

How to Allocate New Spectrum Among Alternative Uses

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I. INTRODUCTION

Deciding how to allocate commercial radio spectrum among a myriad of competing interests are among the most consequential choices in telecommunications policy, yet economic analysis plays a surprisingly limited role in these decisions.¹ Spectrum policy debates are instead dominated by industry advocacy emphasizing auction revenue potential, imbalances in spectrum allocations among competing uses, international spectrum allocation comparisons claiming the United States “lags behind” other nations (particularly China), and fantastical claims about transformative economic benefits.² Yet, the proper allocation of newly available spectrum has almost nothing to do with this sort of advocacy.

In this paper, we present clear principles for optimal resource allocation that should help policymakers make better spectrum allocation choices. To do so, we contemplate the allocation of a new block of spectrum between two competing uses (*e.g.*, licensed mobile wireless and unlicensed Wi-Fi). There are, of course, other licensing models, including shared licensed spectrum, and our findings would translate directly to those other models. As might be expected, spectrum resources should be allocated to uses that generate the highest marginal social value. This marginal social value need not bear any relationship to the sorts of pedantic advocacy we typically see in spectrum allocation debates. Moreover, while alternative spectrum licensing arrangements (*e.g.*, licensed versus unlicensed) are typically treated as rivals, they are often complements. Most data on a 5G home fixed wireless service, for example, originates and terminates over Wi-Fi, so an increase in spectrum allocated to 5G might require a contemporaneous increase in the allocation of spectrum for Wi-Fi services. In all, about 90% of traffic on smartphones used at home (amounting to 75% of total smartphone use) is carried by Wi-Fi and about 80% of smartphone traffic *away from home* uses Wi-Fi, so Wi-Fi is

1. C.f. T. Randolph Beard, George S. Ford, Lawrence J. Spiwak and Michael Stern, *Wireless Competition Under Spectrum Exhaust*, 65 FED. COMM. L.J. 79 (2012); T. Randolph Beard, George S. Ford, Lawrence J. Spiwak, and Michael Stern, *Taxation by Condition: Spectrum Repurposing at the FCC and the Prolonging of Spectrum Exhaust*, 8 HASTINGS SCI. & TECH. L.J. 183 (2016); T. Randolph Beard, George S. Ford, Lawrence J. Spiwak and Michael Stern, *A Policy Framework for Spectrum Allocation in Mobile Communications*, 63 FED. COMM. L. J. 639 (2011); T. Randolph Beard, George S. Ford, Lawrence J. Spiwak and Michael Stern, *Market Mechanisms and the Efficient Use and Management of Scarce Spectrum Resources*, 66 FED. COMM. L. J. 263 (2014).

2. Recent empirical evidence suggests these promises have been significantly overstated. George S. Ford, *The 5G Promise Falls Short of Reality: Examining Economic Impact Claims*, PHOENIX CTR. POL'Y PERSPECTIVE No. 25-03 (May 28, 2025).

vital to wireless communication even over smartphones that use exclusively-licensed spectrum.³

We do not attempt to quantify the relevant margins, which will require a rich mix of engineering and economic considerations, and perhaps other concerns. We do explain, however, what sort of factors are irrelevant to the decision. Certainly more work on this issue is required, and we hope this analysis will help guide such efforts.

II. SPECTRUM ALLOCATION

Allocating spectrum for commercial use is a challenging task with myriad engineering concerns, interference problems, global coordination, consumer demand considerations, and competing corporate interests. This complexity may, in part, explain why spectrum advocacy attempts to focus the debate on politically-charged rhetoric rather than upon genuine concerns.

