore excluded from this number. On the other hand, 66.4% of Wi-Fi traffic in the same category relies on self-provisioned/private Wi-Fi sites, which include private residences and enterprises. Likewise, a small portion of this traffic should be considered "public and free" insofar that it represents guest access to a private site (see figure III-2).

[23] The detailed model used for this estimation is included in appendix B.
[24] As noted before, residential Wi-Fi benefits are addressed in a separate section.

**Figure III-2. United States: Android Smartphone Traffic Distribution**




*Source: Mobidia*

Alternatively, self-reported data collected by Cisco indicates that 12% of the daily mobile device connect time occurs at retail locations (5%) and public places (7%) (Cisco IBSG, 2012). Assuming that self-reported data over-emphasizes free access, we estimate that all 2% of Public Wi-Fi is conducted in free sites, and only 1% is conducted in “guest” private sites. Along these lines, 3% of the total wireless traffic is "true no cost traffic."

The estimation of consumer surplus proceeds, then, by multiplying the total Wi-Fi traffic from table III-7 by 4.32%, representing the “true free traffic” conducted by public sites.

**Table III-8. United States: Total Free Wi-Fi Traffic (2012-2017)**

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| Total Wi-Fi Traffic | 0.45 | 0.67 | 1.07 | 1.80 | 3.22 | 0.45 |
| Total Free Traffic (in Exabytes per month) | 0.02 | 0.03 | 0.05 | 0.08 | 0.14 | 0.02 |
| Total Free Traffic (in Exabytes per year) | 0.23 | 0.35 | 0.55 | 0.94 | 1.67 | 0.23 |
| Total Free Traffic (in million Gigabytes per year) | 248.46 | 372.12 | 593.40 | 1,004.71 | 1,790.87 | 3,233.38 |

*Source: TAS 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 four major US wireless carriers (see table III-9).

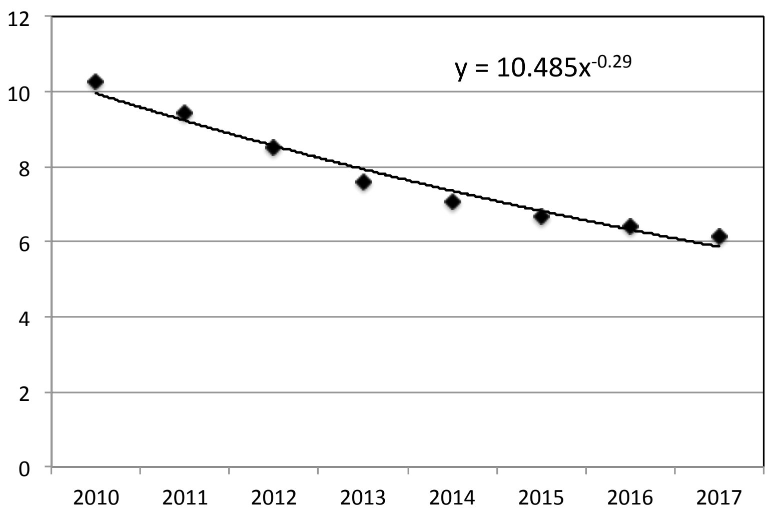
**Table III-9. United States: Average Price Per Gigabyte (2013)**

| Carrier | Plan | Price per Gb |
|---|---|---|
| ATT | $50/5 Gigabytes cap | $ 10.00 |
| Verizon | $355/50 Gigabytes cap | $ 7.10 |
| Sprint | $79.99/12 Gigabytes cap | $ 6.67 |
| T-Mobile | $70/10 Gigabytes cap | $ 6.67 |
| Average | | $ 7.61 |

*Source: TAS analysis*

Data for ATT and Verizon for 2010 and 2011 allowed for a projection of future prices per Gigabyte (see figure III-3).

**Figure III-3. Estimate of Future Average Price Per Gigabyte (2010-2017)**




*Source: TAS analysis*

According to these prices, while the average price per GB in 2013 is $ 7.61, by 2017, it will reach an estimated $6.15. As to the cost of offering the 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). By relying on the total free Wi-Fi traffic shown in table III-8 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 III-10).

**Table III-10. United States: Consumer Surplus of Free Wi-Fi Traffic (2012-2017)**

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Total |
|---|---|---|---|---|---|---|---|
| Total Free Traffic (in million Gigabytes per year) | 248.46 | 372.12 | 593.40 | 1,004.71 | 1,790.87 | 3,323.38 | |
| Price per cellular gigabyte ($) | 8.52 | 7.61 | 7.05 | 6.68 | 6.39 | 6.15 | |
| Cost per Wi-Fi provisioning ($) | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | |
| Consumer surplus per Gigabyte ($) | 6.02 | 5.11 | 4.55 | 4.18 | 3.89 | 3.65 | |
| Total Consumer surplus (in $ million) | 1,496 | 1,902 | 2,700 | 4,200 | 6,966 | 12,130 | 29,394 |

*Source: TAS analysis*

As indicated in table III-10, consumer surplus of free Wi-Fi traffic in 2013 would reach an estimated $ 1.902 billion. It is important to mention that this estimate does not consider whether traffic would remain the same if the currently "free" traffic were to be charged. In other words, price elasticity could yield a scenario where traffic would diminish with a price increase. An analysis of consumer surplus would need to base its quantification on willingness to pay. However, data on Wi-Fi willingness to pay is not available.

**III.4. Estimating producer surplus of carrier-grade Wi-Fi**

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 through small cells (for network capacity).[25] By building hybrid networks, carriers preserve spectrum and reduce the CAPEX required to deploy additional base stations.[26] In addition, some service providers also claim they monetize their Wi-Fi offerings by directly charging customers[27]. Carriers also benefit from service differentiation and an improvement in the customer experience.[28]

To underscore the importance of deploying carrier-grade Wi-Fi, recent research conducted by Amdocs (2013) indicates that 89% of all service providers surveyed (including fixed, mobile, and cable) have either deployed - or plan to deploy or leverage - Wi-Fi networks complementing their cellular infrastructure.[29] In the United States, AT&T alone operates 32,000 hot-spots, while Softbank in Japan has deployed over 500,000 access points.[30]

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. 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.

The analysis is then predicated on the following model (see figure III-4).

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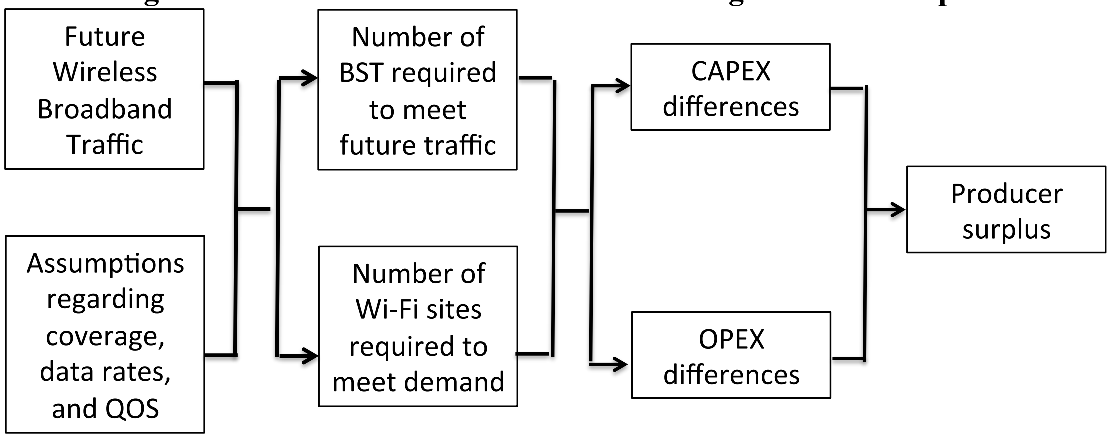
[25] Carriers can also off-load traffic by deploying femtocells, which provide higher capacity. However, since these operate in licensed spectrum bands, they are not part of this analysis.
[26] Hybrid network architectures allow wireless operators to shift traffic away from the cellular network, where the capacity constraints are most acute, to cheaper shorter range small cells network, connected over a variety of backhaul connections (see Eslambolchi, 2012).
[27] See the example of ATT.
[28] See Amdocs (2013).
[29] On average, respondents ranked Wi-Fi's importance as 7+ out of 10, underscoring the strategic value of Wi-Fi for service provider growth.
[30] GSMA Intelligence (2013).

**Figure III-4. Model Structure For Calculating Producer Surplus**




The analysis starts with the predicted incremental wireless data traffic generated between 2013 and 2017. According to table III-7, future monthly traffic will amount to 5.97 Exabytes.

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[31], while a carrier-grade Wi-Fi access point requires an investment of $2,500[32]. In addition, other capital and operating expense items show a clear advantage to Wi-Fi vis-à-vis an LTE macro cell (see table III-11).

**Table III-11. 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 hot-spots 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.

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

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 incremental wireless data traffic would require approximately 34,000 new base stations[33], 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 III-12).

**Table III-12. 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 |
| TCO | $ 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[34].

### III.5. Estimating the economic return to speed of Wi-Fi Off-loading[35]

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 site 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 (Roston et al., 2010, and 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 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.

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[33] 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).
[34] See Cooper (2012).
[35] The detailed model used for estimating this effect is included in Appendix C.

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 of table III-6) and calculating the speed decrease if cellular networks transported all Wi-Fi traffic (see table III-13).

**Table III-13. Estimation of Speed Differential for Total US Traffic (in megabits per second)**

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| Average speed of cellular networks | 2.41 | 3.43 | 4.88 | 6.94 | 9.87 | 14.05 |
| Average Wi-Fi speed | 11.50 | 13.32 | 15.43 | 17.88 | 20.72 | 24.00 |
| Average speed of weighted average of cellular and Wi-Fi traffic | 8.68 | 10.15 | 12.09 | 14.60 | 17.75 | 21.60 |
| Speed decrease (average speed of cellular/average weighted average speed) | -72.21% | -66.21% | -59.65% | -52.45% | -44.36% | -34.96% |

*Source: Cisco; TAS analysis*

It is worth noting that the speed differential of the hybrid cellular and Wi-Fi network diminishes over time because LTE is achieving a wider coverage. Nevertheless, the estimates confirm Morgan Stanley's statement that Wi-Fi is ten times faster than 3G, and that the 802.11n Wi-Fi standard is twice as fast as LTE (Morgan Stanley Research, 2009). Research cited by Benkler (2012) indicates that average 4G speed ranges between 3 and 14 Mbps, while 802.11c at 100 feet range is 208 Mbps.

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 III-14).

**Table III-14. 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 III-14 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 III-15).

**Table III-15. Broadband Speed Impact on GDP**

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|
| Speed decrease (%) | -72.21% | -66.21% | -59.65% | -52.45% | -44.36% | -34.96% |
| Model coefficient | 0.30% | 0.30% | 0.30% | 0.30% | 0.30% | 0.30% |
| Decrease in GDP per capita | -0.22% | -0.20% | -0.18% | -0.16% | -0.13% | -0.10% |
| GDP per capita (current prices) | 49,922 | 51,248 | 53,328 | 55,837 | 58,436 | 61,134 |
| Wi-Fi Traffic (% Total Traffic) | 6.74% | 8.79% | 11.95% | 16.63% | 23.15% | 31.37% |
| GDP Reduction (in $ millions) (current prices) | -2,284 | -2,831 | -3,634 | -4,695 | -5,831 | -6,565 |

*Source: Cisco; TAS analysis*

Table III-15 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 2013 from an average 10.15 Mbps to 3.43) would have a $2.831 billion impact on GDP. This figure reflects the economic value of Wi-Fi in terms of increasing the speed of transporting wireless data.

### III.6. Estimating new business revenues generated by Wi-Fi Off-loading

In addition to the value generated by the other effects, Wi-Fi off-loading can create new business opportunities for service providers offering Wi-Fi services in public places (airports, hotels) for a fee. In the last three years, operators in this space have deployed next-generation hot-spot technologies to replicate the ease of access and security provided by cellular networks. At the same time, to facilitate interoperability, they are signing up of roaming agreements. From a business model standpoint, innovation has allowed this sector to expand beyond the original pay-as-you-go access offer. 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[36] (Maravedis-Rethink, 2013).

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 (e.g. Trustive). Similarly, Wireless Internet Service Providers are addressed in chapter V.

Table III-16 presents a compilation of US Wi-Fi service providers, including some key financial metrics that allow for the estimation of their revenues.

[36] 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.

**Table III-16. Compilation of Retail Wi-Fi Service Providers in the United States**

| Company | Business focus | Revenues (in $ millions) | Estimated portion of US revenues | US Revenues (in $ millions) |
|---|---|---|---|---|
| Boingo | Retail access; wholesale access (to ATT, Verizon); military bases; advertising | $ 105.98 | 7,000 sites in the US (out of 13,000) Per 10-K "revenue is predominantly generated in the US" | $ 105.98 |
| iPass | Enterprise Wi-Fi services; wholesale access | $ 114.89 | Per 10-K, 57% of revenues generated in the United States | $ 65.5 |
| SONIFI (Lodgenet Interactive) | Hotels and Health care (cable and Wi-Fi) | $ 126.7 | SONIFI's primary customer base is in the continental United States, however it also delivers services in Canada, Mexico and 15 other countries through relationships with local licensees. | $100 |
| Total | | | | 271.5 |

*Source: Company Annual reports and 10-K reports; TAS analysis*

As table III-16 indicates, estimated total revenues generated by this sector in the United States have reached $ 271.5 million.

### III.7. Conclusion

In summary, cellular traffic off-loading has multiple drivers of economic value. The analyses contained in this chapter enabled the calculation of annual economic value of Wi-Fi acting as a complement of wireless networks operating in licensed spectrum (see table III-17).

