OVERESTIMATING WIRELESS DEMAND: POLICY AND INVESTMENT IMPLICATIONS OF UPWARD BIAS IN MOBILE DATA FORECASTS

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I. INTRODUCTION+

A. Assumptions of a Spectrum Crunch

It is now taken almost as a matter of faith among telecommunications professionals that there is a "spectrum crunch"[1] precipitated by ever-growing demand for mobile broadband.[2] This, in turn, has driven a strong policy consen-

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1 *See, e.g.*, *Spectrum Crunch*, FCC, http://www.fcc.gov/encyclopedia/spectrum-crunch (last visited May 05, 2015).

2 This paper uses "mobile broadband" to refer to wireless data access over facilities-based mobile network operator (MNO) infrastructure. *See* FED. COMMC'NS COMM'N, ANNUAL REPORT AND ANALYSIS OF COMPETITIVE MARKET CONDITIONS WITH RESPECT TO MOBILE

sus among industry and policymakers for the U.S. federal government to actively make available to mobile network operators (MNOs) vast new swathes of spectral resources via exclusive-use licenses.[3] In the National Broadband Plan, for example, the Federal Communications Commission (FCC) argued that "[t]he growth of wireless broadband will be constrained if government does not make spectrum available to enable network expansion and technology upgrades."[4] The White House has taken up this cause as well, issuing a memorandum calling for 500 MHz of new spectrum to be made available for mobile and wireless broadband by 2020[5] and making new spectrum resources central to policies supporting "everything from smart phones to wireless broadband connectivity for laptops to new forms of machine-to-machine communication within a decade."[6] Similar efforts to free up spectrum for mobile broadband are taking place across the globe.[7]

It is indisputable that mobile connectivity, driven by new technological developments in materials, miniaturization, and computing, has increased dramatically around the world and radically transformed economic and social life.[8] Both mobile subscriptions and the amount of data traversing mobile networks has increased substantially in the past several years; by the end of 2014,

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WIRELESS, INCLUDING COMMERCIAL MOBILE SERVICES 39, 42 (2013), *available at* https://apps.fcc.gov/edocs_public/attachmatch/FCC-13-34A1.pdf.

3 *See* FED. COMMC'NS COMM'N, CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN xii (2010), *available at* http://download.broadband.gov/plan/national-broadband-plan.pdf.

4 *See id*. at 77.

5 *See* The White House, Memorandum from the White House on Unleashing the Wireless Broadband Revolution, for the Heads of Executive Departments and Agencies (2010), *available at* http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution. These are based on FCC recommendations. Fed. Commc'ns Comm'n, *supra* note 3, at 84.

6 Office of the Press Sec'y, *President Obama Details Plan to Win the Future through Expanded Wireless Access*, THE WHITE HOUSE (Feb. 10, 2011), http://www.whitehouse.gov/the-press-office/2011/02/10/president-obama-details-plan-win-future-through-expanded-wireless-access.

7 *See* Frank Swain, *Will We Ever... Face a Wireless 'Spectrum Crunch'?*, BBC (Oct. 15, 2013), http://www.bbc.com/future/story/20131014-are-we-headed-for-wireless-chaos (noting that "[m]any governments, then, are looking for ways to alleviate the [spectrum crunch] problem before the wireless signal to our electronic devices starts failing. So far, the principle strategy has been to find more spectrum").

8 *See* DELOITTE, WHAT IS THE IMPACT OF MOBILE TELEPHONY ON ECONOMIC GROWTH? A REPORT FOR THE GSM ASSOCIATION 2 (2012), *available at* http://www.gsma.com/publicpolicy/wp-content/uploads/2012/11/gsma-deloitte-impact-mobile-telephony-economic-growth.pdf; MANUEL CASTELLS ET AL., THE MOBILE COMMUNICATION SOCIETY: A CROSS-CULTURAL ANALYSIS OF AVAILABLE EVIDENCE ON THE SOCIAL USES OF WIRELESS COMMUNICATION TECHNOLOGY 238-249 (2004), *available at* http://hack.tion.free.fr/textes/MobileCommunicationSociety.pdf.

there were an estimated 2.3 billion mobile broadband subscriptions globally, almost five times as many as in 2008.[9]

At the same time, decisions about spectrum should not and cannot be made lightly due to the physically limited nature of spectrum and the corresponding strong public interest in efficient spectrum allocation.[10] Regulators must consider social, equity, public safety, environmental, and other factors in addition to economic impacts when determining whether and how to repurpose spectrum. Furthermore, freeing up "new" spectrum is only one of several mechanisms for dealing with increasing mobile demand, and exclusive-use licenses are one among many different management options for spectrum bands.[11] Although conventional spectrum wisdom highlights making new exclusive-use allocations available to MNOs, this may not be the most efficient or socially beneficial decision in all cases. It is exactly these kinds of concerns that led to calls in the National Broadband Plan for the U.S. government to make spectrum allocation and licensing data more accessible, as the "complexity of the [existing] system and the resulting lack of transparency and usability create impediments to public policy and limit the emergence of new technologies that could employ such data to optimize use of the spectrum automatically."[12]

In this paper, we examine the provenance, reliability, and uses of mobile demand forecasts and find that several highly visible spectrum demand estimates over the past several years have exceeded actual traffic, which may have biased spectrum allocation decisions and policies in socially suboptimal ways.[13] These reports include Cisco Visual Networking Index (VNI) esti-

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9 INT'L TELECOMM. UNION, THE WORLD IN 2014: ICT FACTS AND FIGURES (2014), *available at* http://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2014-e.pdf (charting growth from 2007 to 2014 of mobile broadband and all mobile subscriptions, respectively).

10 *See* Nat'l Broad. Co. v. United States*,* 319 U.S. 190 (1943) (noting "certain basic facts about radio as a means of communication—its facilities are limited; they are not available to all who may wish to use them; the radio spectrum simply is not large enough to accommodate everybody").

11 *See* Jon M. Peha, *Sharing Spectrum Through Spectrum Policy Reform and Cognitive Radio,* 97 Proc. of the IEEE 708, 710-16 (2009); Fed. Commc'ns Comm'n, Spectrum Policy Task Force, Report of the Spectrum Rights and Responsibilities Working Group 2 (2002) *available at* http://webcache.googleusercontent.com/search?q=cache:3Vmxfxyxo4wJ:www.fcc.gov/sptf/files/SRRWGFinalReport.doc+&cd=5&hl=en&ct=clnk&gl=us (describing alternative models).

12 Fed. Commc'ns Comm'n, *supra* note 3, at 80.

13 George S. Ford correctly points out that data "demand," in its economic sense, is difficult or impossible to measure directly and will always be higher than actual traffic due to carrier adjustments in the face of spectral congestion, including changes in pricing or technology. *See* George S. Ford, *Have We Got it All Wrong? Forecasting Mobile Data Use and Spectrum Exhaust*, PHOENIX CENTER FOR ADVANCED LEGAL & ECON. PUB. POL'Y STUD.

mates,[14] which are commonly cited in government and industry reports, including the National Broadband Plan, as well as estimates endorsed in ITU's WRC-07. We explore potential technological, economic, and sociological factors that may drive these biases, as well as possible solutions and policy remedies. This paper is not meant to imply any deliberate misrepresentation from any party, although this is certainly possible when billions of dollars are at stake, as with spectrum policy. Rather, the paper investigates various potential sources of bias and methods to mitigate such risks, in the hopes that it might inform businesses, regulators, and the general public about how to better allocate and manage finite spectrum resources.

Neither does this analysis imply that making any new, exclusive-use available for mobile broadband is the suboptimal policy decision. In the near future, such reallocations provide benefits to both MNOs and the general public through deficit reduction and economic multipliers.[15] Rather, it suggests additional caution and scrutiny are warranted for long-term spectrum policy decisions, rather than a blind faith about ever-increasing mobile data demand. In these cases, especially, policymakers should push for new, higher quality data before committing to long-term policies as well as favor flexibility and reversibility in their decision-making.

B. The Importance of Data Provenance in Policy: Lessons from Intellectual Property Debates

The issue of unreliable data taking "a life of its own" is not just a theoretical one.[16] The history of intellectual property policy in the United States provides one telling example of how data with uncertain provenance can become well-

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2 (Oct. 21, 2014), http://www.phoenix-center.org/perspectives/Perspective14-06Final.pdf. As argued in greater detail later, in this paper we typically interpret mobile demand forecasts as forecasts of actual data traffic, since these forecasts typically incorporate supply-side and pricing adjustments into their calculations.

14 *See* CISCO, CISCO VISUAL NETWORKING INDEX: GLOBAL MOBILE DATA TRAFFIC FORECAST UPDATE 2014-2019 (2015), *available at* http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf.

15 Office of the Press Sec'y, *Fact Sheet: Doubling the Amount of Commercial Spectrum to Unleash the Innovative Potential of Wireless Broadband,* THE WHITE HOUSE (June 28, 2010), http://www.whitehouse.gov/the-press-office/fact-sheet-doubling-amount-commercial-spectrum-unleash-innovative-potential-wireless.