One virtue of economics is that it is often able to tell us important things even when the specifics of the problem under consideration are debatable. We exploit this facility here by analyzing a spectrum allocation decision in the simplest of cases: there is a hypothetical block of spectrum that policymakers must allocate between two uses, licensed mobile wireless service (m) and unlicensed Wi-Fi services (w). Our purpose is to highlight the basic issues involved in doing this efficiently—*i.e.*, to the greatest benefit of society. Let S denote the total available spectrum and let S_m and S_w denote the amount allocated to the two services (mobile and Wi-Fi) respectively. Hence, society faces the following endowment constraint related to scarce spectrum:

$$S_m + S_w = S. \quad (1)$$

We presume that the allocated spectrum can be used to produce mobile and Wi-Fi data services with their demands denoted by D_m and D_w . Let $f(S_m)$ and $g(S_w)$ denote the production functions whereby spectrum is used to produce mobile and Wi-Fi data services.

3. Rupert Bapty, Andrey Popov, and Francesco Rizzato, *Wi-Fi Drives Smartphone Data Consumption in the US, but Trends Vary Across Operators*, OPENSIGNAL (Oct. 31, 2024), https://www.opensignal.com/2024/10/31/wi-fi-drives-smartphone-data-consumption-in-the-us-but-trends-vary-across-operators?_ga=2.145110452.1696707333.1748359883-370070466.1745866310; Claus Hetting, *Bombshell Report: Mobile Data Consumption Over Wi-Fi Closes in on 90% in the US*, WIFINOW (Nov. 1, 2024), <https://wifinowglobal.com/news-blog/bombshell-report-mobile-data-consumption-over-wi-fi-closes-in-on-90-in-the-us/#:~:text=Wi%2DFi's%20share%20of%20data,Above%20graphic%20courtesy%20OPENSIGNAL;WiFi%20Dominates%20Android%20Mobile%20Data%20Usage>, USTELECOM (Jan. 13, 2017), <https://ustelecom.org/wifi-dominates-android-mobile-data-usage> [<https://perma.cc/44XF-SJRX>]; *What Drives Data Usage?*, NIELSEN (Nov. 2016), <https://www.nielsen.com/insights/2016/what-drives-data-usage> [<https://perma.cc/DCA5-88KF>].

Consumers are presumed to derive utility, denoted by $U(D_m, D_w)$, from the consumption of these data services. (We aggregate all consumers together for simplicity.) A society that wishes to use its spectrum resources efficiently faces the following constrained optimization problem:

$$\max_{S_m, S_w} \{U(D_m, D_w)\}, \text{ such that,} \quad (2)$$

$$D_m = f(S_m), \quad D_w = g(S_w), \quad \text{and } S_m + S_w = S. \quad (3)$$

This constrained optimization problem defines the optimal allocation of spectrum to mobile and Wi-Fi, denoted- by S_m^* and S_w^* , as functions of the total available spectrum (S). This optimal allocation will depend on both the productivity of spectrum in its two applications as well as the social value of mobile and Wi-Fi services.

Any interior optimal allocation must satisfy the following two first-order necessary conditions:

$$\frac{\partial U}{\partial D_w} g'(S_w^*) = \frac{\partial U}{\partial D_m} f'(S_m^*), \quad (4)$$

$$S_m^* + S_w^* = S. \quad (5)$$

In Condition (4), the left-hand side represents the marginal social benefit of allocating one more unit of spectrum to Wi-Fi services and the right side represents the marginal social benefit of allocating one more unit to mobile wireless services.⁴ The marginal social benefit of a service is generally composed of two elements: the marginal utility of additional service ($\partial U/\partial D_i$) and the marginal productivity of allocated spectrum (g' and f'). Condition (4) reminds us of the correct principles for allocating scarce spectrum—when society is operating at an efficient optimum, if a very small bit of additional spectrum becomes available, then society should be indifferent between the use to which it was put because, at the margin, each application should generate equal benefits.

From a practical perspective, there are (at least) two things worth observing about the optimal condition. First, it is worth considering what is *not* in Condition (4):

Excluded from Condition (4) is how much spectrum has, in the past, been allocated to the two services. The optimality condition *does not require equal spectrum allocation*, but rather an allocation that *equalizes marginal*

4. Wi-Fi spectrum, being unlicensed, permits a wide range of uses beyond the standard Wi-Fi networks that connects homes, businesses, and public areas to the internet. The freedom to innovate in the spectrum bands, unlike licensed spectrum where innovation is limited to the choices of few providers, is a source of value.

social benefits. Yet, comparing the “stock” of spectrum among services is frequently mentioned in the mobile wireless industry’s advocacy. For instance, an Accenture study (Commissioned by CTIA) on spectrum observes that “unlicensed spectrum users have access to over 7x” the amount of licensed mid-band spectrum.⁵ But such “they have more than me” and “it’s my turn” arguments are irrelevant to optimal spectrum allocation;

it is the marginal benefits among services and not the present stock of spectrum that is important.