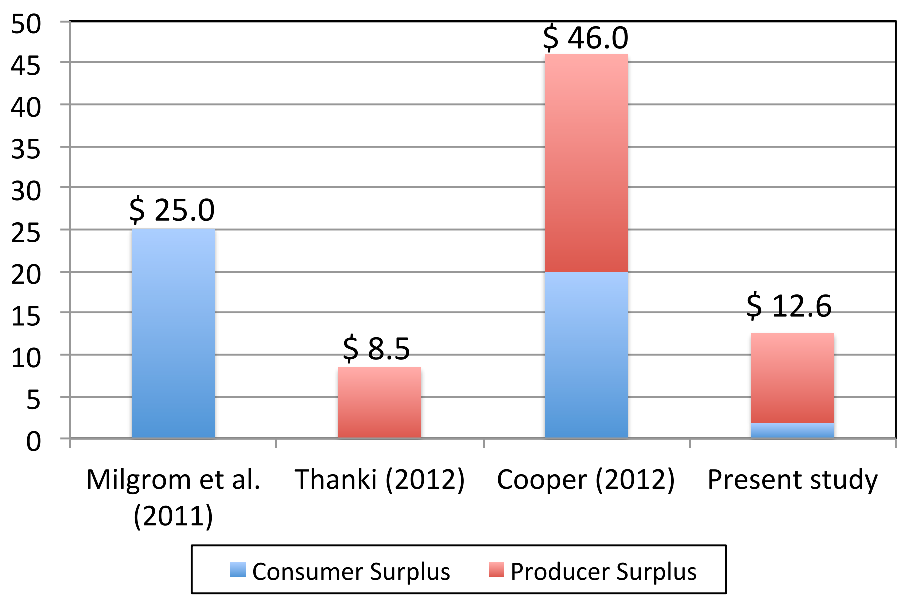
**Table III-17. Summary of Economic Value of Wi-Fi Cellular Off-Loading (2013)**

| Effect | Underlying Premise | 2013 Economic Value |
|---|---|---|
| Consumer Surplus | Value of Free Wi-Fi traffic offered in public sites | $ 1.902 billion |
| Producer Surplus | Total cost of Ownership (cumulative CAPEX and OPEX) required to accommodate future capacity requirement with Wi-Fi complementing cellular networks | $ 10.7 billion |
| Return to Speed | Contribution to GDP of increase of average mobile speed resulting from Wi-Fi off-loading | $ 2.831 billion |
| New Business Revenue | Sum of revenues of service providers offering paid Wi-Fi access in public places | $ 0.271 billion |
| Total | | $ 15.704 billion |

*Source: TAS analysis*

This value includes the producer surplus generated by the operators' deployment of carrier-grade Wi-Fi sites to respond to the growth in wireless data traffic ($ 10.7 billion). If we exclude the speed contribution to GDP and the new business revenue, economic surplus would amount to $ 12.602 billion. This figure is higher than Thanki's 2012 $ 8.5 billion estimate due to the increase in the volume of Wi-Fi sites since the author conducted his analysis. Wi-Fi off-loading's second value-creation effect comes from the consumer surplus derived from the utilization of free Wi-Fi sites deployed in public locations ($ 1.9 billion). This is calculated as the cost of the total wireless traffic transported in free Wi-Fi sites (3%) if the consumer would have to pay to a wireless carrier minus the cost to provide free Wi-Fi service. Our estimate is lower than Cooper's since we have a more conservative estimate of the annual benefit of off-loading for the carriers and because a portion of the consumer surplus assumed by Cooper (and Milgrom et al, 2011) has already been assigned to residential Wi-Fi (see figure III-5).

**Figure III-5. Economic Value of Wi-Fi Off-Loading: Thanki (2012), Milgrom et al. (2012), Cooper (2012) Versus Present Study (in $ billions)**




*Source: TAS analysis*

## IV. THE VALUE OF RESIDENTIAL Wi-Fi

The economic value of cellular off-loading purposely excluded residential Wi-Fi insofar that this application does not represent a substitute to cellular transmission. Assessing the value of residential Wi-Fi is fairly complex because most service providers in the United States offer residential Wi-Fi connectivity as part of a bundled package with broadband access (see examples in table IV-1).

**Table IV-1. Examples of Broadband Services**

| Operator | Offer | Wi-Fi as a component of bundle |
|---|---|---|
| AT & T (U-Verse) DSL | 3 Mbps for US$ 29.95/month | Yes (*) |
| AT & T (U-Verse) DSL | 6 Mbps for US$ 34.95/month | Yes (*) |
| Comcast CABLE | 3 Mbps for US$ 19.99/month | Yes (At Home) |
| Comcast CABLE | 105 Mbps for U$ 79.99/month | Yes (**) |
| Time Warner CABLE | 3 Mbps for US$ 29.99/month | Yes (At Home) |

(*) Wi-Fi at home and access to the entire AT&T national Wi-Fi network, at no extra charge
(**) Includes access to 500,000 Wi-Fi hot-spots at no extra cost
*Source: Compiled by TAS*

The approach taken by Thanki (2009) is based on the central assumption that, in the absence of residential Wi-Fi, customers' willingness to pay for broadband would be significantly lower. Based on the consumer surplus study by Orzag et al. (2009), which states that approximately 50% of users would be willing to pay $50 more for broadband, the author estimates a new demand curve for Wi-Fi only households[37]. With this new estimate, Thanki (2009) constructs three sensitivities in a scenario of no Wi-Fi: in other words, the author estimates the reduction of the imputed willingness to pay in the absence of Wi-Fi in the broadband offer. Based on this estimation, he finds that the economic value of residential Wi-Fi in the United States ranges between $4.3 billion (for a 10% of value attributed to Wi-Fi) and $12.6 billion (for 30% of value attributed to Wi-Fi). At the same time, Thanki (2009) noted that his estimates exclude the benefit derived from other uses, such as Internet for other home devices that cannot rely on a wired link (e.g. video game consoles, tablets). In a later work, Thanki (2012) updated his analysis while relying on the same approach, estimating the annual economic value of residential Wi-Fi in the United States to be $15.545 billion.

[37] The author extrapolates the UK Wi-Fi adoption (57% of households) to the US.

Rather than replicating Thanki's work, we consider it useful to restate the economic value of residential Wi-Fi using the technology, and then calibrating the results back to Thanki's estimates from 2012[38]. After all, the use of the technology determines the value and consumer surplus. The following list attempts to draw an exhaustive itemization of benefits of residential Wi-Fi:

- Provide internet access for devices that lack a wired port (e.g. tablets, smartphones, game consoles)
- Avoidance of investment in in-house wiring
- Easy networking between devices (printers, storage devices, computers)
- Sharing and streaming of media content (sound systems, home theaters, etc.)
- Hub of a network handling home automation
- Interface with the smart grid

We will quantify the value derived by each of these applications in turn.

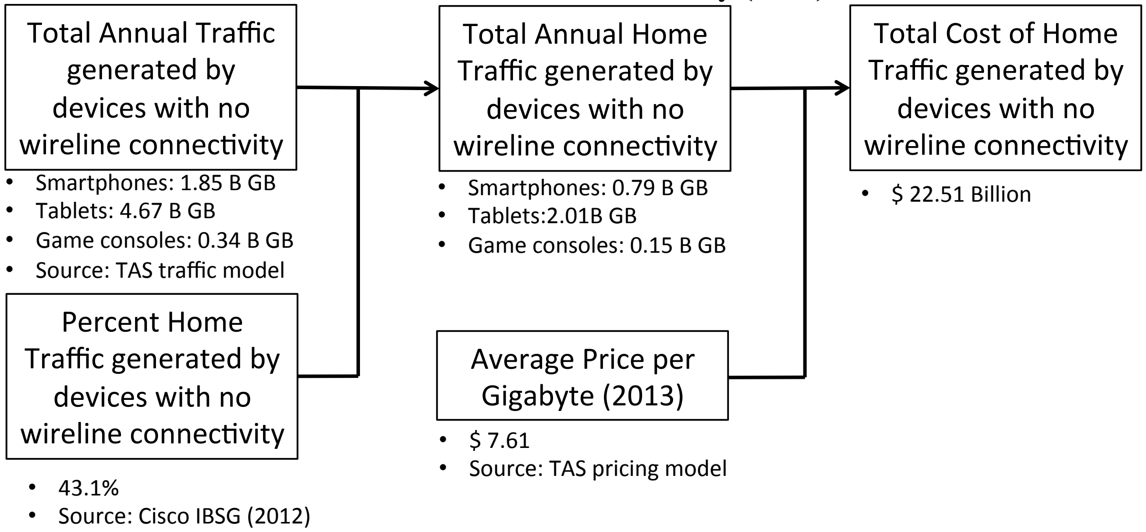
**IV.1. Home Internet access for devices that lack a wired port**

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.

Based on our traffic model, the total traffic generated by these types of devices in 2013 in the United States amounts to 6,862 million Gigabytes. According to Cisco IBSG (2012), 43% of use time of devices that lack a wired port occurs at home. Therefore, the portion of said traffic generated at home reached 2,959 million Gigabytes, which if it had to be transported by cellular networks resulting in costs of $22.51 billion in 2013 (see figure IV-1).

[38] The details of the estimates are presented in the model in Appendix D.

**Figure IV-1. Annual Costs To Be Incurred by Home Traffic Generated by Devices With No Wireline Connectivity (2013)**




*Source: TAS analysis*

### IV.2. 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.). The average cost of deploying inside wiring in residence reaches approximately $190 per household[39]. Considering that 61% of US households currently have Wi-Fi[40], the avoidance cost of inside wiring for 70 million households, which in the absence of Wi-Fi yields a total cost of wiring of $13.567 billion.

### IV.3. Other residential Wi-Fi applications

The economic value of other residential Wi-Fi applications mentioned in the introduction of this chapter, such as easy networking between devices, and the sharing and streaming of media content could be assimilated to the first two areas analyzed. In fact, these two areas could not exist without Wi-Fi enabling device connectivity. As a result, we consider that their value is already counted in sections 1 and 2.

In addition, the last two examples (hub of a network handling home automation, and interface with the smart grid) are more forward-looking and difficult to estimate in terms of their economic value.

### IV.4. Conclusion

In sum, the analyses contained in this chapter enabled the estimation of economic value of residential Wi-Fi (see table IV-2).

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[39] This is calculated based on a premise visit ($30), 3 hrs. of labor ($12/hr.), and number of rooms connected ($4.95 per room)

[40] Source: Watkins, David. *Broadband and Wi-Fi Households Global Forecast 2012*. Strategy Analytics

**Table IV-2. Summary of Economic Value of Residential Wi-Fi**

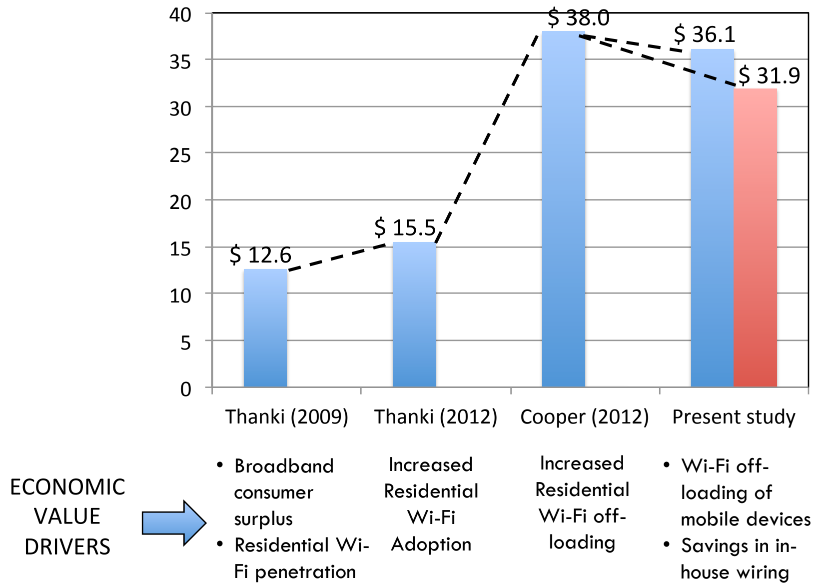
| Effect | Underlying Premise | Amount |
|---|---|---|
| • Internet access for devices that lack a wired port (e.g. tablets, smartphones, game consoles) | • Cost required for those devices to access the Internet via cellular networks | $ 22.51 billion |
| • Avoidance of investment in in-house wiring | • Cost to wire the residence | $ 13.57 billion |
| • Easy networking between devices (printers, storage devices, computers)<br>• Sharing and streaming of media content (sound systems, home theaters, etc.) | • Value captured in two prior effects | N.A. |
| • Hub of a network handling home automation<br>• Interface with the smart grid | • Forward-looking applications and, therefore, difficult to quantify | N.A. |
| Total | | $ 36.08 billion |

*Source: TAS analysis*

In sum, the total annual economic value of residential Wi-Fi amounts to $36.08 billion, more than twice the value estimated by Thanki in 2012. Thanki's original estimate (2009), based on the extrapolation of consumer surplus (Dutz et al., 2009) and 57% Wi-Fi adoption across households, was ranged between $4.3 billion and $12.6 billion. In 2012, Thanki updated his analysis based on increased Wi-Fi households and estimated its economic value at $15.5 billion. In the same year, Cooper (2012) provided a higher estimate (which he considers to be conservative) of $38 billion. This last author factors in not only the increase in Wi-Fi penetration but also the growth in cellular off-loading. Our approach differs from Thanki's and Cooper's. Rather than extrapolating from fixed broadband consumer surplus research, we quantify savings incurred by consumers as a result of deploying Wi-Fi in their residences (all data, sources and calculations are included in chapter IV). As of 2013, 61% of US households are equipped with Wi-Fi, which has a net effect of providing free access for devices designed for wireless access (tablets, smartphones), generating annual transport savings of $22 billion. In addition, residential Wi-Fi services generate $13 billion in savings for households that do not require in-house wiring to interconnect PCs, printers, audio equipment, and the like. These estimates are two and a half times higher than Thanki's 2012 figures, and close to Cooper's (see figure IV-2). To calibrate our results, we replicated Thanki's estimates, multiplying the total number of Wi-Fi households (72,450,000) by an assumed willingness to pay of $36.8 per household per month[41]. This yields a total surplus of $31.9 billion (considered to be a low bound estimate).

[41] Thanki estimates the average monthly consumer surplus to be $27.6, which represents 30% of the home broadband value. He also states that there is additional value not captured in his analysis. (pp.35). Given the current Wi-Fi adoption and usage patterns, it is reasonable to assume that willingness to pay would amount to 40% of the value, which equals to $36.8 per month.

**Figure C. Economic Value of Residential Wi-Fi: Thanki (2009, 2012), Cooper (2012) Versus Present Study (in $ billions)**




*Source: TAS analysis*

## V. WIRELESS INTERNET SERVICE PROVIDERS

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).

As demonstrated by the National Broadband Plan and the corresponding mapping effort, WISPs are critical in providing broadband service in rural areas. In 2008, the National Broadband Map determined that in 21 states with a large rural footprint, 4.93% of households were only served exclusively by a WISP (see Table V-1).

**Table V-1. Occupied Households Passed by WISPs Only (2008)**

| State | Total Occupied Households | % of Households Passed by WISPs Only | Occupied Households Passed by WISPs Only |
|---|---|---|---|
| Michigan | 4,009,186 | 4.34 % | 173,834 |
| Oregon | 1,516,658 | 9.41 % | 142,760 |
| West Virginia | 757,767 | 0.01 % | 107 |
| Texas | 8,924,973 | 23.47 % | 2,094,479 |
| Massachusetts | 2,615,877 | 0.10 % | 2,489 |
| Wyoming | 215,923 | 4.87 % | 10,517 |
| Nebraska | 730,577 | 10.66 % | 77,845 |
| Indiana | 2,543,090 | 2.40 % | 61,140 |
| Ohio | 11,870,733 | 1.28 % | 151,893 |
| Idaho | 562,067 | 9.19 % | 51,646 |
| Illinois | 4,851,822 | 2.83 % | 137,330 |
| Arkansas | 2,942,753 | 2.36 % | 69,319 |
| Colorado | 1,959,789 | 4.88 % | 95,698 |
| Arizona | 2,336,959 | 4.21 % | 98,382 |
| California | 12,764,753 | 1.40 % | 178,743 |
| Maryland | 2,202,016 | 0.25 % | 5,529 |
| Montana | 394,719 | 5.55 % | 21,916 |
| Nevada | 994,992 | 7.34 % | 73,000 |
| Pennsylvania | 5,062,337 | 0.47 % | 23,957 |
| South Carolina | 1,825,000 | 0.84 % | 15,393 |
| Washington | 2,581,680 | 1.95 % | 50,225 |
| Total | 71,663,671 | 4.93 % | 3,536,202 |

*Sources: FCC*

Wireless Mapping extended its analysis to the rest of the country and assessed coverage as of 2011. They concluded that WISP coverage grew .43 percentage points from 2008 to 2011 as shown in Table V-2.