16 *See, e.g.*, Julian Sanchez, *750,000 Lost Jobs? The Dodgy Digits Behind the War in Piracy,* ARS TECHNICA (Oct. 8, 2008, 11:30 PM), http://arstechnica.com/tech-policy/2008/10/dodgy-digits-behind-the-war-on-piracy (describing the misrepresentation of job numbers lost to piracy stemming from unreliable data).

established, and then exert an influence on policy.[17] In particular, for much of the prior decade, advocates of strong IP protections emphasized data claiming that 750,000 U.S. jobs have been lost to IP theft and that IP infringement cost the U.S. economy $200 to $250 billion each year.[18] These figures were then routinely cited by the U.S. Customs & Border Patrol (CPB), Federal Bureau of Investigation (FBI), and Federal Trade Commission (FTC),[19] even though investigative analysis revealed that there was "no good reason to think that either [figure] is remotely reliable."[20] Yet such figures, bolstered in part by industry groups that had a vested financial interest in claiming significant losses, became a primary input into calls for legislation strengthening intellectual property rights.[21] Although it is impossible to precisely trace the impact of these figures on the strong IP protections passed or proposed in recent years, the numbers were repeatedly cited in IP policy debates, including, for example, around the PRO-IP Act,[22] which was passed in 2008.[23]

The history of these numbers provides four important lessons regarding the origin and use of empirical analysis in policy debates. First, a source that is unreliable or only partially addresses a specific issue can become a "reliable" fact if it is repeated enough and its origin becomes obfuscated.[24] More precisely, over time, such data gain reliability when qualifiers and nuance that accompanied the original reports are dropped, as well as by association with large, well-known organizations that lend the figures their institutional credibility.[25] For example, the 750,000 job-loss figure was originally the upper end of a broad estimate, but over time that range, and even the "up to," qualifier, disappeared.[26] Both figures were commonly referenced by industry and government sources in part because of their use by credible government agencies.[27] Second, industry groups and associations, to the extent that skewed numbers might provide financial gains or policy leverage, can assist this process by repeating

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17 *Id.*

18 *Id.*

19 U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-10-423, OBSERVATIONS ON EFFORTS TO QUANTIFY THE ECONOMIC EFFECTS OF COUNTERFEIT AND PIRATED GOODS 19 (2010).

20 Sanchez, *supra* note 16.

21 *Id.*

22 H.R. 4279, 110th Cong. (2008).

23 Prioritizing Resources and Organization for Intellectual Property Act of 2008, Pub. L. No. 110-403, 122 Stat. 425 (to be codified in scattered sections of 15 U.S.C., 17 U.S.C., and 18 U.S.C.).

24 *See* Sanchez, *supra* note 16 (describing several sources for a jobs figure that was repeated over a series of years).

25 *See id.* (stating that the jobs figure was repeated by the United States Customs and Border Patrol).

26 *Id.*

27 U.S. GOV'T ACCOUNTABILITY OFFICE, *supra* note 19, at 18.

the numbers or obscuring their origin.[28] Third, the government is willing to use data with unclear provenance in policy decisions, in part due to the ways in which unreliability becomes obscured over time.[29] And finally, once a figure becomes established, it can persist for a long time; the 750,000 figure traced back nearly a quarter-century[30] before some government sources stopped relying on it, and even then "[t]hese estimates attributed to FBI, CBP, and FTC continue to be referenced by various industry and government sources as evidence of the significance of the counterfeiting and piracy problem to the U.S. economy."[31]

The IP debate is not, nor is intended to serve, as a perfect analogy to spectrum demand forecasts. In the case of IP, estimates revolved around economic costs, not future demand.[32] Moreover, wireless demand figures are regularly and reliably updated, and there are a greater number of forecasters.[33] However, the underlying dynamics surrounding how data provenance can be obscured in policy debates contain several similarities, and we find evidence of all four of these factors in spectrum policy.

C. Spectrum Forecasts Have Been Important Determinants of National Policy

Like IP policy, in the U.S., outside data with unclear reliability have been key inputs into national spectrum policies. In the U.S., for example, spectrum forecasts are routinely cited in national policy decisions about the allocation of wireless frequencies.[34] Former Commission Chairman Julius Genachowski has referenced Cisco projections in justifying clearing 500 MHz of spectrum and

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28 *See* Sanchez, *supra* note 16 (citing both the FBI and International Anti-Counterfeiting Coalition as organizations that quote the figure).

29 *Id.*

30 *Id.*

31 U.S. GOV'T ACCOUNTABILITY OFFICE, *supra* note 19.

32 *See* Sanchez, *supra* note 16.

33 *See, e.g.*, CISCO, *supra* note 14, at 1 ("Global mobile data grew 69 percent in 2014."); *see also* ERICSSON, ERICSSON MOBILITY REPORT 3 (2014), *available at* http://www.ericsson.com/res/docs/2014/ericsson-mobility-report-november-2014.pdf (stating that "60 percent growth in mobile data traffic" for the year between Q3 2013 and Q3 2014).

34 *See In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands,* Report and Order, GN Docket No. 13-185, 29 FCC Rcd 4610, para. 3 (Mar. 31, 2014) ("The demand for spectrum…is expected to continue increasing" and the FCC is continuing to "make available additional licensed and unlicensed spectrum to meet this growing demand"); FED. COMMC'NS COMM'N, FCC STAFF TECHNICAL PAPER: MOBILE BROADBAND: THE BENEFITS OF ADDITIONAL SPECTRUM 9 Exhibit 4 (2010), *available at* http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf; FED. COMMC'NS COMM'N, *supra* note 3, at 84.

warned that "we should remember that the clock won't stop in 2020, and data demand will continue to increase."[35] As recently as August 1, 2014, FCC experts emphasized that "[c]onsumer demand is exploding, data usage is growing exponentially, and faster 4G networks enable even more data services."[36] MNOs, citing increasing demand for their services, have with great success argued that they need additional spectrum to expand and improve their networks; for example, CTIA cites both Cisco and ITU in arguing that without additional spectrum, the wireless industry will face a "crisis."[37]

Regulators face complex decisions in how to manage and allocate spectrum bands. Economists argue that the overall value to society through increased economic efficiency brought by new communication services is several multiples of the value to the spectrum license holder, as reflected in their bids for exclusive-use licenses.[38] However, in some cases, shared spectrum management plans facilitate device and application innovation that can also generate significant social and economic value. This may be the case even when access rights are open to all qualified users and are not auctioned.[39] The most notable example is the 2.4 GHz ISM band that supports significant Wi-Fi, Bluetooth, and other unlicensed uses. For certain applications—including certain types of intensive wireless data transmission—such unlicensed bands can be significantly more efficient means for wireless data transfer than potential alternatives.[40] Moreover, additional social benefits to using spectrum, such as improvements to public safety, quality of life, and national defense, are difficult

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35 Julius Genachowski, Chairman, Fed. Commc'ns Comm'n, Winning the Global Race: Opportunities and Challenges for Mobile Broadband, Address at the University of Pennsylvania – Wharton (Oct. 4, 2012), *available at* https://apps.fcc.gov/edocs_public/attachmatch/DOC-316661A1.pdf.

36 Roger C. Sherman, *Empowering Small Businesses,* OFFICIAL FCC BLOG (Aug. 1, 2014, 10:01 AM), https://www.fcc.gov/blog/empowering-small-businesses.

37 John Marinho, *It is No Trick – There is a Spectrum Crisis,* CTIA – THE WIRELESS ASS'N BLOG (Oct. 23, 2012), http://blog.ctia.org/2012/10/23/it-is-no-trick-there-is-a-spectrum-crisis.

38 *See, e.g.*, Thomas W. Hazlett & Roberto E. Munoz, *A Welfare Analysis of Spectrum Allocation Policies* 2 (George Mason Law & Econ. Research Paper Series, Working Paper No. 06-28, 2008), *available at* http://ssrn.com/abstract=908717 (arguing that total social welfare benefits produced in public spectrum auctions are dominant over auction revenues).

39 *See* PAUL MILGROM, JONATHAN LEVIN & ASSAD EILAT, THE CASE FOR UNLICENSED SPECTRUM 16-19, ¶¶ 42-49 (2011), *available at* http://siepr.stanford.edu/?q=/system/files/shared/pubs/papers/pdf/10036_Paper_Milgrom.pdf (estimating that Wi-Fi creates $25 billion in the economic value of mobile data traffic, $12 billion in the economic value of mobile data speed, and a possible $15 billion in the economic value of Wi-Fi only peripherals).

40 *See id.* at 9, ¶ 24 (2011) (noting that unlicensed Wi-Fi spectrum allows "devices to make intensive use of spectrum by reusing spectrum many times, but compared to cellular networks, its much smaller transmission radius allows much more reuse").

to quantify or allocate using market demand-based methods and require regulators to make value judgments about the importance of various services.[41] To accommodate and balance these various sources of demand, regulators rely on projections of the future types and intensity of wireless usage, among other inputs.[42]

For these reasons, when spectrum demand forecasts are inaccurate, governments may make suboptimal policy decisions. Overestimating the growth of mobile network traffic and focusing on exclusive-use licenses, for example, can crowd out other types of wireless communication by increasing spectrum scarcity.[43] This directly hinders wireless innovation by raising the entry costs for new applications or services that require spectrum access.[44] Thus, communications services that might offer greater overall social benefit—by, for example, offering cheaper service at reduced, but acceptable, quality of service—may be shortchanged.[45] Due to the ubiquitous nature of wireless communication, this effect may be felt throughout the economy as well as in a range of government activities, from law enforcement to defense.[46]

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41 *See* FED. COMMC'NS COMM'N, SPECTRUM POLICY TASK FORCE, *supra* note 11, at 4 (discussing several important services that market-based methods might disrupt).