Excluded from Condition (4) is the amount of spectrum allocated to mobile wireless services in China. But, again, the “5G race with China,” whatever that is, is frequently mentioned in spectrum allocation debates.⁶ Mobile wireless services provided on Chinese networks cannot be purchased in the United States.

Excluded from Condition (4) is any term regarding how many jobs would be created if 100 MHz of spectrum was allocated to mobile wireless services. Yet, once more, this is the sort of “evidence” presented to policymakers by the mobile wireless industry regarding spectrum allocation decisions.⁷

Excluded from Condition (4) is the amount of auction revenue raised by auctioning spectrum, though the potential for auction revenues is commonly used in spectrum allocation debates.⁸ Certainly, the U.S. Government needs revenue to cover its prolific spending, but using spectrum auctions to obtain it is not relevant to the optimal allocation decision. Auctions may, however, do better than other mechanisms in sorting out where the marginal benefits are larger for licensed spectrum (though not unlicensed spectrum, which is not auctioned), at least for that portion of benefits that can be captured by providers (which is less than the total social benefit).

Second, while the marginal benefits are equal at the margin in the optimal state, for the current allocation there is no reason to expect that the marginal benefits are equal. If they are not equal, then society could benefit

5. *Spectrum Allocation in the United States*, ACCENTURE (COMMISSIONED BY CTIA) (Sept. 2022), <https://www.ctia.org/news/spectrum-allocation-in-the-united-states> [<https://perma.cc/A2NE-CMLK>].

6. *Licensed, Mid-band Spectrum Needed to Keep Pace with China*, CTIA (last visited May 28, 2025), <https://api.ctia.org/wp-content/uploads/2023/09/Licensed-Mid-band-Spectrum-Needed-to-Keep-Pace-with-China-1.pdf> [<https://perma.cc/3UVF-PPAM>].

7. *The Economic Impact of Each Additional 100 MHz of Mid-band Spectrum for Mobile*, NERA (COMMISSION BY CTIA) (Jan. 2023), <https://www.ctia.org/news/the-economic-impact-of-each-additional-100-mhz-of-mid-band-spectrum-for-mobile> [<https://perma.cc/3M4K-RF8S>].

8. Meredith Atwell-Baker, *#RestoreAuctionAuthoritywithaSpectrumPipeline*, CTIA BLOG (Mar. 8, 2024), <https://www.ctia.org/news/restoreauctionauthority-with-a-spectrum-pipeline> [<https://perma.cc/F3VG-F9P9>].

by increasing the amount of spectrum allocated to the service with the higher-value marginal use. In doing so, the marginal benefit of the higher-value use declines (due to diminishing marginal returns) so the marginal benefits move closer together. If there is a large block of new spectrum to be allocated, or else the margins are very sensitive to even small amounts of additional spectrum, then both service types might receive some portions of the large block of spectrum to approach the optimal condition. If one use always produces lower social benefits than the other then, even if these benefits are positive, that use should not be awarded any spectrum.

We may push this reasoning a bit further. Say that use i has sufficient spectrum to meet all current and forecast demand. In this scenario, the marginal benefit of allocating more spectrum to service i is zero ($\partial U/\partial D_i = 0$), and it is pointless to allocate more spectrum to service i . Or, if service i has insufficient spectrum to meet current or expected demand, then the marginal benefit from additional spectrum is presumably large. If both services are spectrum constrained, then the allocation requires a balancing act. Robust evidence on spectrum exhaustion, therefore, is probative and affects policy choices.⁹ At present, both the mobile wireless industry and Wi-Fi analysts claim the capacity of the services are constrained by a lack of spectrum, so the engineers need to determine where the need is greatest.¹⁰ Of course, if one use of spectrum has no social value, then all the spectrum should be used in the productive sector regardless.