**Table V-2. United States: WISP Coverage (2011)**

| Total Households | Households With Access to a WISP | Households Where WISP Is Only Broadband Provider |
|---|---|---|
| 131,704,731 | 60,147,903 (45.67 %) | 3,226,087 (5.36 %) |

*Source: Wireless Mapping*

To assess the economic value of the WISP industry we estimate total revenues for the sector. This approach first compiles the number of customers and then multiplies it by average revenue per customer.

Thanki (2012) estimates that the WISP customer base is approximately 3,000,000. This number is fairly close to the WISP-only served base shown in table V-2, although cable or telecommunications providers also serve some of the 3,000,000 customers belonging to the universe also served by cable or telecommunications carriers. Ubiquiti quotes 18 million subscribers but this number is based on equipment sales and includes machine-to-machine installations. Therefore, we opt to rely on Thanki's more conservative number.

We then multiply the number of subscribers by the lowest price of broadband service. We selected the most economic offer of a WISP´s supplier in Texas[42] (39.99 per month). Based on this metric, the estimated total annual revenues of the sector would be $1.439 billion. This number might be somewhat conservative because the customer base could be larger that 3,000,000 (although we do not have reliable statistics) and the average revenue per subscriber could be higher than the less expensive offer.

## VI. THE VALUE OF Wi-Fi ONLY TABLETS

The only known assessment of the value of Wi-Fi only tablets conducted so far was done in a cursory fashion by Milgrom et al. (2011) in their estimation of the economic value of the iPad. The authors use the installed base of iPads as their starting point. Their assessment assumes that the sum of the producer surplus (equivalent to the production cost of $300) and the consumer surplus (inferred to be the difference between the retail price of $599 and the production cost) represent the economic value of a tablet with Wi-Fi only capability. This would approximate $15 billion.

It is important to mention that the consumer surplus calculated by Milgrom et al. (2011) is equated to price, which does not consider the fact that willingness to pay would exceed the price paid for the good. What, then, is the WTP for a tablet sold at $499? From a pricing strategy, most tablet vendors follow a versioning strategy (i.e. they sell a variety of products at different prices to different types of buyers), which pushes the consumer to self-select the product that takes the most of his consumer surplus. If successful, the willingness to pay for a Wi-Fi only tablet sold at $499 would not be as high as Milgrom et al. (2011) state. We will address this issue below.

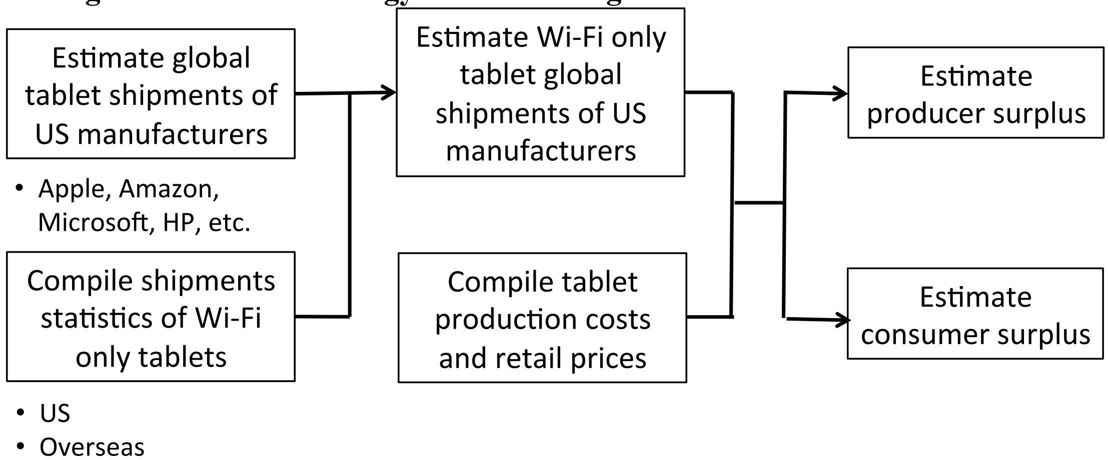
Further, considering the prior analysis to be conceptually correct, we will replicate it by updating the numbers along the following lines:

- Consider total shipments of Wi-Fi only tablets (while the iPad controls the largest share, we will include other alternatives as well)
- Contrary to limiting ourselves to the 32Gb Wi-Fi only models, we will include also devices with 16Gb and 64Gb
- Production costs and retail prices will be updated to reflect changes in economies of scale, and production learning curves

We will structure the approach to estimating the economic value of unlicensed spectrum in regard to tablets as follows:

[42] Internet America (http://www.internetamerica.com/) for a broadband connection.

**Figure VI-1: Methodology for Estimating Wi-Fi Tablets Economic Value**




We start by compiling statistics on worldwide shipments of tablets. Following Milgrom et al. (2011), we consider only those tablets manufactured by US companies (since we are estimating economic value for the United States). With these numbers, we estimate the portion of Wi-Fi only tablet shipments as opposed to tablets with both Wi-Fi and cellular connectivity. By calculating the total retail value and compiling statistics on gross margins, we calculate both consumer and producer surplus.

### VI.1. Shipments of Wi-Fi only tablets

Based on different analyses, worldwide tablet shipments for 2013 ranged between 117 million and 145 million. The following table presents both the historical trends and a forecast summary of worldwide tablet shipments (see table VI-1).

**Table VI-1. World-Wide Tablet Shipments (2010-2017) (in millions)**

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| IDC | 17.9 | 70.9 | 117.1 | 221.3 | 270.5 | 332.4 | 359.4 | 386.3 |
| Gartner | 17.6 | 60.0 | 120.2 | 184,4 | 263.2 | --- | --- | --- |
| Juniper | --- | 55.2 | | | | | 253.0 | --- |
| HIS iSuppli | 17.4 | 60.0 | 120.0 | 138.0 | 248.0 | 275.3 | --- | --- |
| Statista | 19.0 | 76.0 | 145.0 | 227.3 | 287.0 | 332.0 | --- | --- |

*Source: Compiled by TAS*

Considering the wide divergence in forecasts that reflect a rapidly growing market, we rely on the most recent study, produced by IDC; accordingly, 2013 shipments amount to 221.3 million, reaching 386.3 by 2017. Since the analysis aims to measure the economic value of unlicensed spectrum for the United States, we only use shipment statistics from US manufacturers. We apply shipment share statistics to the overall shipment numbers (see table VI-2).

**Table VI-2. Tablet Shipment Market Share (2010-2017) (in percentage)**

| | | 3Q2011 | 2Q2012 | 2Q2013 |
|---|---|---|---|---|
| US Manufacturers | Apple | 59.7 % | 60.3 % | 32.4 % |
| | Others (1) | 24.6 % | 23.2 % | 36.5 % |
| | Total | 84.3 % | 83.5 % | 68.9% |
| Overseas Manufacturers | Samsung | 6.5 % | 7.6 % | 17.9 % |
| | Asus | 3.8 % | 3.3 % | 4.5 % |
| | Lenovo | 1.1 % | 1.3% | 3.3 % |
| | Other (Acer, etc.) | 4.0 | 4.3 % | 5.4 % |

(1) HP, Microsoft, Amazon, Dell, Google

*Source: IDC; TAS estimates*

Based on these numbers, we estimate that tablet shipments from US manufacturers (Apple, Amazon, HP, Microsoft) will reach 152 million by the end of 2013 (see table VI-3).

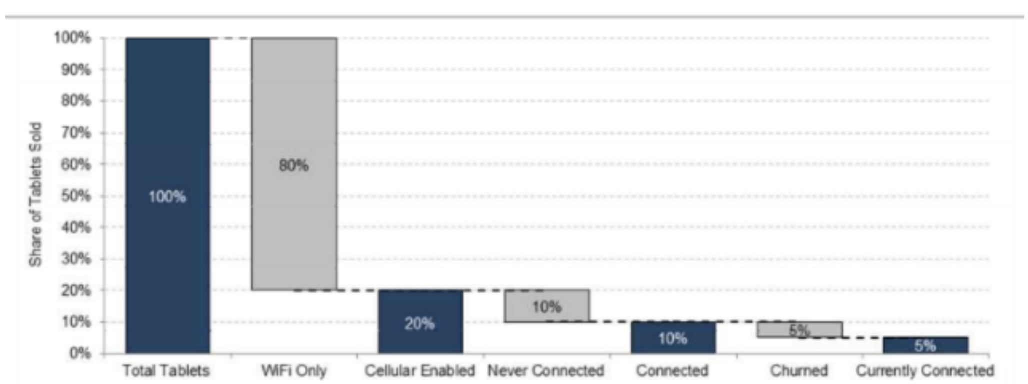
**Table VI-3. US Manufacturers: Tablet Shipments (in millions)**

| | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Total US | 16.82 | 59.77 | 97.78 | 152.47 |

*Source: TAS analysis*

According to the latest selling figures, the value of tablets is intrinsically linked to Wi-Fi rather than cellular connectivity. Moffett (2013) estimates that only 20% of tablets are sold with wireless chipsets, and of this 20%, only half of these devices are connected to a wireless network. In other words, even amongst those users that purchase tablets with cellular connectivity capability, only 50% purchase a cellular contract. Furthermore, of those users that do purchase a contract, 50% end up churning out and disconnecting. The author therefore concludes that tablets are devices for nomadic connectivity in a stationary context, whereby Wi-Fi is the critical component of value (see figure VI-2)[43].

**Figure VI-2. Tablets Purchased Versus Tablets Connected to Cellular Network**

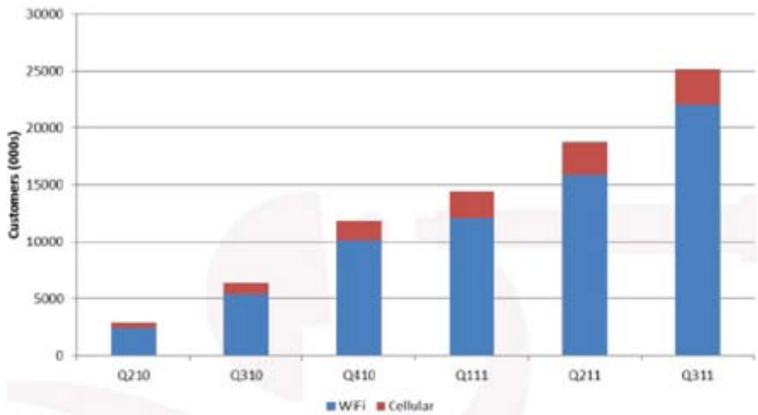



*Source: Moffett Research (2013)*

[43] This conclusion is consistent with time-of-day usage pattern, indicating that tablets are primarily devices used at home.

Research from the consulting firm Chetan Sharma confirms Moffett's (2013) estimates, determining that approximately 90% of tablets sold in the US were Wi-Fi only models (see figure VI-3).

**Figure VI-3. US Tablet Shipments (2010-2011)**




*Source: Chetan Sharma (2011)*

This finding is an important confirmation of the original assumption made by Milgrom et al. (2011):

> *"How much (of the iPad) value can we attribute to the presence of Wi-Fi? It seems hard to believe that a product for which 3G access is not standard but only an option, would have been nearly as successful or widespread, and perhaps it might not have succeeded at all, if users were forced to rely on a combination of cellular and wireline access to data and services" (p. 17)*

Wi-Fi only pricing versus the pricing of Wi-Fi and cellular devices helps in understanding the willingness to pay. An entry-level 16GB Wi-Fi only iPad costs $499, while a similar device with 4G connectivity costs $629. Including the fees associated with a data plan (e.g. ATT's less expensive 250 MB cap plan at $14.99 per month), it would add an additional $179 per year to the total cost of ownership without any impact on acquisition costs due to the lack of carrier subsidy. According to sales figures, most consumers are not willing to pay 60% more for cellular connectivity if the functionality of an essentially nomadic device can be met through Wi-Fi. More importantly, consumers are more likely to rely only on a tethered smartphone as Wi-Fi device, rather than needing two cellular devices.

Will this situation change in the future? Some analysts believe that Wi-Fi only tablets will decline 50% by 2016 (Juniper Research, 2013), although this trend doesn't seem likely given the current figures. Nevertheless, in trying to reverse this loss of value, cellular carriers could react by limiting two-year contract obligations (a big deterrent for a device with such a short replacement rate) and/or offering bundled data plans for tablets and smartphones. Furthermore, as seen in some emerging countries, the lack of broadband fixed access and Wi-Fi hot spots would render the purchase of a tablet with cellular connectivity a necessity. However, research conducted in India shows that only 23% of tablets shipped in 1Q2013 were cellular-enabled (CyberMedia Research, 2013).

Considering Moffett's more current US estimate, and extending this estimate to overseas shipments, we estimate Wi-Fi only shipments in (see table VI-4).

**Table VI-4. US Manufacturers: Tablet shipments (in millions)**

| | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Total Shipments | 16.82 | 59.77 | 97.78 | 152.47 |
| Percent Wi-Fi only | 90% | 90% | 90% | 90% |
| Wi-Fi only shipments | 15.14 | 53.79 | 88.00 | 137.23 |

*Source: TAS analysis*

## VI.2. Tablets retail pricing and production costs

As mentioned above, the assessment conducted by Milgrom et al. (2011) assumes that the economic value of a tablet with Wi-Fi only capability is represented by the sum of the producer surplus (equivalent to the production cost of $300) and the consumer surplus (inferred to be the difference between the retail price of $599 and the production cost). To determine the retail pricing and production costs of units sold, it is important to mention that many Android suppliers tend to offer only cellular connectivity products. For example, the Samsung Galaxy Note cannot be purchased without a data plan. In that sense, focusing solely on the economics of the iPad might not be that far off the mark (see table VI-5).

**Table VI-5. iPad Air Economics**

| | | Retail Price | Manufacturing Costs | Producer Surplus |
|---|---|---|---|---|
| Wi-Fi Only | 16 GB | 499 | 274 | 225 |
| | 32 GB | 599 | 282.40 | 316.6 |
| | 64 GB | 699 | 300 (E) | 399 (E) |
| | 128 GB | 799 | 325 (E) | 474 (E) |
| Wi-Fi + Cellular | 16 GB | 629 | 310 | 319 |
| | 32 GB | 729 | 319 (E) | 410 (E) |
| | 64 GB | 829 | 340 (E) | 489 (E) |
| | 128 GB | 929 | 361 | 568 |

*Source: IHS iSuppli; TAS analysis*

Apple succeeded in reducing the manufacturing cost of the iPad while maintaining its retail price and leveraging production scale and experience curve. For example, the 16GB with Wi-Fi and cellular connectivity costs $310, 4.6% less expensive than the equivalent 3G iPad. Also, the margins increase with storage capacity because of scale in the core processor, which happens to be the same used core processor in the iPhone 5s.

To calculate consumer and producer surplus, we average economics for Wi-Fi and Wi-Fi and Cellular models (see table VI-6).

**Table VI-6. Average iPad Air Economics**

| | Retail Price | Manufacturing Costs | Producer Surplus |
|---|---|---|---|
| Wi-Fi Only | 649 | 295 | 354 |
| Wi-Fi + Cellular | 779 | 332 | 447 |

*Source: TAS analysis*

To calibrate iPad economics with other products, we compiled manufacturing costs for Apple's competitors (table VI-7).