42 *See, e.g.*, Report and Order, *supra* note 34 ("The demand for spectrum…is expected to continue increasing" and the FCC is continuing to "make available additional licensed and unlicensed spectrum to meet this growing demand"); FED. COMMC'NS COMM'N, *supra* note 34, at 9, Exhibit 4; FED. COMMC'NS COMM'N, *supra* note 3, at 84; REAL WIRELESS, STUDY ON THE FUTURE UK SPECTRUM DEMAND FOR TERRESTRIAL MOBILE BROADBAND APPLICATIONS i, iii (2014), *available at* http://stakeholders.ofcom.org.uk/binaries/consultations/cfi-mobile-bb/annexes/RW_report.pdf.

43 *See* FED. COMMC'NS COMM'N, SPECTRUM POLICY TASK FORCE, *supra* note 11, at 7.

44 *See* MARTIN COOPER, THE MYTH OF SPECTRUM SCARCITY: WHY SHUFFLING EXISTING SPECTRUM AMONG USERS WILL NOT SOLVE AMERICA'S WIRELESS BROADBAND CHALLENGE 5 (2010), *available at* http://dynallc.com/wp-content/uploads/2012/12/themythofspectrumscarcity.pdf; *cf.* JOHN M. CHAPIN & WILLIAM H. LEHR, MASS. INST. OF TECH., MOBILE BROADBAND GROWTH, SPECTRUM SCARCITY AND SUSTAINABLE COMPETITION 22 (2011), *available at* http://people.csail.mit.edu/wlehr/Lehr-Papers_files/chapin_lehr_tprc2011%20mobile%20broadband.pdf (noting that dedicated unlicensed spectrum supports competition and innovation in new applications and services).

45 *See* CHAPIN & LEHR, *supra* note 44, at 5-6 (noting that when facilities-based operators lack additional spectrum, they must resort to cell-splitting at higher infrastructure costs per square kilometer; this leads to a concentrated market where most firms will "either exit the market or be reduced to niche competitors that offer lower-quality discount services").

46 *See* Jessica Rosenworcel, *A Federal Wireless Policy Built on Carrots, Not Sticks*, THE HILL CONGRESS BLOG (June 17, 2013, 1:30 PM), http://thehill.com/blogs/congress-blog/technology/308011-a-federal-wireless-policy-built-on-carrots-not-sticks.

D. Demand Forecasts Affect Network and Capital Investment

Like regulators, those investing in wireless services also use spectrum demand estimates to make long-lasting decisions about billions of dollars of capital.[47] Wireless operators, for example, have several means of dealing with increasing demand in addition to obtaining new spectrum. These include splitting cell sites or increasing deployment of small cells (densification),[48] upgrading to LTE or other more efficient technologies (including refarming of spectrum bands dedicated to less efficient transmission technologies),[49] improving offloading techniques,[50] or using financial incentives to adjust customer demand.[51] However, when national regulators emphasize clearing new spectrum, investing in new spectrum licenses is more likely to become the most economical means for managing demand, and MNOs are therefore less likely to invest in physical infrastructure even when this might be the most socially beneficial outcome.[52]

Demand estimates also drive outside investment decisions. When future estimates of wireless demand are high, investors are more likely to invest in such businesses, typically at the expense of investing in other areas of the economy or into different technologies.[53] Demand estimates that are not accurate can therefore hurt the efficient allocation of the larger economy by incentivizing

47 *See* Thomas Gryta, *A Gold Rush Hits Wireless Spectrum*, WALL ST. J. (Dec. 10, 2013, 7:51 PM), http://www.wsj.com/articles/SB10001424052702303330204579248041603159658 (noting that Verizon Wireless purchased $3.9 billion of spectrum, and AT&T purchased a rival for $1.2 billion "largely to take over its rights to use the airwaves" in order to keep up with the demand for spectrum); BROAD. CABLE FIN. MGMT. ASS'N, UNDERSTANDING BROADCAST AND CABLE FINANCE 29 (2013) (noting that FCC licenses are generally treated as indefinitely lived intangible assets).

48 *10 Ways to Deal with Mobile Data Capacity Crunch*, AMDOCS 3, http://www.amdocs.com/Whitepapers/OSS/WhitePaper-MobileDataCapacityCrunch.pdf (last visited Mar. 07, 2015) (noting that service providers can spatially separate the transmissions from each cell site, install additional carriers per cell site, or roll out additional macro cell sites to deal with the mobile data capacity crunch).

49 Dan Hays et al., *Solving the Spectrum Crunch: Reduce, Reuse, Recycle,* 18 COMM. REV. 12, 19 (2013).

50 *See 10 Ways to Deal with Mobile Data Capacity Crunch*, *supra* note 48, at 4-5 (noting that "dramatic capacity increase" can be made by offloading mobile data to Wi-Fi and femtocells).

51 *See* DAN HAYS ET AL., PRICEWATERHOUSECOOPERS, THREE WAYS MOBILE OPERATORS CAN (PROFITABLY) HELP CUSTOMERS SELF-MANAGE DATA CONSUMPTION (2013), *available at* http://www.pwc.com/en_US/us/industry/communications/publications/assets/pwc-mobile-operators-help-customers-self-manage-data.pdf; Ford, *supra* note 13, at 4.

52 *See* FED. COMMN'CS COMM'N, *supra* note 34, at 7 (noting that additional spectrum is an economic substitute for additional network investment).

53 *See* Hays et al., *supra* note 49, at 14.

over- or under-investment in communications-related enterprises vis-à-vis other areas of the economy. Overestimates may also cause investors to overpay for wireless assets.[54] As this over-allocation becomes apparent, prices typically drop and the industry must downsize or correct.[55] This creates unnecessary volatility and may drive away future investments.[56] For example, "wildly optimistic" predictions in the 1990s that Internet traffic was doubling every three months[57]—driven in part by "false" Internet traffic reports from Worldcom[58]—led to overinvestment in fiber optic capacity and the subsequent bankruptcy of many wireline infrastructure companies. As with IP figures, the Worldcom reports were routinely cited by government officials and business reporters despite "a lack of hard data" to substantiate them, being lent an "air of credibility" due to the proprietary nature of Internet traffic volumes and Worldcom's unique position at the time to monitor such information.[59]

E. Spectrum Forecasts Should Have a High Burden of Proof

In general, getting spectrum policy right is even more important than pure economic factors would indicate, for at least four major reasons. First, unlike most other resources, the electromagnetic spectrum, by its very nature, is a physically limited resource; no new frequencies can ever be created or destroyed.[60] In general, this means that once spectrum is allocated to one set of

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54 *See id.* (noting how mobile-data use has become "indoor and nomadic – after many operators have invested steeply in outdoor coverage, capacity, and poorly propagating spectrum").

55 Once the industry realizes the spectrum has been over-allocated, demand will drop, and the law of demand states that prices will also drop. *See* David R. Henderson, *Demand*, *in* THE CONCISE ENCYCLOPEDIA OF ECON. (2008), *available at* http://www.econlib.org/library/Enc/Demand.html.

56 *Cf.* Ian Huntsley, *Investment Strategies for Volatile Markets*, INVESTOPEDIA, http://www.investopedia.com/articles/trading/08/strategies-for-volatile-market.asp (last visited Feb. 25, 2015) (noting that as volatility rises, investors face a rise in risk of loss, therefore driving away investors).

57 Yochi J. Dreazen, *Wildly Optimistic Data Drove Telecoms to Build Fiber Glut*, WALL ST. J. (Sept. 26, 2002, 3:38 PM), http://www.wsj.com/articles/SB1032982764442483713.

58 J. Gregory Sidak, *The Failure of Good Intentions: The WorldCom Fraud and the Collapse of American Telecommunications After Deregulation*, 20 YALE J. ON REG. 207, 228 (2003).

59 *Id.*; ANDREW ODLYZKO, AT&T LABS RESEARCH, INTERNET GROWTH: MYTH, REALITY, AND ABUSE, *available at* http://www.dtc.umn.edu/~odlyzko/doc/internet.growth.myth.pdf.

60 Historically, in the long-run, technology improvements have greatly increased the range of usable frequencies for wireless communication. *See* Kevin Werbach & Aalok Mehta, *The Spectrum Opportunity: Sharing as the Solution to the Wireless Crunch*, 8 INT'L J. COMM. 133, 140 (2014). However, we do not consider such frequency expansions in this paper since the timing of such improvements is uncertain and is generally beyond the planning range of most business and policy decisions. *See, e.g.*, Dan Hays et al., *supra* note 49,

users, it is not available for alternative applications or technologies.[61] This finite nature of spectrum allocation, in fact, drives much of modern communications policy.[62]

This aspect of spectrum also strongly distinguishes wireless industries from their wireline counterparts.[63] In wireline industries, expansion of, say, fiber-optic backbones—even when this requires access to public resources such as rights-of-way—does not generally crowd out the ability of competing companies or applications to deploy their own infrastructure.[64] Thus, both the Commission and courts have acknowledged the existence and importance of a "virtuous cycle of innovation" for wireline broadband, in which excess bandwidth drives novel application development, which in turn pushes additional network expansion.[65] Such dynamism is problematic in wireless industries, where over-investment may stifle, rather than encourage, *overall* application development by reducing spectrum availability for alternative uses.[66] This can lower overall social welfare. Self-fulfilling prophecies, in which expectations about behavior

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at 13.