III. BALANCING SPECTRUM ALLOCATION

This logic can be generalized if we interpret the analysis as the problem of considering how an *increase* in available spectrum should be used or

9. See Ford, *Wireless Competition Under Spectrum Exhaust*, supra note 1; George S. Ford, *Have We Got It All Wrong? Forecasting Mobile Data Use and Spectrum Exhaust*, PHOENIX CTR. POL'Y PERSPECTIVE No. 14-06 (Oct. 21, 2014) <https://www.phoenix-center.org/perspectives/Perspective14-06Final.pdf> [<https://perma.cc/3QWY-W8H8>]; J.Pierre De Vries, Ljiljana Simic, Andreas Achtzehn, Marine Petrova, and Petri Mahonen, *The Wi-Fi "Congestion Crisis": Regulatory Criteria for Assessing Spectrum Congestion Claims*, 38 TELECOMM. POL'Y 838-580 (2014).

10. See, e.g., Coleman Bazelon, Paroma Sanyal, and Preetul Sen, *Assessing Wi-Fi Exhaustion and Shortfalls in Wi-Fi Capacity*, BRATTLE (Apr. 30, 2025), <https://wififorward.org/wp-content/uploads/2025/05/Assessing-Wi-Fi-Exhaustion-and-Shortfalls-in-Wi-Fi-Capacity.pdf> [<https://perma.cc/QF4L-BNLZ>]; Mark Walker, *Wi-Fi Spectrum: 6 GHz Use Is Surging and Headed Toward Exhaustion*, CABLELABS (May 20, 2025), <https://www.cablelabs.com/blog/wi-fi-spectrum-6-ghz-use-surfing-headed-toward-exhaustion> [<https://perma.cc/LZE5-PC48>]; Claus Hetting, *Spectrum: Unlicensed Bands in Focus at US Senate Hearing on 5G*, WiFi NOW (July 30, 2018), <https://wifinowglobal.com/news-and-blog/spectrum-unlicensed-bands-in-focus-at-us-senate-hearing-on-5g>; *The Looming Spectrum Crisis*, ACCENTURE (COMMISSIONED BY CTIA) (2025), <https://api.ctia.org/wp-content/uploads/2025/03/Looming-Spectrum-Crisis-Accenture.pdf> [<https://perma.cc/6ZMW-ENLF>]; William Webb, *It's Time to Rethink 6G*, IEEE SPECTRUM (Feb. 10, 2025), <https://spectrum.ieee.org/6g-bandwidth> [<https://perma.cc/593G-YNDJ>]; *The Evolution of 5G Spectrum*, 5G AMERICAS (Jan. 2024), <https://www.5gamericas.org/wp-content/uploads/2024/01/WP-Evolution-of-5G-Spectrum-1.pdf> [<https://perma.cc/WC38-GZ82>].

“shared” between competing applications. In this generalization, the historic allocation of spectrum between uses affects both the production possibilities and the social value derived from the “additional” distribution of S . This analytical construct highlights an important fact: when advocates for one or another plan for allocating newly available frequencies speak about existing spectrum allocations, their arguments are relevant only if they establish why these historic patterns of usage affect current social values and production opportunities.

The analysis supports a further, conditional conclusion. Differentiating these equations with respect to the total available spectrum (S), and collecting and rearranging terms, yields

$$[U''_{wm}f'g' - U''_{ww}g'g' - U'_wg''] \frac{dS_w^*}{dS} = [U''_{wm}f'g' - U''_{mm}ff' - U'_mf''] \frac{dS_m^*}{dS}, \quad (6)$$

and,

$$\frac{dS_m^*}{dS} = 1 - \frac{dS_w^*}{dS}. \quad (7)$$

Solving for the derivative of the optimal spectrum allocation for Wi-Fi yields the expression:

$$\frac{dS_w^*}{dS} = \frac{[U''_{wm}f'g' - U''_{mm}ff' - U'_mf'']}{[U''_{wm}f'g' - U''_{ww}g'g' - U'_wg''] + [U''_{wm}f'g' - U''_{mm}ff' - U'_mf'']}. \quad (8)$$