**TableVI-7. Other Tablet Economics**

| | Retail Price | Manufacturing Costs | Producer Surplus |
|---|---|---|---|
| Google Nexus 8 GB | 199 | 181.75 | 17.25 |
| Google Nexus 16 GB | 249 | 199 | 50 |
| Amazon Kindle Fire | 199 | 201.70 | -2.70 |
| HP TouchPad 16 GB (Wi-Fi only) | 279.99 | 306 | -26 |
| HP TouchPad 32 GB (Wi-Fi only) | 370 | 328 | 42 |

Note: The negative surplus for Amazon and HP is not accurate insofar that both suppliers are cross-subsidizing the products with other revenue streams (e.g. for Amazon, e-book sales).
*Source: HIS iSuppli*

Considering the volumes of Wi-Fi only tablets, following Milgrom's assumption, total producer surplus in 2013 for Wi-Fi only Tablets amounts to $34.6 billion (see table VI-8).

**Table VI-8. Producer Surplus of Wi-Fi Only Tablets (2013)**

| | Apple | Competitors | Total |
|---|---|---|---|
| Volume (in millions) | 96.06 | 41.17 | 137.23 |
| Average Producer Surplus | $ 354 | $ 16 | |
| Total Producer Surplus (in $ millions) | $ 34,196 | $ 659 | $ 34,855 |

*Source: TAS analysis*

Following Milgrom et al. (2011) in their assumption that consumer value is of the same magnitude as producer value, total economic value would amount to $ 69 billion. However, recent research on willingness to pay for tablets conducted by the Institute for Mobile Markets Research conducted in 2011 indicates that willingness to pay for a 16GB Wi-Fi only model ranges between $351and $524. Considering that the research was conducted in 2011 and the content value of tablets has greatly increased since then, we take the upper range. Considering that 60% of tablets sold are entry model (16GB Wi-Fi only), and keeping the 70%-30% split in favor of Apple, consumer surplus would equate to $ 7.987 billion.

In addition to the tablet estimates, one could add the somewhat less reliable producer surplus figures from devices such as the iTouch, an Apple product that connects exclusively through

Wi-Fi. Apple released US shipment numbers from 2007 of 46.5 million. Considering replacement and tablet substitution rates, the current installed base approximates 26 million. Retail price ranges between $ 229 and $399, with the mid-level model of $299. An estimate of manufacturing and parts cost (realized in 2007 and therefore not factoring in scale or experience effects) estimates a total of $155.04[44]. Considering a unit producer surplus of $144 would yield a total of $ 3.744 billion. Given the limited reliability of these figures, we decided to include them only as a reference.

## VII. THE VALUE OF WIRELESS PERSONAL AREA NETWORKS

Wireless Personal Area Networks connect two or more devices within a very limited geographic area (sometimes within line of sight) by relying on unlicensed spectrum bands of 2.4 GHz and 915 MHz. While the most common standard is *Bluetooth*, two new standards (ZigBee and WirelessHART) now support specific application such as home automation and industrial device monitoring respectively. This chapter estimates the value added generated by these three standards.

### VII.1. Bluetooth Applications

Mobile phone headsets, PC networking, PC peripherals, medical equipment, traffic control devices, barcode scanners, and credit card payment machines all rely on this technology. Quantification would rely on measuring the total US market for each Bluetooth-enabled technology. The following application sub-categories will be addressed in turn:

- Automotive
- Consumer Electronics
- Health & Wellness
- Mobile Telephony
- PC & Peripherals
- Sports & Fitness

#### *VII.1.1 Automotive*

The market for Bluetooth enabled devices, originally focused on hands-free voice calling, has grown to encompass a wide range of automotive applications. Safety concerns[45] and new hands-free driving laws originally spurred the deployment of hands-free calling systems. As of today, the majority of new cars and trucks[46] now include Bluetooth enabled hands-free voice calling systems as standard equipment. In addition, many consumers tend to add hands-free calling by

[44] iSuppli teardown reveals Apple's iPod touch is more than an iPhone without a phone, EMS Now, December 19, 2007.

[45] Eleven percent of drivers are talking on the phone while driving.
[46] All 12 of the world's major car manufacturers offer Bluetooth hands-free calling systems in their vehicles.

purchasing Bluetooth speakerphones that attach to their car's visor or rely on headsets. For example, according to NPD, the market for Bluetooth-equipped speakers represented $264 million in 2012[47].

Many different devices consumers use in the car offer hands-free calling ability - not just factory installed hands-free calling systems. For example, many car navigation systems now include Bluetooth hands-free calling. These devices include the small, affordable navigation devices that consumers can mount on the windshield if the car lacks an integrated navigation system. This added hands-free calling capability gives portable navigation devices benefits beyond just maps and navigation.

Beyond hands-free voice calling, Bluetooth now supports a whole range of automotive applications. Automakers and consumer electronic manufacturers have developed Bluetooth-enabled smartphone applications that run in the car.[48] The applications allow users to stream music over the Internet, listen to podcasts, get instructions from GPS systems, and receive information (traffic information, weather reports, destination information, cheapest gas station, etc.) on the flat-panel display in the car.

Finally, new phone applications that communicate wirelessly with a car to monitor and diagnose its mechanical and electrical systems have emerged. Adding wireless sensors to cars eliminates copper wires, thereby reducing vehicle weight, improving fuel economy, and lowering manufacturing costs[49].

Per the Consumer Electronics Association, the 2013 United States market for automotive consumer electronics is worth an estimated $ 9.2 billion[50]. However, only 35 percent of all devices are Bluetooth-enabled[51], which results in an approximate $3.22 billion total market for Bluetooth in-vehicle electronics.

### *VII.1.2. Consumer Electronics*

Bluetooth technology can be found in many consumer electronics devices. The consumer electronics devices equipped with Bluetooth technology is segmented in two categories: at home and on the go applications (see table VII-1):

**Table VII-1. Bluetooth Consumer Electronics Applications**

| Home | On the go |
|---|---|
| • TV sets<br>• Remote controls<br>• 3D glasses | • Headphones<br>• Ear buds<br>• Cameras |

[47] http://allthingsd.com/20130703/bluetooth-speakers-popping-up-everywhere-heres-why/
[48] For example, Toyota and Hyundai offer new Bluetooth enabled systems for smartphone applications in the car, and Ford is aggressively pursuing the application market with its Bluetooth enabled Ford Sync system. Pioneer and Sony have developed the ability to connect smartphones to their latest car receivers.
[49] Carmakers are also testing other possible future uses. For example, Ford is exploring Bluetooth enabled systems that monitor a person's vital signs while driving.
[50] Source: Consumer Electronics Association. “The U.S. Consumer Electronic Sales and Forecasts”.
[51] Source: http://www.isuppli.com/Automotive-Infotainment-and- Telematics/Pages/Products.aspx.

| | |
|---|---|
| • A/V receivers<br>• Game consoles<br>• Game controllers | • Speakers<br>• Media players |

The consumer electronics Bluetooth-enabled market comprises a primary area (Audio) and various applications (Ultra HD TV, Desktop 3D printers, video games).

Home audio unit shipments in the United States will increase by a projected 11%, reaching 11.4 million shipments by 2017. Soundbars and Bluetooth/Airplay-enabled speakers fuel this demand. Soundbar shipments could increase by 40% from 2012 to reach 2.8 million units, while portable connected speakers could generate $302 million in total revenue in 2013 – an increase of 35% year-over-year[52].

Television consumer equipment market analysts forecast Bluetooth-enabled device shipments - like TVs, set-top-boxes, remotes, and 3D glasses - to grow to almost 500 million units a year by 2018. The Bluetooth-enabled television market includes 3D television sets, TV remote controls, and Ultra HD. Annual shipments of Ultra HD in the United States are projected to reach 57,000 units, earning revenues of $314 million[53].

Another Bluetooth-enabled application, desktop 3D printers will reach unit sales in the United States of 41,000, with revenues of $52 million.

Finally, Bluetooth technology is already well established in the gaming industry because it is already built into every Nintendo Wii and Sony PlayStation. There's a large third-party market for Bluetooth enabled headsets, stereo headphones, remote controllers, and game controllers that work with these game consoles.

### *VII.1.3. Health & Wellness*

Bluetooth-enabled health and wellness devices already on the market include wireless blood glucose monitors, heart rate monitors, weight scales, and stethoscopes. These devices collect vital health information from consumers with a wide variety of medical conditions – even allowing healthcare providers to monitor patients while at home or on the go.

The emergence of Bluetooth Smart devices with low energy technology allows manufacturers to design extremely small and longer-lasting wireless devices by shrinking battery size and requiring less power. Consumers can now wear tiny wireless sensors that operate for months or years with just a coin-cell battery. Bluetooth technology allows sensors to collect data securely and send it to enabled phones, tablets, and laptops. The sensor sends the health information to the computerized hub device, which stores and analyzes this information. Consumers can view their own health information or securely share their medical information with their healthcare provider. This ability to alert health care providers is critical. People can pair their phone with new types of Bluetooth wireless sensors to monitor everything from glucose and oxygen levels to heart rate and electrocardiograms.

[52] Source The U.S. Consumer Electronic Sales and Forecasts.
[53] Source The U.S. Consumer Electronic Sales and Forecasts

Smart watches that monitor abnormal vital signs serve as another example of a Bluetooth-enabled health application. For example, a smart watch can help people with epilepsy by detecting abnormal movements in people prone to seizures and then sending alerts to their phones and their doctors.

By 2018, ABI Research expects more than 46 million Bluetooth enabled health and medical devices to ship per year. According to TechNavio, the global market for wireless patient-monitoring equipment should reach $9.3 billion by 2014. With the United States representing 26.7% of world GDP, this market amounts to $ 2.48 billion in 2014.

### *VII.1.4 Mobile Telephony*

Most mobile phones and smartphones already include Bluetooth technology, allowing them to work with headsets, headphones, wireless speakers, hands-free calling systems in the car, and an array of other Bluetooth-enabled devices. This vast network of compatible products creates as many opportunities for companies making Bluetooth accessories as it does for companies manufacturing wireless phones.

According to market research firm ABI Research, nearly two billion smartphones will ship globally by 2018, almost triple the amount in 2011. Considering that the 2013 smartphone installed base in the United States is 192.75 million and that the cost of a Bluetooth chip required in each phone is worth $1, the total Bluetooth-related smartphone market amounts to $ 192.75 million[54].

### *VII.1.5 PC and Peripherals*

The explosion in tablet sales and the continued growth in laptop sales is sparking demand for more Bluetooth enabled keyboards, speakers, stereo headphones, and other wireless computer accessories. They allow consumers to travel with their tablets and increase productivity by turning the tablet into a full-featured computer. In addition, since most laptops and tablets have weak speakers with poor sound, consumers shop for Bluetooth speakers or headphones to enhance their mobile computing experience. Laptop users also like to move around their home while continuing to listen to music without the hassle of speaker wires or headphone cords.

Tablet sales are expected to approach 250 million units by 2017 (virtually all with Bluetooth technology)[55]. Despite the skyrocketing tablet sales, the laptop market will also continue to grow. Research firm, ETForecasts, expects laptop sales to grow to 369 million in 2015. Most laptops come with integrated Bluetooth technology. Because laptops still outsell tablets by a wide margin, there are more laptops than tablets able to connect with Bluetooth accessories.

We used a similar approach to quantify the Bluetooth market in the PC, tablet, and peripheral sectors (see table VII-2).

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[54] Source: http://www.nickhunn.com/bluetooth-low-energy-aiming-for-the-trillions/
[55] Source: InStat

**Table VII-2. United States: PC and Peripherals Bluetooth Market**

| Market | Value |
|---|---|
| PCs | $ 316.50 |
| Tablets | $ 61.52 |
| Printers | $ 7.00 |
| Total | $ 385.02 |

*Source: http://www.nickhunn.com/bluetooth-low-energy-aiming-for-the-trillions; TAS analysis*

As indicated in table VII-2, the Bluetooth-enabled PC and peripheral market in the United States is worth $ 385.02 million.

### *VII.1.6 Sports & Fitness*

As in the case of Health Care, Bluetooth technology has dramatically shrunk the size and power requirements of sensors able to measure pace, pulse, cadence, distance, and other workout information. Tiny sensors that operate for months with just a coin-cell battery have created a new wave of sports and fitness devices that help consumers track their workouts and athletic performance. Convenience also drives the popularity of fitness products, with Bluetooth technology allowing consumers to listen to music with wireless headphones while exercising. Some of the new wireless exercise devices made possible by Bluetooth technology include:

- Heart-rate monitors connected to a Bluetooth phone, which allows consumers to set the phone on a treadmill or other exercise machine, watch their pulse in real-time during workouts, and then analyze the information later
- Heart-rate monitors that automatically connect to a piece of exercise equipment at the gym and display users' heart rate on the machine while they work out
- Cycling computers that send speed, route, and other performance data wirelessly to a phone, where users can analyze it after a ride
- Bluetooth-enabled sports watches that connect wirelessly to a heart-rate strap, foot pod, or phone
- Wireless, water-resistant ear buds made to wear while working out

The many new wireless fitness devices enabled by Bluetooth increases demand for compatible applications that can analyze runs, bike rides, gym exercises, or other types of workouts. Bluetooth technology sends the workout data wirelessly to any Bluetooth ready device. From there, consumers process and analyze the information with the latest sports and fitness apps and securely share results online with personal trainers or friends. This workout data creates demand for new PC and phone applications to process and analyze a wealth of exercise information.

According to IMS Research, more than 60 million sports, fitness, and health monitoring devices with Bluetooth technology will ship between 2010 and 2015. Sport and Fitness unit shipments in the United States reached an estimated 10.2 million in 2013, with revenues of $854 million[56].

## VII.2. Other WPAN standard applications

[56] Source: The U.S. Consumer Electronic Sales and Forecasts.

Beyond Bluetooth, ZigBee and WirelessHART also support Personal Area Networks. These products have a much lower proximity requirement than Bluetooth (up to 75 meters[57]), although the transfer data rate is lower (250 kbps).

### *VII.2.1 ZigBee*

ZigBee supports secure communications at a low data transfer rate (maximum: 250 kbps) and an extended battery life, making Zigbee the standard of choice for home automation. ZigBee Home Automation offers a global standard for interoperable products enabling smart homes that can control appliances, lighting, environment, energy management, and security while offering the option to connect with other ZigBee networks. ZigBee technology will likely lead the smart home market.[58]

By the end of 2012, over 11 utilities installed more than 40 million ZigBee-enabled meters in the United States[59]. The world market for ZigBee-enabled energy management systems was worth $1 billion[60]. Assuming that the US represents 26.70% of the world economy, we estimate that the ZigBee US market conservatively amounts to $ 267 million.

### *VII.2.2 WirelessHART*

Wireless HART is a technology operating in unlicensed spectrum bands primarily for industrial applications[61]. It provides connectivity in zones of difficult or costly wireline access. The technology can monitor pumps, cooling units, filters, engines, and valves otherwise difficult to access[62] at a very low cost. According to IDTech[63], the world market for WirelessHART in 2011 was $450 million. We estimate the US market for 2013 to be approximately $160 million.

## VII.3. Conclusion

In order to estimate the total economic value of Wireless Personal Area Networks operating in unlicensed spectrum, we conservatively considered only those revenues to be generated by the applications that could not operate without the technology. We consider this estimate to be extremely conservative in the sense that, if the application is being operated via a competing alternative substitute technology, it was aggregated in a different category (see table VII-3).