61 *See, e.g.*, Dan Hays et al., *supra* note 49, at 15 (noting that incumbent licensees of desirable spectrum are unlikely to "vacate prime holdings due to the lack of alternatives"); Thomas W. Hazlett & Evan T. Leo, *The Case for Liberal Spectrum Licenses: A Technical and Economic Perspective*, 26 BERKLEY TECH. L.J. 1037, 1053 (2011) (noting that "[a]llocating spectrum for unlicensed usage necessarily excludes certain wireless alternatives").

62 *See* ITHIEL DE SOLA POOL, TECHNOLOGIES OF FREEDOM 38 (1983); *see also* Nat'l Broad. Co. v. United States, 319 U.S. 190 (1943).

63 *See Chapter VI – Setting the Predicates: Communications Architecture Today and Tomorrow*, THE ASPEN INST., http://csreports.aspeninstitute.org/Roundtable-on-Spectrum-Policy/2013/report/details/0075/Spectrum (last visited Mar. 07, 2015).

64 Many companies, for example, are simultaneously able to make use of utility poles to deploy wireline infrastructure, and the FCC has authority to regulate rates, terms, and conditions for pole attachments to "provide that such rates, terms, and conditions are just and reasonable." *See* 47 U.S.C. § 224(b)(1) (2012); *see also* FED. COMMC'NS COMM'N, *supra* note 3, at 109.

65 *See Preserving the Open Internet*, Report & Order, 25 FCC Rcd. 17905 at paras. 3, 38 (2010); Verizon v. FCC, 740 F.3d 623, 634 (2014).

66 This is best exemplified by the largely irreversible decision to allocate a frequency band as either licensed or unlicensed use. *See* Coleman Bazelon, *Licensed or unlicensed: The economic considerations in incremental spectrum allocations*, 47 IEEE COMM. MAG. 110, 110 (2009) (noting that there currently is no way to trade spectrum between licensed and unlicensed uses); MILGROM ET AL., *supra* note 39, at 2, ¶ 5 (noting that unlicensed use offers lower barriers to entry due to freedom from the need to negotiate with exclusive license holders); William H. Lehr, *The Role of Unlicensed in Spectrum Reform*, *in* INTERNET POLICY AND ECONOMICS 169, 174 (William H. Lehr & Lorenzo Maria Pupillo eds., 2d ed. 2009), noting that flexible licensing favors network-centric service providers while unlicensed favors an equipment-centric end-user model); Hazlett & Leo, *supra* note 61 (noting that "[a]llocating spectrum for unlicensed usage necessarily excludes certain wireless alternatives").

propel that very behavior, as seen with Moore's law, [67] are therefore problematic in a wireless context.

Second, spectrum is a public resource that is "owned" by a nation's citizenry.[68] As such, its exploitation carries a much stronger consideration of public welfare than many other resources; spectrum managers are obliged to balance the needs of scientific, non-commercial, and amateur users, as well as considerations of free speech, public safety, the national defense, and equity.[69] Any use of exclusive-use licenses, to the extent that they completely block off a spectrum band from public or government access for the length of the license, therefore should face an extremely strong burden of proof from a public policy perspective.

Third, decisions about spectrum have longer time-scales and less reversibility than many other areas of policy.[70] Moving incumbent users off spectrum bands in response to technological or economic changes, for example, is generally time-consuming, expensive, and contentious, often taking billions of dollars of upfront investment to facilitate relocation and more than a decade to complete.[71] This arises in part because wireless industries are characterized by high up-front capital costs and generally need to meet minimum coverage areas and densities for business or licensing reasons.[72] Moreover, the potential uses of a particular band of spectrum are often limited by physical constraints and interference from adjacent users, requiring regulators to explicitly pre-judge the potential applications of a spectrum band to maximize overall usage.[73] Un-

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67 CORNELIUS DISCO & BAREND VAN DER MEULEN, GETTING NEW TECHNOLOGIES TOGETHER 206-07 (1998).

68 *See* Christian A. Herter, *The Electromagnetic Spectrum: A Critical Natural Resource,* 25 NAT. RESOURCES J. 651, 655 (1985) (noting spectrum is a natural resource and that generally, natural resources within the geographic boundaries of a nation are owned by that nation); *see generally* J. Armand Musey, *Broadcasting Licenses: Ownership Rights and the Spectrum Rationalization Challenge*, 13 COLUM. SCI. & TECH. L. REV. (2012) (discussing the quasi-property nature of spectrum licenses).

69 The FCC, for example, must determine "whether the public interest, convenience, and necessity will be served by the granting of" a spectrum license. *See* § 309(a); *see also* FED. COMMN'CS COMM'N, *supra* note 2, at 7, 40, 53.

70 *See* FED. COMMN'CS COMM'N, *supra* note 3, at 78, 79.

71 *See* U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-13-472, REPORT TO THE COMMITTEE OF THE ARMED SERVICES, U.S. SENATE: SPECTRUM MANAGEMENT: FEDERAL RELOCATION COSTS AND AUCTION REVENUES 2, 3 (2013); *see* FED. COMMN'CS COMM'N, *supra* note 3, at 79 (noting historical time lags of between 6 and 13 years for reallocating spectrum).

72 *See Spectrum Management: FCC's Use and Management of Buildout Requirements: What GAO Found*, GOV'T ACCOUNTABILITY OFFICE, http://www.gao.gov/products/GAO-14-236 (last visited Mar. 07, 2015).

73 *See, e.g.*, Hazlett & Leo, *supra* note 61; *see also* GREGORY L. ROSSTON, STANFORD INST. FOR ECON. POLICY RESEARCH, INCREASING THE EFFICIENCY OF SPECTRUM ALLOCATION 1, n. 2 (2014).

der many licensing regimes, incumbent wireless users also have little incentive to deploy future-proof receiver or transmitter technology even if marginal costs are low, and may also have the political power to stifle or slow down relocations in many cases (such as when adjacent incumbent GPS users successfully prevented LightSquared from launching a wholesale mobile network).[74] This process has become even more difficult now that most lightly-used bands have already been cleared and reallocated.[75]

Fourth, carriers have alternatives to additional spectrum for managing traffic demand, for both short- and long-term timescales. The amount of traffic a given amount of spectrum can handle is somewhat flexible. For example, wireless carriers can deploy additional cell sites to "densify" their networks or upgrade to more spectrally efficient technologies.[76] Carriers can also encourage users to offload more of their traffic to Wi-Fi networks.[77]

Carriers can and do use methods to adjust user behavior as well, including through pricing adjustments.[78] Contrary to some critics, however, price rationing of limited capacity is not the primary method of dealing with increased demand.[79] In fact, U.S. wireless carriers have accommodated a massive increase in wireless demand since the smartphone revolution without use of any significant new spectrum since FCC Auction 73 (the 2008 700 MHz auction).[80] For example, in 2010 the FCC released a report predicting that carriers would

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74 *See, e.g.*, *Statement from FCC Spokesperson Tammy Sun on Letter from NTIA Addressing Harmful Interference Testing Conclusions Pertaining to Lightsquared and Global Positioning Systems*, FCC (Feb. 12, 2014), http://transition.fcc.gov/Daily_Releases/Daily_Business/2012/db0215/DOC-312479A1.txt.

75 PRESIDENT'S COUNCIL OF ADVISORS ON SCI. & TECH., REPORT TO THE PRESIDENT: REALIZING THE FULL POTENTIAL OF GOVERNMENT-HELD SPECTRUM TO SPUR ECONOMIC GROWTH vi (July 2012), *available at* https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf (noting the difficulty and cost of clearing and reallocating Federal spectrum for commercial use).

76 *See* FED. COMMN'CS COMM'N, *supra* note 34, at 12.

77 RYSAVY RESEARCH, MOBILE BROADBAND CAPACITY CONSTRAINTS AND THE NEED FOR OPTIMIZATION 21 (2010), *available at* http://www.rysavy.com/articles/2010_02_rysavy_mobile_broadband_capacity_constraints.pdf.

78 Zachary S. Bischof et al., *Need, Want, Can Afford – Broadband Markets and the Behavior of Users*, *in* IMC '14 PROCEEDINGS OF THE 2014 CONFERENCE ON INTERNET MEASUREMENT CONFERENCE 73,83 (2014), *available at* http://dl.acm.org/citation.cfm?id=2663753 ("[T]he availability of faster services at a lower cost leads subscribers to sign up for services that will be less heavily used."). In addition, carriers may leverage their influence with device makers and application platforms to limit particular uses of mobile devices that typically consume large amounts of data, such as tethering.

79 *See* Ford, *supra* note 13.