It is a standard assumption that production of data services is strictly increasing in allocated spectrum yet there is a (weakly) diminishing return. Moreover, consumer utility almost always has a diminishing margin. Hence, in terms of the signs of derivatives we surely have:

$$f' > 0, g' > 0, f'' \leq 0, g'' \leq 0 \text{ and } U'_m > 0, U'_w > 0, U''_{mm} < 0, U''_{ww} < 0.$$

The one remaining term in the expression for dS_w^*/dS is the cross-partial derivative U''_{wm} . The sign of this partial derivative represents the impact of an increase in mobile data services on the marginal utility from Wi-Fi. Given that most consumers have many Wi-Fi enabled devices that they wish to distribute data across given the acquisition of such data from either mobile or fixed networks, we can generally expect a complementary effect. As mentioned above, recent evidence indicates that about 90% of traffic on smartphones used at home is carried by Wi-Fi and about 80% of smartphone traffic away from home uses Wi-Fi.¹¹ Hence, U''_{wm} would be

11. Bapty, et al., supra note 3.

positive—Wi-Fi service is a complement to mobile service. We can thus determine that both the numerator and denominators are positive in the expression for dS_w^* / dS . The resulting conclusion is that an increase in available spectrum would increase the optimal social allocation of spectrum to Wi-Fi:

$$\frac{dS_w^*}{dS} > 0. \quad (9)$$

Inequality (9) is important and is the most direct and implementable result of this analysis. It can be rendered simply as: when society is efficiently allocating available spectrum, ordinary diminishing returns in consumption and production of data services, combined with complementarity between those services, implies that both uses will receive a share of any additional spectrum. It is generally not socially efficient to allocate all newly available spectrum to one application or the other when the services are complements. Since that appears to be the case with mobile and Wi-Fi, when new spectrum is allocated some of it should be directed to unlicensed uses. Spectrum allocation need not be an either/or scenario.

IV. CONCLUSION

Radio spectrum is the lifeblood of wireless communications. Mobile wireless networks, which rely heavily on exclusive, high-power licenses, create enormous benefits for society and are constantly demanding more radio spectrum to meet their users' needs. Yet, it is Wi-Fi networks that carry the bulk of the wireless data transmissions—a ratio of 9:1 relative to mobile wireless. When spectrum is cleared for reallocation, policymakers face the challenging task of prudently allocating the resource among alternative uses, at least when the spectrum cannot be shared. We outline the broad parameters of that decision here. While the analysis is somewhat technical, the findings are simple. What matters is how much benefit is created—at the margin—when spectrum is assigned to one use or another. If one service creates more value than another for some small increment of spectrum, then the spectrum should be put to that higher-valued use. When large increments are involved, there may be some balancing act in the allocations, especially when alternative uses are complementary, such as the relationship between mobile and Wi-Fi networks.

A key finding of this analysis is that much of the advocacy directed at the issue is utterly irrelevant. The shares of spectrum already assigned to different uses, what China is doing, how many jobs are created by one use or another are all irrelevant. How much auction revenue is generated is *nearly* irrelevant though it can help, to some extent, expose where the marginal and extractable benefits are greatest. However, the unlicensed nature of Wi-Fi

spectrum and the transactions cost of organizing users weakens the relevance of auction revenues.

Certainly, we cannot claim that the proper allocation of newly available spectrum is an easy task—the analysis here is theoretical and it is not obvious exactly how the relevant marginal benefits can be measured. Policymakers must condense many considerations into a choice, including engineering concerns, global spectrum practices, economic value, and perhaps many other factors. Still, the policy choice should be based on the relevant factors measured as accurately as feasible. Perfection need not be the enemy of good, but advocacy that is extraneous to the genuine concerns should be ignored.