**Table VII-3. United States: Revenues Generated by Wireless Personal Area Networks Markets (in $ millions)**

| Standards | Applications | Application Could Not Be Operated Without Unlicensed Spectrum Standard | Unlicensed Spectrum Standard Supports Alternative Technology |
|---|---|---|---|
| Bluetooth | Automotive | $ 1,161.60 | $ 2,058.40 |

[57] Data rate for WirelessHART outdoors reaches 250 meters.
[58] Source: http://www.fiercetelecom.com/press-releases/worldwide-smart-meter-revenue-surpass-us12-billion-2016-zigbee-early-techno
[59] http://www.onworld.com/smartenergyhomes/SmartHomeEnergyExecSum.pdf
[60] Source: ON World. *2016 Wireless/Wired Home Energy management Equipment*.
[61] Maley, R. (2013). *Building Secure Standards for the Smart Grid*. Presentation at the US-Mexico Smart Grid Conference.
[62] http://www.edcontrol.com/ins/novedades/nov_154_01_porquewirelesshart.htm
[63] IDTech. *Wireless Sensor networks 2011-2021*.

| | | | |
|---|---|---|---|
| | Consumer Electronics | | $ 668.00 |
| | Health and Wellness | | $ 2,483.10 |
| | Mobile Telephony | $ 192.75 | |
| | PC and Peripherals | $ 385.03 | |
| | Sports and Fitness | | $ 854.00 |
| Zigbee | | $ 267.00 | |
| WirelessHART | | $ 160.00 | |
| Total | | $ 2,166.38 | $ 6,063.50 |

*Source: TAS analysis*

In summary, the revenue generated by Wireless Personal Area Network technologies operating in unlicensed spectrum in the United States in 2013 is $ 2.17 billion for applications that could not operate without technologies in those standards. If we add applications that can operate with unlicensed network technologies as a substitute to other alternatives (primarily wired connections), revenues would reach $ 8.23 billion.

Beyond the value generated by these applications, it is important to conclude that, since wireless personal area networks are purely private goods, generating minimal interference, there is no economic rationale to license the spectrum in which they operate.

## VIII. THE VALUE OF RFID

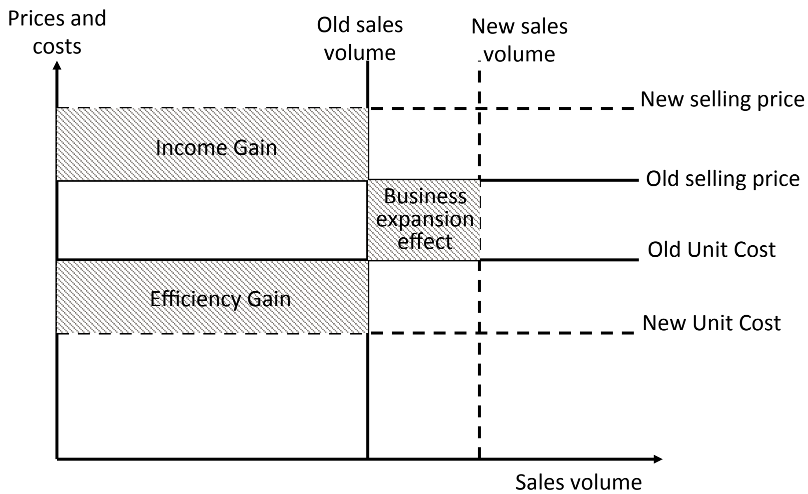
When Thanki assessed the economic value of RFID (2009) dependent on unlicensed spectrum[64], he focused on a sector that had adopted the technology early (retailing) and one for which researchers had already developed studies on economic impact (Hardgrave et al., 2009). However, at the same time, he acknowledged that the usage of unlicensed spectrum in combination with RFID was "at its infancy." For that purpose, while anchoring the benefits in the areas of retailer efficiency (fewer out-of-stock items) and increased sales, he had to range the impact scenarios depending on technology adoption in the sector. By running a net present value of economic returns across three scenarios, he concluded that RFID enabled by unlicensed spectrum in the retail sector supply chain could generate an annual value between $3.3 billion and $13.1 billion.

Since the time that Thanki produced his study, RFID has achieved a much wider adoption. In particular, the blending of general-purpose networks and RFID has yielded new applications such as powered, attachable tags that Wi-Fi APs can read. This led to its adoption in manufacturing plants, warehouses, logistics, hospitals, and other large facilities equipped with Wi-Fi networks and the need the track the movement of people or assets. The value of the US RFID market for 2013 is estimated at $7.88 billion, up from $6.51 billion in 2011, which includes tags, readers, software, labels, and other items. As expected, retail apparel is the largest pocket of demand, although benefits in the health care sector are also growing.

[64] RFID applications rely on the unregulated 120-150 kHz Low Frequency band, the 13.56 MHz high frequency ISM band, and the 902-928 MHz UHF band, among others.

The assessment of RFID benefits can be summarized in terms of both the operational efficiencies and revenue enhancing opportunities (see figure VIII-1).

**Figure VIII-1. Economic Value of RFID**




The efficiency gains include a reduction in labor costs, shrinkage losses, inventory write-offs, and non-working inventory. Income gains include increased product availability and faster time to market. Business expansion provides ubiquitous access to customers across multiple distribution channels. In addition, consumers benefit from some of the efficiency gains by way of lower prices. Furthermore, by allowing for less waiting time, an enhanced shopping experience, and improved customer care, RFID can increase consumer surplus. In the particular case of health care, consumer surplus results from improved compliance and fewer errors.

These benefits should be factored against the investment to understand the net present value of resulting cash flows. A study conducted at the University of Texas (Anitesh Barua, Deepa Mani & Andrew B. Whinston, 2006), from which the following analyses are compiled, follows this methodology.

### VIII.1. RFID and retailing

The authors summarize the retailer and consumer benefits in the following areas (table VIII-1).

**Table VIII-1. RFID Benefits in Retailing**

| Retailers | Consumers |
|---|---|
| • Reduction in Labor costs<br>• Reduction in Shrinkage losses<br>• Enhanced Inventory Turns<br>• Reduction in Inventory Write-Offs<br>• Reduced Stock-Outs and Improved Product Availability<br>• Decrease in Lost Sales Due to Shipment Errors<br>• Faster Time-to-Market for New Products<br>• Ubiquitous Access Across Multiple Channels | • Customization of products and services<br>• Enhanced shopping experience |

Relying on case study data and results from other research, the authors develop an estimation of financial benefits for the sector, at both the 45% adoption, and the 100% RFID adoption level (table VIII-2).

**Table VIII-2. Estimates of RFID Benefits in Retailing (in $ billions)**

| Benefit | Total Cost/losses | Cost Reduction at 45% Adoption | Cost Reduction at 100% Adoption |
|---|---|---|---|
| Reduction in labor costs | $ 260.63 | $ 46. 33 | $ 102.95 |
| Reduction in shrinkage losses | $ 60.22 | $ 11.67 | $ 19.06 |
| Enhanced inventory turns | $ 105.65 | $ 7.35 | $ 16.33 |
| Reduction in inventory write-offs | $ 26.41 | $ 2.11 | $ 10.56 |
| Reduced stock-outs | $ 51.00 | $ 0.294 (*) | $ 0.652 (*) |
| Reduced shipment errors | $ 5,611.2 | $ 0.089 (*) | $ 0.197 (*) |
| Faster time to market | $ 39.152 | $ 0.63 (*) | $ 3.132 (*) |
| Ubiquitous access across multiple channels | $ 2,280.52 | $ 0.112 (*) | $ 0.559 (*) |
| Customization | | $ 20.45 | $ 102.24 |
| Enhanced experience | $ 29,054 (**) | $ 5.81 | $ 29.05 |

(*) Quantified as EBITDA impact
(**) Measured as willingness-to-pay.
*Source: Barua et al. (2006)*

A survey conducted by Accenture found that more than 50% of US retailers had adopted RFID, meaning that the 45% adoption level offers a more realistic estimate of the current situation[65].

[65] The survey also states that based on reports of pilots projects in place, by 2017, take-up of RFID in retail will reach 100%.

According to the estimates for the 45% adoption scenario, the total economic value of RFID in the retailing sector in 2013 is $ 94.84 billion (see table VIII-3).

**Table VIII-3. United States: RFID Economic Value in Retailing (2013) (in billions)**

| | Producer Surplus | Consumer Surplus |
|---|---|---|
| Reduction in labor costs | $ 46. 33 | |
| Reduction in shrinkage losses | $ 11.67 | |
| Enhanced inventory turns | $ 7.35 | |
| Reduction in inventory write-offs | $ 2.11 | |
| Reduced stock-outs | $ 0.29 | |
| Reduced shipment errors | $ 0.09 | |
| Faster time to market | $ 0.63 | |
| Ubiquitous access across multiple channels | $ 0.11 | |
| Customization | | $ 20.45 |
| Enhanced experience | | $ 5.81 |
| **Total** | $ 68.58 | $ 26.26 |

*Source: TAS analysis based on Barua et al. (2006)*

Assuming a 30% adoption rate, Thanki (2009) estimated the total economic value in retail clothing stores alone to be $ 13.1 billion in 2019. As such, we find the estimate of a study pertaining to the total retail sector at 45% adoption to be fairly realistic.

**VIII.2. RFID and health care**

In the case of the health care sector, the authors of the University of Texas study differentiate the benefits across the constituencies of the value chain (table VIII-4).

**Table VIII-4. RFID Benefits in Health Care**

| Product and Service Providers | Consumers |
|---|---|
| • Pharmaceutical manufacturers<br>o Reduction in counterfeit, shrinkage and parallel trade<br>o Efficient product recall<br>o Efficient sample management<br>o Enhanced inventory turns<br>o Shorter clinical trials and faster time-to-market<br>• Healthcare distributors<br>o Enhanced inventory turns<br>o Reduction in labor costs<br>• Hospitals<br>o Better equipment tracking and increased asset utilization<br>o Enhanced inventory turns<br>o Wider access to healthcare at reduced costs | • Faster access to better healthcare<br>• Improved quality of patient care – fewer medical errors and improved compliance<br>• Reduced mortality rates |

In this case, the authors develop an estimation of financial benefits for the sector, both at 50% adoption and 100% adoption of RFID. However, in health care the adoption of RFID is relatively high for certain applications, in some cases stimulated by FDA mandates, and relatively low for others such as pallet-level tags (table VIII-5).

**Table VIII-5. Estimates of RFID Benefits in Health Care (in $ billions)**

| Product and Service Providers | Benefit | Total Cost/losses | Cost Reduction at 50% Adoption | Cost Reduction at 100% Adoption |
|---|---|---|---|---|
| Pharmaceutical manufacturers | Reduction in counterfeit, shrinkage and parallel trade | $ 4.307 | $ 1.000 | $ 1.852 |
| | Efficient sample management | | $ 6.500 | $ 12.73 |
| | Enhanced inventory turns | | $ 4.505 (**) | $ 15.54 |
| | Shorter clinical trials and faster time-to-market | | $ 0.100 | $ 0.159 (*) |
| Healthcare distributors | Enhanced inventory turns | $ 5.984 | $ 0.410 (***) | $ 1.784 |
| | Reduction in labor costs | $ 1.878 | $ 0.130 (***) | $ 0.563 |
| Hospitals | Better equipment tracking | $ 7.253 | $ 1.451 (****) | $ 3.627 |
| | Enhanced inventory turns | $ 544.02 | $ 17.952 (****) | $ 44.881 |
| | Wider access to healthcare at reduced costs | | | $ 2.503 |
| Consumers | Faster access to better healthcare | | $ 1.500 | $ 3.417 |
| | Improved quality of patient care – fewer medical errors and improved compliance | $ 148.30 | (*****) | (*****) |

(*) Quantified as EBITDA impact
(**) At 29% adoption levels
(***) At 23% adoption levels
(****) At 40% adoption levels
(*****) Excluded because difficult to replicate calculations
*Source: Barua et al. (2006)*

Based on the more conservative adoption estimates of the study, the total economic value of RFID in the health care sector in 2013 is $ 36.07 billion (see table VIII-6)

**Table VIII-6. United States: RFID Economic Value in Health Care (2013) (in $ billions)**

| Product and Service Providers | Benefit | Producer Surplus | Consumer Surplus |
|---|---|---|---|
| Pharmaceutical manufacturers | Reduction in counterfeit, shrinkage and parallel trade | $ 0.925 | |
| | Efficient sample management | $ 6.50 | |
| | Enhanced inventory turns | $ 4.50 | |
| | Shorter clinical trials and faster time-to-market | $ 0.10 | |
| Healthcare distributors | Enhanced inventory turns | $ 0.41 | |
| | Reduction in labor costs | $ 0.13 | |
| Hospitals | Better equipment tracking | $ 1.45 | |
| | Enhanced inventory turns | $ 17.95 | |
| | Wider access to healthcare at reduced costs | | $ 2.53 |
| Consumers | Faster access to better healthcare | | $ 1.50 |
| | Improved quality of patient care – fewer medical errors and improved compliance | | --- |
| **Total** | | $ 31.96 | $ 4.03 |

*Source: TAS analysis based on Barua et al. (2006)*

### VIII.3. Conclusion

The implementation of RFID in the Retail and Health Care industries generates a total economic value of $130.3 billion (see table VIII-7).

**Table VIII-7 United States: RFID Economic Value in Retail and Health Care (in $ billions)**

| Sector | Producer Surplus | Consumer Surplus | Total |
|---|---|---|---|
| Retailing | $ 68.58 | $ 26.26 | $ 94.84 |
| Health Care | $ 31.9 | $ 4.03 | $ 35.99 |
| Total | $ 100.54 | $ 30.29 | $ 130.83 |

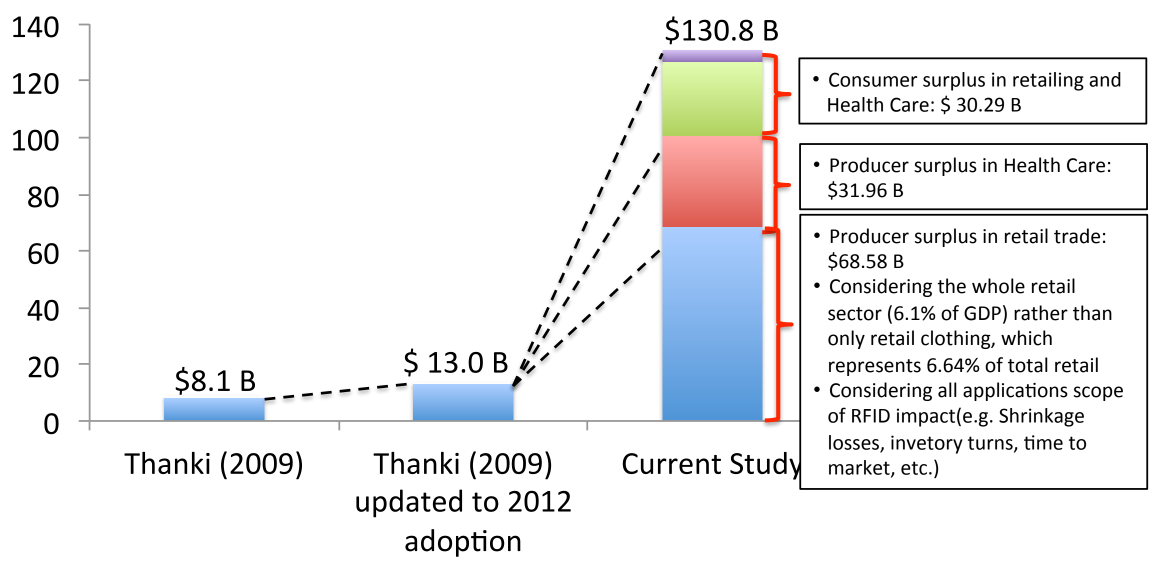
*Source: TAS analysis*

This number is considerably higher than Thanki's estimate in his 2009 paper. Thanki conducted the only prior estimate of RFID impact in 2009, focusing only on retail clothing (understandably so, since retail clothing was an adoption leader of RFID and there was already research on economic impact available at the time). The economic value estimated by Thanki in 2009 ranged between $2.1 and $8.1 billion. However, he recognized that the usage of RFID was "at its infancy". In fact, his model assumed that RFID in retail clothing would reach 60% (high take up scenario) only in 2019.