80 FED. COMMC'NS COMM'N, *supra* note 3, at 78 (describing the spectrum allocations to mobile services from 1983 to 2008, and the corresponding spike in demand and innovation).

have a 300 MHz spectrum deficit by 2014.[81] U.S. carriers, however, are not using any significant amount of spectrum allocated since the FCC's Auction 73 in 2008 to address that deficit and significant portions of the spectrum allocated in the Auction 73, and before, remain minimally used.[82] Moreover, despite significant capital investment by U.S. carriers,[83] the U.S. still has significantly lower cell site density than many other countries and new small cell site technologies to allow further densification of wireless networks are rapidly growing.[84] Spectrum exhaust is simply not on the horizon.

In addition, the viability of "new" spectrum allocation to address these issues may be limited. A typical spectrum reallocation precedes service deployment by many years due to the lengthy process of identifying and testing candidate bands, designing and conducting the auction, and relocating incumbent users.[85] Carriers must then identify potential new cell sites or upgrade candidates, develop and deploy new infrastructure, and manage any potential sources of interference, which leads to a gradual process of deploying new infrastructure for managing demand.[86] In addition, only after spectrum has been authoritatively licensed is it rational for equipment manufacturers to invest in developing necessary hardware and for service providers to raise money to build-out new services.

Spectrum demand forecasts are therefore critical for regulators to efficiently allocate spectrum and maximize overall social benefit. As a result of the long lead-time between spectrum allocation and start of service, regulators rely on demand projections years into the future to help guide their decisions.[87] They

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81 *See* FED. COMMC'NS COMM'N, *supra* note 34, at 26.

82 Neal Gompa, *T-Mobile buys Verizon's Lower 700 MHz Spectrum to Enable Broad Coverage 200Mbps LTE*, EXTREME TECH (Jan. 8, 2014, 10:30 AM), http://www.extremetech.com/computing/174299-t-mobile-buys-verizons-lower-700mhz-spectrum-to-enable-broad-coverage-200mbps-lte (explaining that Verizon was not using the A-Block).

83 *See Background on CTIA's Wireless Industry Survey*, CTIA 12 (June 2014), http://www.ctia.org/docs/default-source/Facts-Stats/ctia_survey_ye_2013_graphics-final.pdf?sfvrsn=2 (stating that U.S. carriers have invested a cumulative total of nearly $400 billion since 1985).

84 *See* Sean Kinney, *Some 75 Mobile Network Operators Have Deployed Small Cells,* RCRWIRELESSNEWS (Mar. 19, 2015), http://www.rcrwireless.com/20150319/hetnet-news/small-cell-shipments-top-10-million (noting 10.2 million small cell units being used by 75 mobile network operators).

85 *See* FED. COMMC'NS COMM'N, *supra* note 3, at 79 (noting that historically it has taken 6 to 13 years to reallocate spectrum, from first step to availability for use).

86 *See id.* at XII-XIII (describing the spectrum allocations to mobile services from 1983 to 2008, and the corresponding spike in demand and innovation).

87 *See id.* at 79 (noting historical time lags of between 6 and 13 years for reallocating spectrum); *see generally* Dr. Robert Roche, *Mobile Usage Continues to Increase + Projection Say Skyrocketing Demand = More Spectrum Required*, CTIA BLOG (Feb. 6, 2015),

also use application-specific demand forecasts to help determine whether clearing spectrum bands is profitable and what conditions (such as participation restrictions, interference mitigation methods, or buildout requirements) should apply to various spectrum bands.[88] These decisions in turn significantly shape how wireless industries evolve and what kind of wireless infrastructure is deployed. Ensuring that demand data is as reliable as possible, and that measures are taken to mitigate risk of error, is therefore essential for effective spectrum management. This paper, however, finds evidence that, despite the importance, regulators have come to rely on reports that have repeatedly proven to be inaccurate and have taken few measures to adjust policies or mitigate the risk of error going forward.

The remainder of this paper is organized as follows: Section II examines several major demand forecasts and assesses their reliability through qualitative and statistical evidence. Section III explores some possible underlying reasons for inaccuracy in these reports. Due to the small overall number of such forecasts, larger-scale econometric analyses are infeasible, so the analysis focuses on general trends and themes. Section IV focuses on methods to mitigate errors going forward, while Section V presents some spectrum-specific policy suggestions and concluding thoughts.

II. MAJOR DATA FORECASTS AND THEIR HISTORICAL RELIABILITY

Many spectrum demand estimates, even those used to determine national policy, are conducted by private entities rather than government agencies.[89] Expert agencies rely on these estimates, perhaps by combining and/or averaging several forecasts at once, for policy analysis and planning, either due to lack of sufficient in-house expertise or for cost and time reasons.[90] When government agencies do directly address demand, they often commission spectrum demand projections from outside experts.[91] While this may be justified by an

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http://blog.ctia.org/2015/02/06/mobile-usage-more-spectrum-required/ (demonstrating the necessity of projections in determining spectrum usage).

88 Such factors are key in FCC rulemakings about spectrum auction policies and procedures. *See, e.g.*, *Spectrum Management*, *supra* note 72.

89 *See, e.g.*, CISCO, CISCO VISUAL NETWORKING INDEX: GLOBAL MOBILE DATA TRAFFIC FORECAST UPDATE, 2012-2017 (2013), *available at* http://newsroom.cisco.com/documents/10157/1142732/Cisco_VNI_Mobile_Data_Traffic_Forecast_2012_2017_white_paper.pdf.

90 Tim Farrar, *Is Cisco Stacking the Deck with its Mobile Data Numbers?*, GIGAOM (Feb. 09, 2013, 10:30 AM), https://gigaom.com/2013/02/09/is-cisco-stacking-the-deck-with-its-mobile-data-numbers/.

91 Examples include the FCC using projections from Cisco, the Canadian Government using Plumb Research projections, and Ofcom's use of Real Wireless projections. *See also*

internal lack of appropriate econometric and technical expertise, it may also reduce the quality of external and oversight scrutiny about the results. Such scrutiny can also consume significant amounts of agency time and resources.[92] By pointing to market estimates and referring to outside expertise, on the other hand, agencies are able to suggest an industry consensus and avoid industry and government challenges to their data.[93] Of course, to the extent the estimates in the market are inaccurate, the range of estimates used by the government agencies will have the same shortcomings.

A. Industry Participant Forecasts

Industry forecasts are among the most common and most frequently updated spectrum forecasts.[94] For example, the Cisco Visual Networking Index (VNI), which projects wireless and wireline demand four to six years into the future, has estimated mobile demand for many years, is widely cited, and in recent years has faced few competing projections.[95]

However, Cisco VNI projections have proven unreliable when compared to their actual measurements and updated projections (Chart II-1).[96] For example, over the most recent seven forecasts, overestimates were nearly twice as frequent as underestimates (19 vs. 10).[97] Overestimates are also on average of greater magnitude than underestimates (103 vs. 81 PB/month).[98] Cisco's overestimation was particularly high in their 2011-2016 forecast;[99] the two subsequent reports have featured demand forecasts approximately twenty-five per-

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id.

92 *See generally* Steven J. Crowley, *Three Invalid Assumptions that Make the FCC's Spectrum Requirements Model Skew High*, STEVEN CROWLEY (Nov. 19, 2011), http://stevencrowley.com/2011/11/19/three-invalid-assumptions-that-make-the-fcc's-spectrum-requirements-model-skew-high/.

93 *See id.*

94 *See, e.g.*, FED. COMMC'NS COMM'N, *supra* note 34, at 5-6.

95 *See, e.g.*, Farrar, *supra* note 90 (illustrating the authority of Cisco's mobile VNI forecast).

96 Author's calculations based on Cisco Global Mobile Data Traffic Forecasts and Cisco Visual Networking Index spanning a timeframe of 2007-2017.

97 Author's calculations based on Cisco Global Mobile Data Traffic Forecasts and Cisco Visual Networking Index spanning a timeframe of 2007-2017.

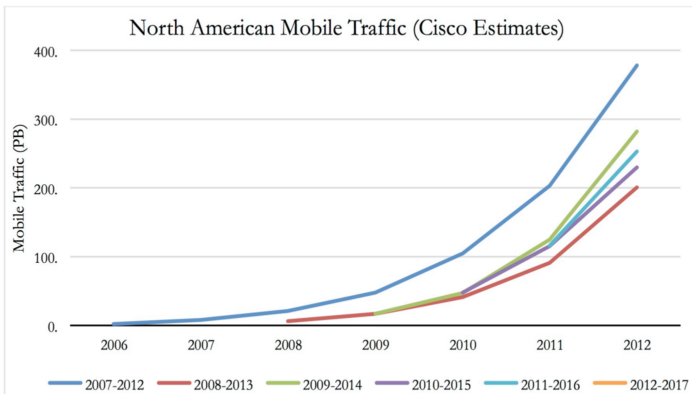
98 Author's calculations based on Cisco Global Mobile Data Traffic Forecasts and Cisco Visual Networking Index spanning a timeframe of 2007-2017.