Several things have happened since 2009. First, adoption of RFID in retail clothing has exceeded Thanki's high uptake scenario (reaching 52% in 2012). If we were to consider only Thanki's original industry (retail clothing), and the acceleration of RFID take-up, the economic value of this technology would increase approximately to $13 billion. Second, the blending of general-purpose networks and RFID has yielded new applications, which has led to their adoption in manufacturing plants, warehouses, and logistics chains. As a result, penetration has increased well beyond retail clothing, reaching the whole retail trade sector. According to a survey by Accenture, more than 50% of US retailers have already adopted RFID. Third, research on the economic value of RFID has greatly expanded since 2009 (Gorshe et al, 2012; Waller et al, 2011). For example, Thanki recognizes that his analysis does not consider the value that might be generated in preventing shrinkage, reducing inventory holdings, and using data for marketing purposes. In conclusion, three trends are at work that greatly enhance RFID economic value beyond the original estimate: more penetration in retail clothing, enhanced adoption in the retail sector as a whole, and more applications.

In addition, beyond retail trade, RFID adoption has expanded in the health care industries, a sector that was not originally considered by Thanki. The impact of all these changes is presented in figure VIII-2.

**Figure VIII-2. Economic Value of RFID: Thanki (2009) Versus Present Study (in $ billions)**




To sum up, implementing Radio Frequency Identification in two of the largest sectors of the US economy (retailing (6.1% of GDP) and health care (7.4% of GDP)) results in efficiencies that generate the largest portion of economic surplus ($ 130.83 billion). This estimate does not include all other areas impacted by RFID, such as manufacturing supply chain (Sarac et al., 2009) and livestock tracking.

## IX. THE VALUE OF FUTURE APPLICATIONS

The study of applications that have reached wide adoption and impact indicates the economic value already created by unlicensed spectrum bands. However, as noted by several academics, the innovation incentives generated by this environment allow us to predict the future impact of still embryonic technologies. This chapter reviews some of those applications, but does not estimate their potential economic value given their limited adoption at present.

### IX.1. WirelessHD

These two technologies rely on the 60 MHz unlicensed spectrum band to deliver a data transfer rate between 6 Gbps and 28 Gbps over a range between 5 and 30 meters. WirelessHD is primarily used for high definition consumer electronic devices, while WiGig supports smartphones, PCs, tablets, and related peripherals[66].

At 28 Gbps of data transfer rate, WirelessHD surpasses HDMI, which is the most utilized HD connectivity (10 Gbps). Companies such as LG, Matsushita, NEC, Samsung, SiBEAM, Sony, and Toshiba have jointly sponsored this technology. WirelessHD is not yet widely adopted although it will likely replace HDMI in future connectivity of high definition devices. It works with a wide range of devices including laptops, tablets, televisions, Blu-ray players, DVRs, camcorders, gaming consoles, adapter products.

### IX.2. Super Wi-Fi and rural wireless coverage

Super Wi-Fi operates in the frequency bands between 54 MHz and 698 MHz to deliver broadband up to 10 miles with high penetration at 20 Mbps download and 6Mbps upload speeds. As discussed in Chapter II, it can extend the range of Wi-Fi and provide broadband in rural areas. Super Wi-Fi relies on empty channels of spectrum (known as white spaces) and uses Dynamic Spectrum Access that optimizes access to available unused bands. Users will predominantly use Super Wi-Fi networks to access smart, radio-enabled devices that report their location to an Internet database. The database will dictate the TV white spaces channels and appropriate power level based on in its current location. The database has a list of all protected TV stations and frequencies across the country, so the devices can avoid interference with TV broadcasts and wireless signals. This technology is truly dynamic – as different TV channels become available, Super Wi-Fi devices can opportunistically switch from one group of channels to another.

### IX.3. Advanced Meter Infrastructure

Advanced Meter Infrastructure systems provide detailed, time-based information regarding the utilization of electric, gas and water meters. The meters have the ability to transmit the collected data through a variety of communications technologies, ranging from Broadband over Power

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[66] Source: http://www.wirelesshd.org/about/specification-summary/.

Line, Fixed Radio Frequency and public networks (landline or cellular)(Adke et al., 2011). If relying on unlicensed spectrum, AMI transmits 1-8 kbps per channel over 0.25 miles[67].

**IX. 4. Energy demand side management**

Smart Home power meters, which utilize Bluetooth-enabled hub devices, can reduce energy costs, helping homeowners to save money and use less energy. As intelligent energy delivery technology advances, two-way communications will allow smart meters to send real-time energy consumption information directly to homeowners, empowering them to conserve energy and save on their utility bills. For example, homeowners will be able to use their Bluetooth-enabled smart phone, tablet or PC to monitor and adjust their heat and air conditioning, even when they're not home. The displays and applications on today's phones and other hub computing devices can allow users to control all the appliances and systems throughout a smart home with ease.

Smart homes will also make it easier for people to make sure all their windows and doors are locked. Cars have had wireless remotes for years, allowing drivers to lock and secure them with the touch of a button. Homeowners, however, must walk around and visually check every door and window in their homes. Companies that solve these challenges will tap into a huge market of homeowners eager to take advantage of technologies they already have in their cars or offices.

**IX.5. Machine to machine communications**

Beyond the technologies mentioned above, unlicensed spectrum bands would be critical to the communication of devices equipped with microcontrollers in order to deliver applications in areas as diverse as environmental management (pollution / air quality monitors, weather stations, water level monitors), urban landscape (street lighting control systems, parking meters), health care (dialysis machines, defibrillators, ventilators, pacemakers). Enhanced connectivity of devices via unlicensed spectrum could increase their ability to process information and interact with other terminals.

As of 2012, the number of interconnected devices had reached 4 billion, including all handheld mobile terminals at a pairwise interconnected rate of $8 * 10^{18}$ (Thanki, 2012). While forecasts vary greatly, they all concur in an explosive growth in the number of devices and the increase in pairwise interconnections. Complementing cellular networks, Wi-Fi, Bluetooth Low Energy, and ZigBee would be highly suited standards to support a large portion of machine-to-machine interconnection. In fact, most home security systems which monitor whether or not windows and doors are open already rely on Wi-Fi technology.

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[67] Electric Power Research Institute (2007). *Advanced Metering Infrastructure.* Palo Alto, California: EPRI.

## X. CONCLUSIONS

The sum of effects outlined above indicate that the technologies operating in unlicensed spectrum bands in the United States generated a total annual economic value of $222 billion in 2013, and contributed $ 6.7 billion to the nation's GDP (see table X-1).

**Table X-1. United States: Summary of Economic Value of Unlicensed Spectrum (2013)**

| | Effect | Economic Value | | | GDP |
|---|---|---|---|---|---|
| | | Consumer Surplus | Producer Surplus | Total Surplus | |
| Wi-Fi Cellular Off-Loading | Value of free Wi-Fi traffic offered in public sites | $ 1.902 | N.A. | $ 1.902 | N.A. |
| | Benefit of total cost of ownership required to support future capacity requirement with Wi-Fi complementing cellular networks | N.A. | $ 10.700 | $ 10.700 | N.A. |
| | Contribution to GDP of increase of average mobile speed resulting from Wi-Fi off-loading | N.A. | N.A. | N.A. | $ 2.831 |
| | Sum of revenues of service providers offering paid Wi-Fi access in public places | N.A. | N.A. | N.A. | $ 0.271 |
| | Subtotal | $ 1.902 | $ 10.700 | $ 12.602 | $ 3.102 |
| Residential Wi-Fi | Internet access for devices that lack a wired port | $ 22.510 | N.A. | $ 22.510 | N.A. |
| | Avoidance of investment in in-house wiring | $ 13.570 | N.A. | $ 13.570 | N.A. |
| | Subtotal (*) | $ 36.080 | N.A. | $ 36.080 | N.A. |
| Wireless Internet Service Providers | Aggregated revenues of 1,800 WISPs | N.A. | N.A. | N.A. | $ 1.439 |
| Wi-Fi Only Tablets | Difference between retail price and manufacturing costs for a weighted average of tablet suppliers | N.A. | $ 34.885 | $ 34.885 | N.A. |
| | Difference between willingness to pay for entry level tablet and prices of iPad and Android products | $ 7.987 | N.A. | $ 7.987 | N.A. |
| | Subtotal | $ 7.987 | $ 34.885 | $ 42.872 | N.A. |
| Wireless Personal Area Networks | Sum of revenues of Bluetooth-enabled products | N.A. | N.A. | N.A. | $ 1.739 |
| | Sum of revenues of ZigBee-enabled products | N.A. | N.A. | N.A. | $ 0.267 |
| | Sum of revenues of WirelessHART-enabled products | N.A. | N.A. | N.A. | $ 0.160 |
| | Subtotal | N.A. | N.A. | N.A. | $ 2.166 |
| RFID | RFID Value in Retailing | $ 26.26 | $ 68.58 | $ 94.84 | N.A. |
| | RFID Value in Health Care | $ 4.03 | $ 31.96 | $ 35.99 | N.A. |
| | Subtotal | $ 30.29 | $ 100.54 | $ 130.83 | N.A. |
| **TOTAL** | | $ 76.26 | $ 146.13 | $ 222.38 | $ 6.707 |

(*) A lower range in Residential Wi-Fi consumer surplus would amount to $ 31.9 billion
*Source: TAS analysis*

The efficiencies derived from implementing Radio Frequency Identification in two of the largest sectors of the US economy (retailing (12% of GDP) and health care (18% of GDP)) generate the largest portion of economic surplus ($130.83 billion). This estimate does not include all other areas impacted by RFID, such as the manufacturing supply chain and livestock tracking.

The next surplus effect in importance is generated by residential Wi-Fi. As of 2013, 63% of US households are equipped with Wi-Fi, which has a net effect of providing free access for devices that are designed for wireless access (tablets, smartphones), thereby generating annual savings of $22.5 billion. In addition, residential Wi-Fi services generate $13.6 billion in savings for households that do not have to deploy in-house wiring to interconnect PCs, printers, audio equipment, and the like. These estimates are three times higher than Thanki's 2009 figures, which are partly explained by the increase in residential Wi-Fi adoption, as well as the enhanced value derived from the technology[68]. To calibrate our results, we replicated Thanki's estimates, multiplying the total number of Wi-Fi households (72,450,000) by an assumed willingness to pay of $36.8 per household per month[69]. This yields a total surplus of $31.9 billion (considered to be a low bound estimate).

The producer surplus resulting from the adoption of tablets ($ 34.9 billion) is almost as high as residential Wi-Fi, and was five times the surplus estimated by Milgrom et al. (2011) for the iPad. While 2013 sales of tablets increased from 17.9 million in 2010 to approximately 220 million in 2013[70], average producer surplus per unit dropped because Apple's competitors tablet margins are substantially lower than the iPad.

The next category in economic value creation is that related to Wi-Fi cellular off-loading. This comprises first the producer surplus generated by operators' deployment of carrier-grade Wi-Fi sites to respond to the growth in wireless data traffic ($ 10.7 billion). The difference with Thanki's 2012 estimate of $ 8.5 billion is due to the increase in the volume of Wi-Fi sites required since the author conducted his analysis. The second value-creation effect derived from Wi-Fi off-loading comprises the consumer surplus derived from the utilization of free Wi-Fi sites deployed in public locations ($ 1.9 billion).

Finally, unlicensed spectrum provides an environment for the development of new businesses generating revenues who should be considered as direct contribution to the GDP ($3.87 billion): paid Wi-Fi access in public places (e.g. Boingo), Wireless Internet Service Providers (WISPs), Bluetooth-enabled products (e.g. chipsets to enable hands-free wireless calling), ZigBee-enabled products (e.g. home automation), and WirelessHART (e.g. industrial monitoring systems). An additional contribution to the GDP is the spillover impact of faster-than-cellular broadband wireless connections ($ 2.8 billion).

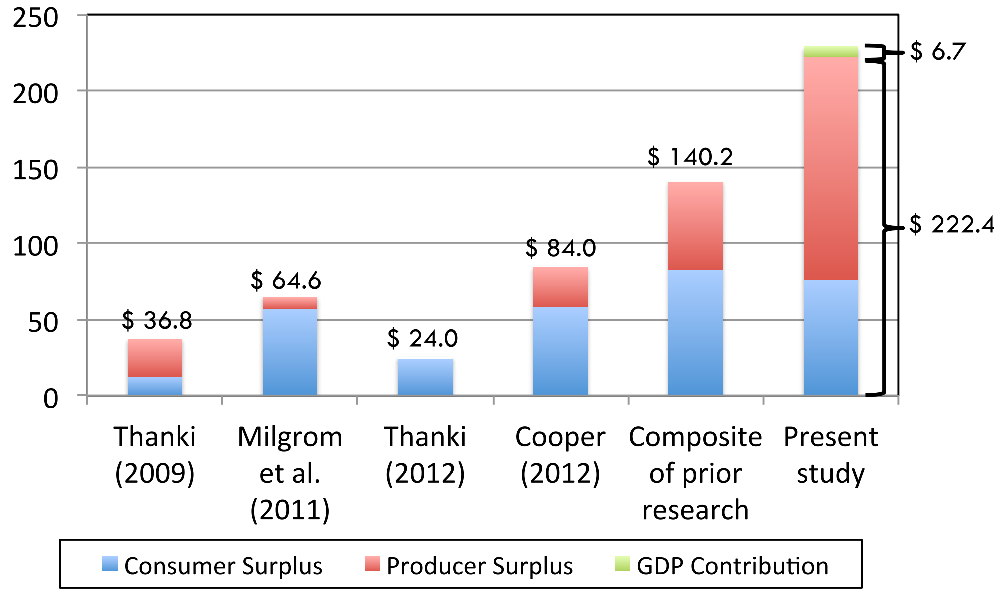
68 It should be noted that our approach for measuring consumer surplus differs from Thanki's.

69 Thanki estimates the average monthly consumer surplus to be $27.6, which represents 30% of the home broadband value. He also states that there is additional value not captured in his analysis. (pp.35). Given the current Wi-Fi adoption and usage patterns, it is reasonable to assume that willingness to pay would amount to 40% of the value, which equals to $36.8 per month.

70 This number was reduced to subtract shipments from manufacturers based overseas, and tablets with cellular connectivity, yielding a total of 137 million units for 2013.