99 *See* CISCO, CISCO VISUAL NETWORKING INDEX: GLOBAL MOBILE DATA TRAFFIC FORECAST UPDATE, 2011-2016 3 (2012), *available at* http://www.puremobile.com/media/infortis/documents/cisco_mobile_forecast.pdf.

cent lower.[100] Moreover, the longer the timeframe, the more likely the estimates are likely to be over-projections due to exponential growth issues.[101]

Perhaps Cisco's most significant forecast inaccuracy was its 2012 projections for Western European mobile traffic. In February 2012, Cisco estimated that December traffic (ten months later) would be 366 PB.[102] But in February 2013, Cisco had lowered this projection more than fifty percent, to 181 PB.[103] Some analysts consider the 180 PB figure to also be too high.[104]

Chart II-1: Cisco VNI Estimates Over Time[105]



Sources: Cisco Global Mobile Data Traffic Forecast; Cisco Visual Networking Index; author's calculations

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100 *See* CISCO, *supra* note 89, at 3; CISCO, CISCO VISUAL NETWORKING INDEX: FORECAST AND METHODOLOGY 2013-2018 (2014), *available at* http://www.cisco.com/c/en/us/solutions/collateral/service-provider/global-cloud-index-gci/Cloud_Index_White_Paper.pdf.

101 Author's calculations based on Cisco Global Mobile Data Traffic Forecasts and Cisco Visual Networking Index spanning a timeframe of 2007-2017.

102 CISCO, *supra* note 99, at 24; *Cisco Slashes its Mobile Data Forecasts, But the Numbers Still Look Far too High*, ANALYSYS MASON (Feb. 15, 2013) http://www.analysysmason.com/About-Us/News/Insight/Cisco-mobile-data-forecasts-Feb2013/.

103 CISCO, *supra* note 89, at 27; *see also Cisco Slashes its Mobile Data Forecasts*, *supra* note 102.

104 *Cisco Slashes its Mobile Data Forecasts*, *supra* note 102.

105 Author's calculations based on Cisco Global Mobile Data Traffic Forecasts and Cisco Visual Networking Index spanning a timeframe of 2007-2017.

B. International

l. Group Forecasts

The ITU has also endorsed a set of spectrum demand projections that were last updated in 2006.[106] These projections combined a variety of industry and research forecasts (Chart II-2) and indicate that, on average, between 1280 MHz and 1720 MHz of spectrum will be needed by 2020.[107] The ITU stratified the estimates based on potential need scenarios, but even the low end of the estimate is well above the FCC's estimate that the U.S. will need 500 MHz of additional wireless spectrum by then (supplementing the already 547 MHz available for mobile broadband as of 2010).[108] However, considering its high level of economic development and device penetration, by ITU's own criteria, the U.S. should garner at least an "average need" classification, which would widen the disparity between ITU and FCC.[109]

Mobile industry analyst Tim Farrar notes that the ITU forecasts imply typical global demand per square kilometer in 2020 will be 100 times greater than the demand in the 1 kilometer square area around the 2014 Super Bowl stadium during the game – arguably one the highest traffic events in the world.[110] Despite their age and a lack of updates to recalibrate baseline figures, however, these ITU estimates are still cited in policy debates, for example by CTIA.[111]

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106 *See, e.g.*, INT'L TELECOMM. UNION, ESTIMATED SPECTRUM BANDWIDTH REQUIREMENTS FOR THE FUTURE DEVELOPMENT OF IMT -2000 AND IMT-ADVANCED (2006), *available at* http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2078-2006-PDF-E.pdf.

107 *See id.* at 1.

108 *See* FED. COMMC'NS COMM'N, *supra* note 3, at 84.

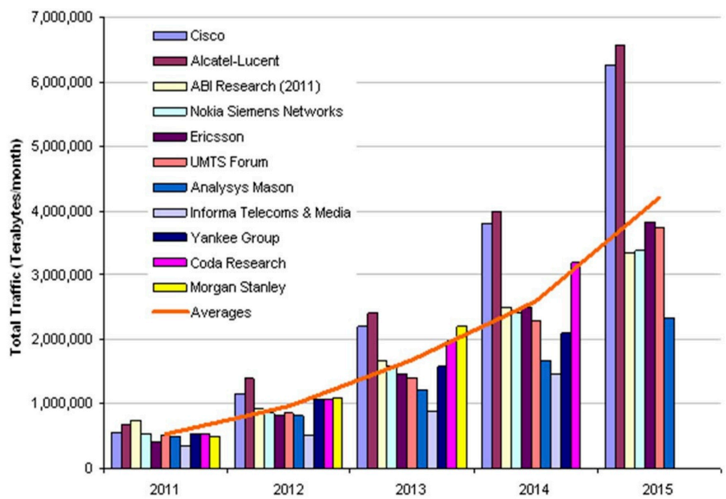
109 *See* INT'L TELECOMM. UNION, FUTURE SPECTRUM REQUIREMENTS ESTIMATE ON TERRESTRIAL IMT 9 (2013), *available at* http://www.itu.int/ITU-R/go/patents/en.

110 Tim Farrar, *A Hundred Superbowls per Sq KM?*, TMF ASSOCIATES MSS BLOG (June 06, 2014), http://tmfassociates.com/blog/2014/06/17/a-hundred-superbowls-per-sq-km/

111 *See* Marinho, *supra* note 37; CTIA, *ITU: More Spectrum is Essential,* CTIA – THE WIRELESS ASS'N BLOG (Oct. 23, 2012), http://blog.ctia.org/2011/02/14/itu-more-spectrum-is-essential/.

Chart II-2: Projections used by ITU[112]

Mobile global data traffic estimates from 2011 to 2015 based on multiple sources



The disparity between different types of estimates included in the report is suggestive. The two highest estimates were from equipment manufacturers (Cisco and Alcatel-Lucent), which tend to directly benefit from spectrum reallocations to MNOs, since they sell much of the equipment used in such relocations and subsequent infrastructure redeployment.[113] The two lowest projections were conducted by independent research firms (Informa and Analysy Mason).[114] As noted in Section IV, even independent research firms may have institutional relationships and biases that potentially hinder complete objectivity. However, independent research firms have a less direct relationship to the benefits of additional spectrum allocation, so it is reasonable to expect that

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112 INT'L TELECOMM. UNION, ASSESSMENT OF THE GLOBAL MOBILE BROADBAND DEPLOYMENTS AND FORECASTS FOR INTERNATIONAL MOBILE TELECOMMUNICATIONS 16 (2011), *available at* http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2243-2011-PDF-E.pdf.

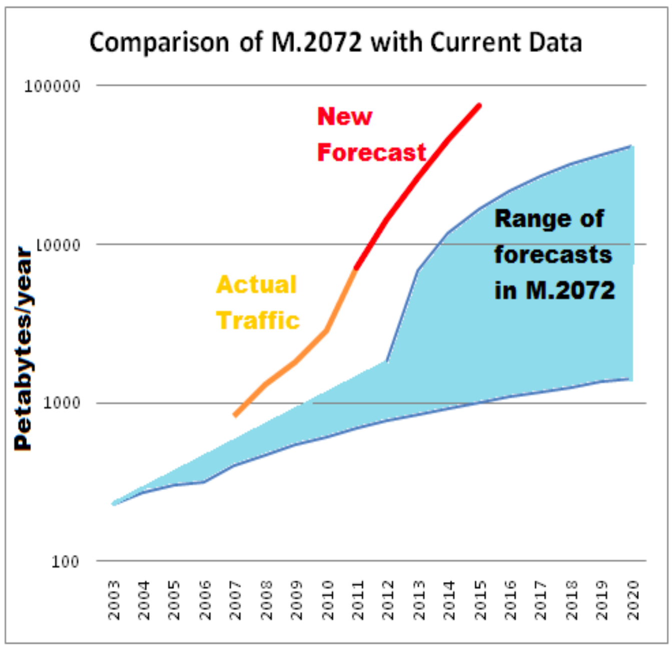
113 *Id*. at 6.

114 *Id.* at 18.

they are less likely, on average, to be subject to such biases than equipment manufacturers or service providers.

Furthermore, a 2011 ITU report[115] noted that earlier ITU projections, made in 2005 (ITU-R M.2072), were too low based on traffic growth in the intervening time period.[116] This suggests that the ITU's aggressive projections two years later, in 2006,[117] were, at some level, a reaction to perceptions of earlier underestimation. A chart from the 2011 report with 2005 and newer projections is shown in Chart II-3 below.

Chart II-3: ITU traffic estimates done at year 2005 (Report ITU-R M.2072)[118]



115 *See generally id.* ITU is the leading publisher of telecommunication technology, regulatory and standard information. A report labeled ITU-R, means that the report was published by the Radio Communication Sector of ITU. *Id.*

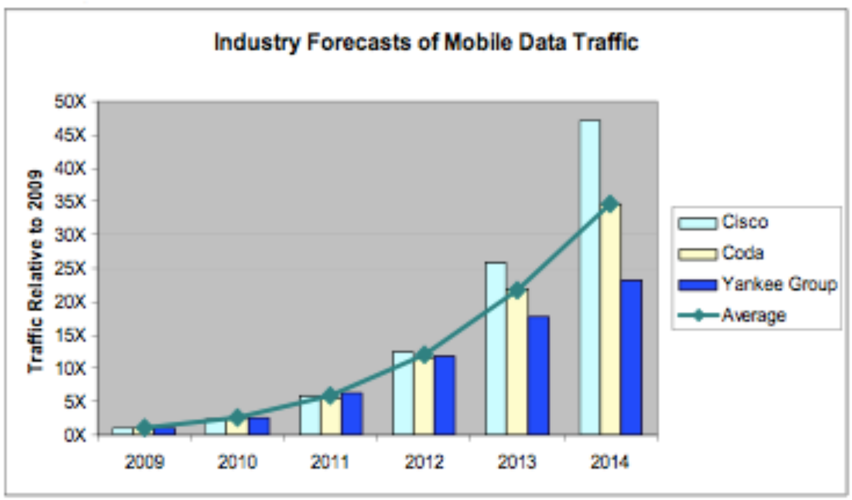
116 *Id.* at 15.

117 INT'L TELECOMM. UNION, *supra* note 106.

118 INT'L TELECOMM. UNION, *supra* note 112, at 15.

Like the ITU, the FCC has only made limited efforts to develop independent spectrum projections. The FCC relied heavily on estimates from Cisco, ITU, Ofcom, and other outside groups for the 2010 National Broadband Report's spectrum allocation recommendations.[119] These recommendations called for allocation of an additional 300 MHz for mobile broadband spectrum between 2010 and 2015, and 500 MHz by 2020.[120] The FCC further justified this projection through a technical paper that estimated a 275 MHz deficit by 2014.[121] Despite being the only technical analysis of spectrum requirements conducted by the FCC in recent years, this paper did not make independent demand estimates but relied on an average of three sets of spectrum demand projections (Cisco, Coda, and Yankee Group, with Cisco's being the highest), with limited further analysis (Chart II-4).[122]

Chart II-4: Demand Forecasts Used by FCC[123]



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[119] *See* FED. COMMC'NS COMM'N, *supra* note 3, at 76-77, 84.
[120] *See id.* at 75, 84.
[121] *See* FED. COMMC'NS COMM'N, *supra* note 34, at 26.
[122] *Id.* at 9, Exhibit 4.
[123] *Id.*

Chart II-5: FCC Traffic Projections vs. Actual

	2009	2010	2011	2012	2013	2014E
Total Network Traffic Growth						
Predicted Traffic (2010 FCC Est)		468	1,090	2,219	4,038	6,489
Actual Traffic & YE 2014 Est	185	389	867	1,468	3,230	5,168
Predicted Y/Y Growth (2010 FCC est)		153%	133%	104%	82%	61%
Actual Y/Y Growth & YE 2014 Est	100%	110%	123%	69%	120%	60%
Predicted Cum Growth Index (2010 FCC Est)	100%	253%	589%	1199%	2182%	3506%
Actual Cum Growth Index & YE 2014 Est	100%	210%	468%	793%	1745%	2792%
Difference		*43%*	*121%*	*406%*	*437%*	*714%*
Traffic Offloading (Wi-Fi & Other)	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Predicted (2010 FCC Estimate)	*15%*	*15%*	*15%*	*15%*	*15%*	*15%*
Actual and YE 2014 Est	*15%*	*20%*	*30%*	*40%*	*43%*	*46%*
Source: Authors' analysis based on FCC and CTIA data						

The National Broadband Plan's recommendations, as further developed in various executive-branch policies, remain the framework for current U.S. spectrum policy, and the FCC has made significant progress in meeting its interim goal of 300 MHz of additional mobile broadband spectrum.[124] However, as Chart II-5 shows, the Plan's forecast results did not come to fruition.[125] The U.S. mobile broadband traffic figures used in the plan's development have not actually increased at the rate projected by the FCC.[126]

The actual traffic acceleration from 2012 to 2013 is likely the result of wireless carriers with excess capacity re-introducing unlimited data plans during the year.[127] As discussed in Section I.D, significant allocated spectrum remains unused in the U.S. The ability to reintroduce mass unlimited plans while leaving significant amounts of spectrum unused indicates that spectrum exhaust is not currently a significant factor in the business decisions of certain MVNOs. Moreover, it is not clear that demand based on usage in a near-zero marginal

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124 U.S. DEP'T. OF COMMERCE, FOURTH INTERIM PROGRESS REPORT ON THE TEN-YEAR PLAN AND TIMETABLE AND PLAN FOR QUANTITATIVE ASSESSMENTS OF SPECTRUM USAGE 17-18 (2014).

125 Author's analysis. *See also* FED. COMMC'NS COMM'N, *supra* note 34, at 18-19, Exhibits 10-11; Ford, *supra* note 13, at 5 tbl. 1.

126 The *Difference* is calculated by subtracting the (Predicted Cum. Growth Index (2010 FCC Est)) from the (Actual Cum. Growth Index & YE 2014 Est.). *See* Ford, *supra* note 13, at 5.

127 *See, e.g.*, Mike Dano, *H2O offers unlimited service on AT&T network for $60/month*, FIERCEWIRELESS.com, (Sept. 2, 2011), http://www.fiercewireless.com/story/h2o-offers-unlimited-service-att-network-60month/2011-09-02; *see also* Marguerite Reardon, *Wireless spectrum shortage? What spectrum shortage?*, CNET (Sept. 27, 2011, 5:40 PM), http://www.cnet.com/news/wireless-spectrum-shortage-what-spectrum-shortage/.

cost environment is the appropriate measurement to use for public policy decisions to allocate a finite resource.

2. Ofcom Projections and UK Policy

In June 2013, the British telecom regulator Ofcom released a spectrum demand forecast conducted by Real Wireless.[128] As some analysts noted, this report predicted an effective demand of 10 petabytes per square kilometer by 2020.[129] After some criticism of this figure, the report was revised downward by a factor of 1,000, to 10 terabytes per square kilometer in the final version, released March 11, 2014.[130] Ofcom did not explain the change and stated that: "since the report has served its purpose we do not plan to carry out any further work to update it."[131] The magnitude of swings in projection undermines its methodological credibility, as well as related policy decisions.[132]

III. FOUR POSSIBLE EXPLANATIONS FOR UNRELIABLE FORECASTING

Spectrum demand forecasts present unusual challenges. Unlike most goods, few consumers want spectrum itself; they want to make phone calls, send text messages, access the internet, send email, and stream video and music.[133] Moreover, the amount of spectrum needed for a consumer voice and data applications can change dramatically depending on the technology employed by the operator, external factors such as the development of applications and application markets, and an operator's pricing and billing model.[134] This section explores several analytical, structural, and economic factors that help explain why spectrum forecast tend towards unreliability. In isolation, each factor highlights the inherent uncertainty of predicting mobile demand and the

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128 REAL WIRELESS, *supra* note 42.

129 *See* Tim Farrar, *Note to the telecom industry: Beware of false models*, GIGAOM.COM (Feb. 22, 2014, 1:30 PM), https://gigaom.com/2014/02/22/note-to-the-telecom-industry-beware-of-false-models/; *see also* Farrar, *supra* note 110.

130 REAL WIRELESS, *supra* note 42, at 55, fig. 44; *see also* Farrar, *supra* note 110.

131 *Future Demand for Mobile Broadband Spectrum and Consideration of Potential Candidate Bands*, OFCOM, http://stakeholders.ofcom.org.uk/consultations/cfi-mobile-bb (last updated Mar. 18, 2013).

132 *See* Farrar, *supra* note 110.

133 *See* Aaron Smith, *U.S. Smartphone Use in 2015,* PEW RESEARCH CENTER (Apr. 1, 2015), http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/.

134 *See* CISCO, *supra* note 89, at 2-3, 25-26 (noting a need for large estimate updates due to unforeseen changes in business models, device usage, and traffic management systems).

amount of spectrum required to satisfy this demand. Together, however, these elements compound to produce far higher overall levels of uncertainty.

A. Technical reasons for bias

There are several technical reasons for bias in spectrum forecasts including:

1. Limited Use of Risk Management and Transparency

Spectrum forecasters make little use of (or at least, often do not release) risk management techniques in their analysis. Sensitivity analysis, scenario analysis, and error ranges are all standard risk analysis tools for complex models where data sources and relationships are uncertain.[135] Cisco's methodology, which "begins with the number and growth of connections and devices, applies adoption rates for applications, and then multiplies the application's user base by Cisco's estimated minutes of use and KB per minute for that application,"[136] exemplifies such a complex model. Although such added complexity can ultimately improve a prediction by incorporating and correcting for various subtle influences, the cost is often uncertainty and variance.[137]

Reporting a single number, for example, is misleading because it implies a stronger certainty than an econometric or analytic model is capable of, especially in the case of multi-step models.[138] Moreover, only loosely associating a result with its methodological underpinnings allows other organizations to more easily ignore qualifications and other nuance, facilitating the processes that disconnect the origins of a projection with its subsequent rhetorical and policy uses.[139] This also helps contribute to the longevity of cited projections; U.S. spectrum policy, for example, still works on the assumption that 500 MHz of new spectrum is needed even though that estimate was made four years ago and the wireless market has changed substantially since then.[140]

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135 *See* DAVID VOSE, SCENARIO ANALYSIS: A QUANTITATIVE GUIDE, 4, 47 (2008); *Scenario Analysis: A Tool for Task Managers*, WORLDBANK, http://siteresources.worldbank.org/INTPSIA/Resources/490023-1121114603600/13053_scenarioanalysis.pdf (last visited Mar. 8, 2015).

136 CISCO, *supra* note 13, at 37.

137 *See, e.g.*, Louis Anthony Cox, Jr, *Internal Dose, Uncertainty Analysis and Complexity of Risk Models*, 25 ENV'T. INT'L 841, 841-42, 847 (1999); Jacques LeLorier et al., *Discrepancies between Meta-Analyses and Subsequent Large Randomized, Controlled Trials*, 337 NEW ENG. J. MED. 536. 536 (1997).