To summarize, we believe that the aggregate economic surplus estimate of $222 billion and $6.7 billion in direct GDP contribution succeeds in capturing the whole range of applications, as well as addressing the increase in value per technology operating in unlicensed spectrum bands (figure X-1)

**Figure X-1. Unlicensed Spectrum Economic Value in the United States: Comparison with Prior Studies (in $ billions)**




*Source: TAS analysis*

This number is well above that one estimated by recent studies because it reflects a more detailed analysis of the multiple relatively heterogeneous applications and technologies that rely on unlicensed spectrum. Following the analysis of numerous authors (Milgrom et al, 2011; Carter, 2003; Cooper, 2011; Bayrak, 2008; Marcus et al, 2013; Benkler, 2012) we conclude that any policies focused on this portion of the spectrum must help to preserve the value generated so far as well while encouraging the generation of future economic surplus.

A final comment related to these estimates has to do whether the current assignment of unlicensed spectrum bands risks, in light of the explosive growth in usage, in becoming a bottleneck of future value creation. Indeed, our estimate of Internet traffic trends indicates that total Wi-Fi traffic in the United States is currently 0.67 Exabytes per month and will reach 5.97 Exabytes by 2017, reflecting a 68.0% growth rate. Wi-Fi households in the US, currently at 61%, are forecast to reach 86% by 2017[71]. According to IDC, tablet worldwide shipments, currently at 221 million, are estimated to reach 386 million by 2017. According to Gorsh et al, while 52% of retailers surveyed had already implemented or piloted RFID within their organization, 23 % are considering launching pilots in the near future[72]. All in all, there are

[71] Gillott, I. (2012). U.S. Home Broadband and Wi-Fi Usage Forecast 2012-2017. Austin, TX: iGR.
[72] Gorsh, M, Rollman, M, and Beverly, R. (2012) Item-level RFID: a competitive differentiator. Chicago, Illinois: Accenture.

currently 20,339 different unlicensed devices certified for use in the 2.4 GHz band alone, approximately three times the amount in any licensed band[73].

In the context of accelerating adoption of applications operating in unlicensed spectrum, it would be relevant to ask the question whether there is enough spectrum space to accommodate the expected growth. As pointed by Indepen, Aegis and Ovuum (2006), congestion could result either from the density of devices used for a given application or when one set of devices of a given application interferes with a set of devices running another application. Until 2008, roughly 955 MHz were allocated to unlicensed uses below 6 GHz (Hazlett et al., 2010). In 2010, the FCC allocated additional unused spectrum between broadcast TV channels. That said, the most used bands remain in the 900 MHz, 2.4 MHz, 5.2/5.3/5.8 GHz, 24 GHz, and above 60 GHz (Milgrom et al., 2011). In fact, the 2.4 GHz and 5GHz bands have become increasingly congested due to the intense Wi-Fi usage.

If future assignment of unlicensed spectrum is not fulfilled, it is plausible to consider that economic value creation would be at risk. This case is similar to the transition from 3G to 4G and the allocation of additional licensed spectrum for mobile broadband. Where do we see the effects that would be most at risk? Our quantification of the risk of not assigning additional unlicensed spectrum assumes that, beyond a certain point of network congestion, application or technology demand stops growing.

In the first place, let us address the so-called return to speed. At the current rate of traffic off-loading, the average speed of mobile traffic in the United States in 2013 was 10 Mbps[74]. Our analysis showed that if all the off-loaded traffic were to be conveyed through cellular networks, the speed would decline to 3.43 Mbps, with the consequent negative impact of $2.8 billion in GDP (see section III.3 for detailed calculations). Over five years, the impact would amount to $ 23.56 billion. The benefit derived from the additional speed resulting from off-loading is what we call the Wi-Fi return to speed. However, if we assume that, due to congestion, the average Wi-Fi speed does not increase to 17 Mbps, as Cisco projects, but stays at current levels (13.32 Mbps), the average speed of all mobile traffic would not change significantly from today, which means that $ 10.6 billion of the Wi-Fi speed return over the next five years would disappear.

Obviously, average speed could decline even further beyond the current level, with the consequent increase in value erosion. According to a study by Williamson et al. (2013), this scenario is highly likely. Once an 80-100 Mbps fiber link is deployed to a customer premise, the last mile is not the bottleneck any more, and the residential Wi-Fi becomes the congestion point. This is because there is a difference between the speed advertised speed in a typical Wi-Fi router (150 Mbps) and the delivered speed, which is below 70 Mbps[75]. Given that Wi-Fi shares available capacity across devices, if a typical Wi-Fi household is running multiple devices, the service will degrade and be substantially less than what could be handled by a fiber link.

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[73] Wireless Innovation Alliance. Background on Unlicensed Spectrum.

[74] This is calculated by prorating total mobile traffic by Wi-Fi and cellular speeds according to off-loading factors (see appendix C).

[75] The difference is due in part to the need to assign part of the capacity to the data overheads. In addition, advertised speeds are based on tests that relying on large packets, while the average packet size is much smaller. Finally, range and attenuation are factors to be considered in the reduction of speed. Williamson et al. (2013) estimate that delivered speed is approximately 50% of the advertised.

A second area of negative impact under a scenario of limited unlicensed spectrum assignment is service degradation in public places (airports, convention halls, etc.). Research by Wagstaff (2009) and Van Bloem et al. (2011) indicates that in dense device environments, data overheads that are generated to keep the connection running consume between 80% and 90% of capacity. In the context of increasing traffic volumes, Wi-Fi is becoming the contention point in public access networks. Some of this pressure could be alleviated by the upcoming Wi-Fi standard 802.11ac. While it is difficult to quantify the negative impact of this degradation, a large portion has been considered above in the reduction of the so-called Wi-Fi speed return. In addition, no additional assignment of unlicensed spectrum could result in the disappearance of the Wi-Fi service provider industry since, with lower service quality level, these operators could not compete with cellular service provider: an erosion of $271 million direct contribution to the GDP.

A third area of negative impact if additional unlicensed spectrum is not assigned could be an erosion of the benefit to carriers generated by cellular traffic off-loading. With high-density device environments being so prone to contention, if Wi-Fi does not benefit from additional spectrum, cellular carriers would experience service degradation when users roam into Wi-Fi. In other words, Wi-Fi's value of complementarity would be greatly diminished, reducing the $10.7 billion estimated producer surplus.

Following the evidence generated in this study, we conclude that any policies focused on this portion of the spectrum must preserve the value generated so far as well as the capacity to generate economic surplus in the future. Given the emerging body of evidence of congestion within the unlicensed spectrum bands and their estimated economic value, it would highly beneficial to pursue additional research linking up the study of congestion scenarios, the advantage of additional allocation and the risks of not proceeding along this path.

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## APPENDICES

### A. United States: Mobile Internet Traffic Forecast (2012-2017)

| Variable | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | SOURCE |
|---|---|---|---|---|---|---|---|---|---|
| Population | 313,579,434 | 316,208,509 | 318,777,991 | 321,316,861 | 323,855,320 | 326,408,880 | 328,976,336 | 331,551,643 | GSMA |
| Number of Internet Users | 232,048,781 | 238,467,001 | 245,000,000 | 253,577,938 | 262,456,206 | 271,645,320 | 281,156,163 | 291,000,000 | CISCO |
| Users of Internet (%) | 74.00% | 75.41% | 76.86% | 78.92% | 81.04% | 83.22% | 85.46% | 87.77% | CISCO |
| Total Devices | N/A | 1,391,317,440 | 1,608,000,000 | 1,782,955,851 | 1,976,947,492 | 2,192,046,080 | 2,430,548,125 | 2,695,000,000 | CISCO |
| Device (by inhabitant) | N/A | 4.40 | 5.04 | 5.55 | 6.10 | 6.72 | 7.39 | 8.13 | CISCO |
| IP Traffic (Exabytes per month) | 7.04 | 9.60 | 13.10 | 16.13 | 19.87 | 24.46 | 30.13 | 37.10 | CISCO |
| Internet Traffic (Exabytes per month) | 4.00 | 5.44 | 7.40 | 9.35 | 11.81 | 14.92 | 18.84 | 23.8 | CISCO |
| Internet Traffic (Share) | 56.87% | 56.68% | 56.49% | 57.94% | 59.44% | 60.97% | 62.54% | 64.15% | CISCO |
| Mobile Traffic (Exabytes per month) | 0.08 | 0.12 | 0.20 | 0.32 | 0.49 | 0.77 | 1.21 | 1.90 | CISCO |
| Mobile Traffic (Share) | 1.09% | 1.29% | 1.54% | 1.95% | 2.49% | 3.16% | 4.02% | 5.12% | CISCO |
| Other Traffic (Exabytes per month) | 2.96 | 4.03 | 5.50 | 6.47 | 7.56 | 8.77 | 10.07 | 11.40 | CISCO |
| Other Traffic (Share) | 42.04% | 42.03% | 41.98% | 40.10% | 38.08% | 35.87% | 33.44% | 30.73% | CISCO |
| Non-PC Device Traffic (Exabytes per month) | 3.57 | 4.74 | 6.29 | 8.35 | 11.09 | 14.73 | 19.56 | 25.97 | CISCO |
| Traffic From non-PC Device (Share) | 41.28% | 44.51% | 48.00% | 51.76% | 55.82% | 60.19% | 64.91% | 70.00% | CISCO |
| Smartphone and Tablets Traffic (Exabytes per month) | 0.11 | 0.21 | 0.39 | 0.75 | 1.41 | 2.68 | 5.09 | 9.65 | CISCO |
| Smartphone and Tablets Traffic (Share) | 1.26% | 1.95% | 3.00% | 4.62% | 7.12% | 10.96% | 16.88% | 26.00% | CISCO |
| PC Traffic (Exabytes per month) | N/A | N/A | 6.14 | 6.80 | 7.53 | 8.34 | 9.24 | 10.23 | CISCO |
| PC Traffic (Share of Internet Traffic) | N/A | N/A | 83.00% | 72.77% | 63.80% | 55.94% | 49.04% | 43.00% | CISCO |
| Fixed/Wi-Fi (Exabytes per month) | N/A | N/A | 3.67 | 4.88 | 6.48 | 8.61 | 11.44 | 15.21 | CISCO |
| Fixed/Wi-Fi (Share) | N/A | N/A | 28.00% | 30.22% | 32.61% | 35.20% | 37.99% | 41.00% | CISCO |
| Fixed/Wired (Exabytes per month) | N/A | N/A | 9.17 | 10.72 | 12.54 | 14.66 | 17.14 | 20.03 | CISCO |
| Fixed/Wired (Share) | N/A | N/A | 70.00% | 66.46% | 63.10% | 59.91% | 56.88% | 54.00% | CISCO |
| Average broadband Speed (Mbps) | 8.22 | 10.30 | 12.90 | 16.01 | 19.87 | 24.67 | 30.62 | 38.00 | CISCO |
| Average Mobile Connection Speed (Mbps) | 0.48 | 1.08 | 2.41 | 3.43 | 4.88 | 6.94 | 9.87 | 14.05 | CISCO |
| Average Smartphone Connection Speed (Mbps) | 0.73 | 1.46 | 2.94 | 4.04 | 5.56 | 7.65 | 10.53 | 14.48 | CISCO |
| Wi-Fi Speeds from Mobile Device (Mbps) | 6.89 | 8.90 | 11.50 | 13.32 | 15.43 | 17.88 | 20.72 | 24.00 | CISCO |
| Average traffic mobile connection (Gb per month) | 0.23 | 0.37 | 0.60 | 0.89 | 1.33 | 1.97 | 2.93 | 4.36 | CISCO |
| Average traffic by smartphone (Gb per month) | 0.06 | 0.11 | 0.20 | 0.37 | 0.68 | 1.27 | 2.37 | 4.42 | CISCO |
| Average Tablet connection Speed (Mbps) | 0.99 | 1.92 | 3.70 | 4.87 | 6.42 | 8.46 | 11.15 | 14.70 | CISCO |
| Average traffic mobile connected laptop (Gb per month) | 1.60 | 1.98 | 2.45 | 3.03 | 3.75 | 4.65 | 5.76 | 7.13 | CISCO |
| Average traffic mobile connected tablet (GB per month) | 0.17 | 0.25 | 0.37 | 0.55 | 0.81 | 1.19 | 1.75 | 2.58 | CISCO |

Note: 2013-2016 are TAS interpolated calculations
Source: VNI Forecast Highlights (CISCO),
http://www.cisco.com/web/solutions/sp/vni/vni_forecast_highlights/index.html.

### B. United States: Free Wi-Fi Traffic (2010-2017)

| 1. Devices | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | SOURCE | CAGR 2010-2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| Smartphones | 112,888,596 | 139,344,317 | 172,000,000 | 192,751,370 | 216,006,342 | 242,066,967 | 271,271,742 | 304,000,000 | CISCO | 19.52% |
| Smartphone (Penetration) | 36.00% | 44.07% | 53.96% | 59.99% | 66.70% | 74.16% | 82.46% | 91.69% | CISCO | 18.56% |
| Tablets | 26,407,591 | 35,008,499 | 46,410,709 | 61,526,599 | 81,565,710 | 108,131,526 | 143,349,784 | 190,038,569 | CISCO (Mail) | 32.57% |
| Tablets (Penetration) | 8.42% | 11.07% | 14.56% | 19.15% | 25.19% | 33.13% | 43.57% | 57.32% | TAS | 31.50% |
| Laptops | 235,184,576 | 237,156,382 | 239,083,493 | 240,987,646 | 242,891,490 | 244,806,660 | 246,732,252 | 248,663,732 | DELOITTE | 0.82% |
| Laptops (Penetration) | 75.00% | 75.00% | 75.00% | 75.00% | 75.00% | 75.00% | 75.00% | 75.00% | DELOITTE | 0.00% |
| Total Devices (Smartphones+Tablets+Laptops) | 374,480,763 | 411,509,198 | 457,494,202 | 495,265,616 | 540,463,542 | 595,005,153 | 661,353,778 | 742,702,301 | TAS | 9.77% |
| Total Devices Per Capita | 1.19 | 1.30 | 1.44 | 1.54 | 1.67 | 1.82 | 2.01 | 2.24 | TAS | 8.88% |
| Portable Gaming Console | 42,615,887 | 46,954,004 | 51,733,724 | 57,000,000 | 62,802,360 | 69,195,376 | 76,239,173 | 84,000,000 | PARK ASSOCIATES | 10.18% |
| Portable Gaming Console (Penetration) | 13.59% | 14.85% | 16.23% | 17.74% | 19.39% | 21.20% | 23.17% | 25.34% | PARK ASSOCIATES | 9.29% |
| PC | 329,082,731 | 329,082,731 | 329,082,731 | 316,501,079 | 304,400,454 | 292,762,467 | 281,569,428 | 270,804,328 | CISCO (Mail) | N/A |
| PC (Penetration) | 105% | 104% | 103% | 99% | 94% | 90% | 86% | 82% | TAS | N/A |
| Phone | 289,085,114 | 292,640,736 | 296,240,090 | 299,883,715 | 303,572,155 | 307,305,961 | 311,085,691 | 314,911,910 | CISCO (Mail) | 1.23% |
| Phone (Penetration) | 92.19% | 92.55% | 92.93% | 93.33% | 93.74% | 94.15% | 94.56% | 94.98% | TAS | 0.41% |
| M2M Connections | 31,111,111 | 46,666,667 | 70,000,000 | 95,042,737 | 129,044,599 | 175,210,742 | 237,892,980 | 323,000,000 | CISCO | 45.10% |
| M2M Connections (Penetration) | 9.92% | 14.76% | 21.96% | 29.58% | 39.85% | 53.68% | 72.31% | 97.42% | TAS | 43.93% |
| **2. Average Traffic per Device (Gb per month)** | | | | | | | | | | |
| Smartphones | 0.28 | 0.40 | 0.56 | 0.80 | 1.13 | 1.60 | 2.27 | 3.21 | CISCO | 41.60% |
| Tablet | 1.74 | 2.68 | 4.12 | 6.33 | 9.73 | 14.97 | 23.01 | 35.38 | CISCO (Mail) | 53.76% |
| Laptop | 1.43 | 2.08 | 2.44 | 2.88 | 3.40 | 4.02 | 4.74 | 5.60 | CISCO | 26.48% |
| Portable Gaming Console | 0.24 | 0.31 | 0.39 | 0.50 | 0.64 | 0.81 | 1.03 | 1.31 | CISCO | 28.11% |
| PC | 15.40 | 17.68 | 20.31 | 23.33 | 26.80 | 30.78 | 35.35 | 40.60 | CISCO (Mail) | 14.86% |
| Phone | 0.31 | 0.49 | 0.79 | 1.28 | 2.06 | 3.31 | 5.33 | 8.59 | CISCO (Mail) | 60.95% |
| M2M | 0.04 | 0.05 | 0.07 | 0.10 | 0.14 | 0.20 | 0.28 | 0.39 | CISCO | 39.05% |
| **3. Total Traffic per device (Gb per month)** | | | | | | | | | | |
| Smartphones | 31,723,574 | 55,448,934 | 96,917,969 | 153,796,072 | 244,054,142 | 387,281,830 | 614,565,337 | 975,234,375 | | 69.25% |
| Tablets | 45,985,183 | 93,735,136 | 191,067,541 | 389,467,671 | 793,881,922 | 1,618,230,608 | 3,298,563,967 | 6,723,716,751 | | 103.84% |
| Laptop | 335,321,758 | 493,535,400 | 584,400,375 | 695,199,712 | 826,953,359 | 983,661,915 | 1,170,044,724 | 1,391,691,259 | | 27.51% |
| Portable Gaming Console | 10,154,567 | 14,535,566 | 20,372,953 | 28,554,596 | 40,021,933 | 56,094,477 | 78,621,647 | 110,195,581 | | 41.15% |
| PC | 5,066,567,473 | 5,819,415,328 | 6,684,129,826 | 7,383,809,800 | 8,156,730,733 | 9,010,559,324 | 9,953,764,811 | 10,995,702,968 | | 13.38% |
| Phone | 88,706,552 | 144,528,663 | 235,479,049 | 383,663,567 | 625,099,064 | 1,018,467,409 | 1,659,378,367 | 2,703,607,931 | | 62.93% |
| M2M | 1,194,306 | 2,490,943 | 5,195,313 | 9,808,199 | 18,516,840 | 34,957,830 | 65,996,676 | 124,594,727 | | 101.76% |
| Total Traffic (Gb per Month) (Smartphones+Tablets+Laptops) | 413,030,514 | 642,719,470 | 872,385,884 | 1,238,463,455 | 1,864,889,422 | 2,989,174,353 | 5,083,174,029 | 9,090,642,385 | | 44.20% |
| Total Traffic (Gb per Month) | 5,579,653,413 | 6,623,689,970 | 7,817,563,024 | 9,044,299,618 | 10,705,257,992 | 13,109,253,394 | 16,840,935,530 | 23,024,743,592 | | 17.47% |
| **3.1 Total Traffic per device (Exabytes per month)** | | | | | | | | | | |
| Smartphones | 0.03 | 0.05 | 0.09 | 0.14 | 0.23 | 0.36 | 0.57 | 0.91 | | 69.25% |
| Tablets (Model) | 0.04 | 0.09 | 0.18 | 0.36 | 0.74 | 1.51 | 3.07 | 6.26 | | 103.84% |
| Laptop (Model) | 0.31 | 0.46 | 0.54 | 0.65 | 0.77 | 0.92 | 1.09 | 1.30 | | 27.51% |
| Portable Gaming Console (Model) | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.10 | | 41.15% |
| PC | 4.72 | 5.42 | 6.23 | 6.88 | 7.60 | 8.39 | 9.27 | 10.24 | | 13.38% |
| Phone | 0.08 | 0.13 | 0.22 | 0.36 | 0.58 | 0.95 | 1.55 | 2.52 | | 62.93% |
| M2M (Model) | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.06 | 0.12 | | 101.76% |
| Total Traffic (Exabytes per Month) (Smartphones+Tablets) | 0.07 | 0.14 | 0.27 | 0.51 | 0.97 | 1.87 | 3.64 | 7.17 | | 91.21% |
| Total Traffic (Exabytes per Month) (Smartphones+Tablets+Laptops) | 0.38 | 0.60 | 0.81 | 1.15 | 1.74 | 2.78 | 4.73 | 8.47 | | 44.20% |
| Total Traffic (Exabytes per Month) | 5.20 | 6.17 | 7.28 | 8.42 | 9.97 | 12.21 | 15.68 | 21.44 | | 17.47% |
| Total Trafifc (CISCO) | 4.84 | 5.64 | 6.62 | 7.60 | 8.92 | 10.85 | 13.89 | 19.02 | | 16.18% |
| Mobile devices like smartphones or tablets (CISCO) | 0.11 | 0.21 | 0.39 | 0.75 | 1.41 | 2.68 | 5.09 | 9.65 | CISCO | 89.67% |
| **4. Percent Wi-Fi Offloading** | | | | | | | | | | |
| Smartphones | 57.11% | 58.05% | 59.00% | 59.97% | 60.95% | 61.95% | 62.97% | 64.00% | CISCO | 1.64% |
| Tablets | 76.60% | 76.80% | 77% | 77% | 77% | 78% | 78% | 78% | CISCO | 0.26% |
| Laptop | 41.03% | 43.91% | 47.00% | 50.30% | 53.84% | 57.62% | 61.67% | 66.00% | TAS | 7.03% |
| Average | 41.03% | 43.91% | 47% | 50% | 54% | 58% | 62% | 66% | CISCO | 7.03% |
| **5. Total Wi-Fi Traffic per device (Exabytes per month)** | | | | | | | | | | |
| Smartphones | 0.02 | 0.03 | 0.05 | 0.08 | 0.13 | 0.21 | 0.34 | 0.54 | | 69.25% |
| Tablets | 0.03 | 0.07 | 0.14 | 0.28 | 0.57 | 1.16 | 2.37 | 4.82 | | 103.84% |
| Laptop | 0.15 | 0.22 | 0.26 | 0.30 | 0.36 | 0.43 | 0.51 | 0.61 | | 27.51% |
| Total Wi-Fi (Exabytes per month) | 0.20 | 0.31 | 0.45 | 0.67 | 1.07 | 1.80 | 3.22 | 5.97 | | 50.20% |
| No cost Wi FI (%) | 4.32% | 4.32% | 4.32% | 4.32% | 4.32% | 4.32% | 4.32% | 4.32% | | |
| No cost Wi Fi (Exabytes per month) | 0.01 | 0.01 | 0.02 | 0.03 | 0.05 | 0.08 | 0.14 | 0.26 | | 50.20% |
| No cost WI Fi (Exabytes per Year) | 0.10 | 0.16 | 0.23 | 0.35 | 0.55 | 0.94 | 1.67 | 3.10 | | 50.20% |
| No cost Wi Fi (Million Gb Per year) | 109.83 | 174.74 | 248.46 | 372.12 | 593.40 | 1004.71 | 1790.87 | 3323.38 | | 50.20% |
| **6. Pricing per Gb** | | | | | | | | | | |
| ATT | $ 10.00 | $ 10.00 | $ 10.00 | $ 10.00 | | | | | | |
| Verizon | $ 10.81 | $ 9.62 | $ 8.37 | $ 7.10 | $ 6.57 | $ 6.24 | $ 5.96 | $ 5.74 | | |
| Sprint | $ 10.15 | $ 9.03 | $ 7.86 | $ 6.67 | | | | | | |
| t-Mobile | $ 10.15 | $ 9.03 | $ 7.86 | $ 6.67 | | | | | | |
| Verizon (Price Evolution) | 12.36% | 14.89% | 17.95% | | | | | | | |
| Average price per Gb | $ 10.28 | $ 9.42 | $ 8.52 | $ 7.61 | $ 7.05 | $ 6.68 | $ 6.39 | $ 6.15 | | |
| Average cost of Wi-Fi provision | $ 2.50 | $ 2.50 | $ 2.50 | $ 2.50 | $ 2.50 | $ 2.50 | $ 2.50 | $ 2.50 | | |
| **7. Economic Impact of Free Wi Fi** | | | | | | | | | | |
| Economic impact (Million USD per year) | 854.19 | 1,209.51 | 1,496.87 | 1,900.86 | 2,697.07 | 4,201.96 | 6,966.73 | 12,121.72 | | 30.56% |

## C. Return to Speed

| 1. Mobile/Wi-Fi Traffic | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | SOURCE |
|---|---|---|---|---|---|---|---|
| Average Mobile Connection Speed (Mbps) | 2.41 | 3.43 | 4.88 | 6.94 | 9.87 | 14.05 | CISCO |
| Wi-Fi Speeds from Mobile Device (Mbps) | 11.50 | 13.32 | 15.43 | 17.88 | 20.72 | 24.00 | CISCO |
| Speed Gap Wi -Fi vs Mobile (Mbps) | 9.09 | 9.89 | 10.56 | 10.94 | 10.84 | 9.95 | TAS |
| Average Speed (Mbps) | 8.68 | 10.15 | 12.09 | 14.60 | 17.75 | 21.60 | TAS |
| Mobile Traffic (Exabytes per month) | 0.20 | 0.32 | 0.49 | 0.77 | 1.21 | 1.90 | #REF! |
| Total Wi-Fi (Exabytes per month) | 0.45 | 0.67 | 1.07 | 1.80 | 3.22 | 5.97 | TAS |
| Total Traffic (Exabytes per month) | 0.65 | 0.98 | 1.56 | 2.58 | 4.43 | 7.87 | TAS |
| Mobile Traffic (Exabytes per year) | 2.41 | 3.78 | 5.93 | 9.29 | 14.55 | 22.80 | TAS |
| Total Wi-Fi (Exabytes per year) | 5.35 | 8.02 | 12.78 | 21.65 | 38.58 | 71.60 | TAS |
| Total Traffic (Exabytes per month) | 7.77 | 11.80 | 18.71 | 30.93 | 53.13 | 94.40 | TAS |
| **2. Economic Impact of Wi-Fi Speed** | | | | | | | |
| Speed Wi-Fi over Mobile Speed (Mbps) | 9.09 | 9.89 | 10.56 | 10.94 | 10.84 | 9.95 | TAS |
| Speed decrease (%) | -72.21% | -66.21% | -59.65% | -52.45% | -44.36% | -34.96% | TAS |
| Wi-Fi Traffic (% Total Traffic) | 6.74% | 8.79% | 11.95% | 16.63% | 23.15% | 31.37% | TAS |
| Coefficient of Bohlin | 0.30% | Growth in GDP per capita | | | | | |
| Decrease in GDP Per Capita | -0.22% | -0.20% | -0.18% | -0.16% | -0.13% | -0.10% | TAS |
| GDP Per Capita (Current Prices) | 49,922.11 | 51,248.21 | 53,327.98 | 55,837.31 | 58,436.31 | 61,133.84 | USA BUREAU |
| Population | 313,579,434 | 316,208,509 | 318,777,991 | 321,316,861 | 323,855,320 | 326,408,880 | USA BUREAU |
| GDP Reduction (Current Prices) | -2,284,207,081 | -2,830,964,976 | -3,634,031,416 | -4,694,544,449 | -5,831,419,302 | -6,565,326,374 | TAS |

# D. Residential Wi-Fi

| Total Traffic per Month | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| Smartphones | 31,723,574 | 55,448,934 | 96,917,969 | 153,796,072 | 244,054,142 | 387,281,830 | 614,565,337 | 975,234,375 |
| Portable Gaming Console | 10,154,567 | 14,535,566 | 20,372,953 | 28,554,596 | 40,021,933 | 56,094,477 | 78,621,647 | 110,195,581 |
| Tablets | 45,985,183 | 93,735,136 | 191,067,541 | 389,467,671 | 793,881,922 | 1,618,230,608 | 3,298,563,967 | 6,723,716,751 |
| Total | 87,863,323 | 163,719,636 | 308,358,462 | 571,818,339 | 1,077,957,997 | 2,061,606,915 | 3,991,750,952 | 7,809,146,706 |

| Total Annual traffic | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| Smartphones | 380,682,884 | 665,387,212 | 1,163,015,625 | 1,845,552,861 | 2,928,649,702 | 4,647,381,961 | 7,374,784,045 | 11,702,812,500 |
| Gamning Conbsoles | 121,854,802 | 174,426,788 | 244,475,433 | 342,655,155 | 480,263,198 | 673,133,721 | 943,459,770 | 1,322,346,971 |
| Tablets | 551,822,192 | 1,124,821,635 | 2,292,810,490 | 4,673,612,048 | 9,526,583,060 | 19,418,767,297 | 39,582,767,607 | 80,684,601,007 |
| Total | 1,054,359,878 | 1,964,635,635 | 3,700,301,548 | 6,861,820,064 | 12,935,495,960 | 24,739,282,979 | 47,901,011,421 | 93,709,760,478 |

Split per location

| Location | Hours | |
|---|---|---|
| Home | 2.6 | 43.1% |
| Friend's home | 0.35 | 5.8% |
| At work | 0.8 | 13.3% |
| At work remote location | 0.4 | 6.6% |
| Retail location (stores, restaurants) | 0.38 | 6.3% |
| Public location (parks, schools) | 0.45 | 7.5% |
| Travel locations | 0.45 | 7.5% |
| On The Go | 0.6 | 10.0% |
| | 6.03 | |

| Total Annual Trafffic at Home | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| Smartphones | 164,141,874 | 286,899,959 | 501,466,107 | 795,760,769 | 1,262,767,699 | 2,003,846,285 | 3,179,840,550 | 5,045,988,806 |
| Gamning Conbsoles | 52,541,042 | 75,208,897 | 105,412,293 | 147,745,175 | 207,078,659 | 290,240,079 | 406,798,574 | 570,166,190 |
| Tablets | 237,933,283 | 484,997,720 | 988,608,172 | 2,015,156,107 | 4,107,647,754 | 8,372,934,490 | 17,067,196,646 | 34,789,380,202 |
| Total | 454,616,199 | 847,106,576 | 1,595,486,571 | 2,958,662,051 | 5,577,494,112 | 10,667,020,853 | 20,653,835,770 | 40,405,535,198 |

| Average Price per Gb | $10.28 | $9.42 | $8.52 | $7.61 | $7.05 | $6.68 | $6.39 | $6.15 |
|---|---|---|---|---|---|---|---|---|

| Price per home traffic | $ 4,672,296,843 | $ 7,981,379,757 | $ 13,600,954,551 | $ 22,509,870,715 | $ 39,293,937,014 | $ 71,279,887,723 | $ 131,980,574,122 | $ 248,389,076,544 |
|---|---|---|---|---|---|---|---|---|