138 *See generally* GEORGE C. JUDGE, INTRODUCTION TO THE THEORY AND PRACTICE OF ECONOMETRICS, 1, 5 (1998).

139 Sanchez, *supra* note 16.

140 *See* FED. COMMC'NS COMM'N, *supra* note 3, at 75, 84.

Moreover, the Cisco forecast uses "Ovum, Machina, Strategy Analytics, Infonetics, Gartner, IDC, Dell'Oro, Synergy, ACG Research, Nielsen, comScore, Verto Analytics, the International Telecommunications Union (ITU), CTIA, and telecommunications regulators in each of the countries covered by VNI."[141] Although using all available data sources is generally an analytical best practice, combining data from many sources may also increase errors and uncertainties from data compatibility issues and different methodologies, and reduces the number of comparable independent assessments that can serve to ground or calibrate an assessment.[142] Combining data sources also presents risk of a form of publication bias, because these sources and analyses are often only reported upon successful conclusion of a particular industry-analyst contract; unfavorable analyses are more likely to be terminated before publication or result in incomplete or low-quality data that must be omitted to preserve overall analytical quality.[143]

The lack of detailed methodological and risk information is also part of a more general trend for industry analysts to closely guard their methodologies and data.[144] As the U.S. Government Accountability Office notes, "according to experts and government officials, industry associations do not always disclose their proprietary data sources and methods, making it difficult to verify their estimates."[145] Although there may be good business reasons for doing so in the case of industry reports and analyses,[146] it is more difficult to make the case that regulators making decisions about public resources should rely on such estimates when assumptions and methodology are opaque.

2. Exponential Estimation

Spectrum demand forecasts typically employ exponential estimation methods for extrapolating demand growth, "based on existing mobile broadband growth and new trends" in Internet and telephone services.[147] However, this means small errors or uncertainties can become extremely large at the edges of the forecast's time horizon. For example, the standard deviation of the external

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[141] CISCO, *supra* note 13, at 36.
[142] Robert E. Slavin, *Best-Evidence Synthesis: An Alternative to Meta-Analytic and Traditional Reviews*, 15 EDUC. RESEARCHER 5, 5 (1986).
[143] *See* Robert Rosenthal, *The "File Drawer Problem" and Tolerance for Null Results*, 86 PSYCHOL. BULL. 638, 638 (1979).
[144] *See* U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-13-762T, INSIGHTS GAINED FROM EFFORTS TO QUANTIFY THE EFFECTS OF COUNTERFEIT AND PIRATED GOODS IN THE U.S. ECONOMY 5, 8 (2013).
[145] *Id.* at 8.
[146] U.S. GOV'T ACCOUNTABILITY OFFICE, *supra* note 19, at 8.
[147] INT'L TELECOMM. UNION, *supra* note 112.

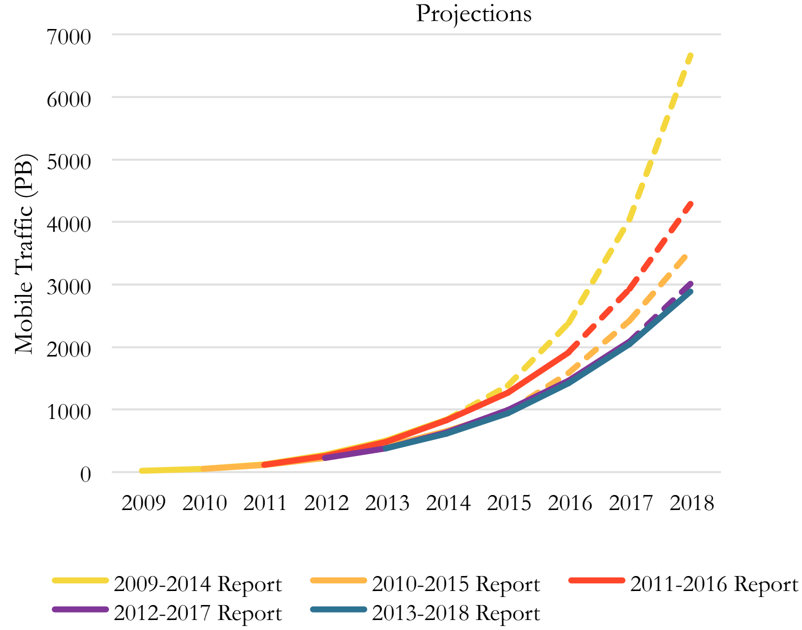
data sources that the ITU used to estimate average global mobile data traffic from 2011 to 2015 steadily and rapidly increased (Table III-1).[148] When the past five Cisco estimates are projected to 2018 using comparable Internet growth rates, they also show high variances in the final predictions (Chart III-1).[149]

Table III-1: Relative Standard Deviation of Global Mobile Traffic Estimates	
2011 (base year)	1
2012	1.96
2013	4.31
2014	7.64
2015	14.26
Note: 2011=1. Bartlett's Test for equality of variances indicates a significant difference (X^2 = 58.6; $p < 0.001$).	

148 The authors used their own calculations to create the numbers in Table III-1. For the initial numbers usein their calculations. *See id.* (stating that by 2020, mobile traffic will have increased 33 times from 2010 figures).

149 The authors used their own calculations to create the numbers in Chart III-1. For the initial numbers used in their calculations, please see CISCO, CISCO VISUAL NETWORKING INDEX: GLOBAL MOBILE DATA TRAFFIC FORECAST UPDATE, 2009-2014 12 (2010), *available at* http://www.slideshare.net/danilogj/global-mobile-data-traffic-forecast-update-2009-2014; CISCO, CISCO VISUAL NETWORKING INDEX: GLOBAL MOBILE DATA TRAFFIC FORECAST UPDATE, 2010-2015 19 (2011), *available at* http://tmfassociates.com/blog/wp-content/uploads/2013/02/Cisco-mobile-VNI-Feb-2011.pdf; CISCO, *supra* note 99, at 24; CISCO, *supra* note 89, at 27; CISCO, *supra* note 100 . Data were extrapolated using lagged growth rates for wireline Internet traffic.

Chart III-1: Cisco North American Mobile Traffic Estimates and Projections



Sources: Cisco Global Mobile Data Traffic Forecast; Cisco Visual Networking Index; author's calculations

3. Pricing and Business Developments

Mobile demand, even if it could be directly measured, will usually exceed actual supply (i.e., mobile network traffic) due to carrier pricing and policy adjustments.[150] Most goods and services, for example, have elastic demand curves - as price increases, demand decreases and vice versa.[151] Mobile broadband is no exception, with carriers continually making a number of pricing adjustments during the boom in smart phone and mobile data usage.[152]

However few goods or services have pricing policies that change as rapidly as seen in the mobile broadband market, which faces demands for higher speeds and data usage at uncertain rates of change.[153] Moreover, it is not appropriate to interpret most carrier pricing adjustments as solely dedicated to reducing data usage. Between 2007 and 2010, most wireless operators, like AT&T, offered unlimited voice and data for relatively low monthly fees,[154] but have since ceased those plans,[155] now finding themselves in trouble for data throttling those who are still on the original plans.[156] As smart phone penetration increased during the 2010 - 2011 time frame, wireless companies began migrating users to plans with data caps, although some customers remained grandfathered into the original plan.[157] Incremental use beyond that of a fixed

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150 *See* Ford, *supra* note 13, at 2, 4 (noting that demand is not directly observable and that actual traffic represents a mix of demand- and supply-side factors, including price increases, offloading, and rationing).

151 Gerhard Adam, *Economic Theory – Supply and Demand*, SCIENCE2.0 (July 10, 2009), http://www.science20.com/gerhard_adam/blog/economic_theory_–_supply_and_demand.

152 Most notably, this occurred when major carriers began transitioning from unlimited to tiered data plans. *See, e.g.*, Peter Suciu, *Mobile users to carriers: 'Give me my unlimited data*,' FORTUNE (Sept. 13, 2012), http://fortune.com/2012/09/13/mobile-users-to-carriers-give-me-my-unlimited-data.

153 INT'L TELECOMM. UNION & THE BROADBAND COMM'N, THE STATE OF BROADBAND 2014: BROADBAND FOR ALL 23 (2014), *available at* http://www.broadbandcommission.org/documents/reports/bb-annualreport2014.pdf.

154 Timothy Stenovec, *AT&T Sued for Reducing Speed of 'Unlimited' Data Plans*, HUFFINGTON POST (Oct. 28, 2014), http://www.huffingtonpost.com/2014/10/28/att-slowing-speeds-data-throttling-ftc_n_6062360.html; Sinead Carew, *Verizon to eliminate unlimited data plans*, REUTERS (July 5, 2011), http://www.reuters.com/article/2011/07/05/us-verizonwireless-tiered-data-idUSTRE7645SF20110705; Lisa Eadicicco, *Which Carrier is the Best? Here's How Data Prices Compare for Verizon, AT&T, Sprint, and T-Mobile*, BUS. INSIDER (Sept. 20, 2014), http://www.businessinsider.com/verizon-vs-att-sprint-tmobile-carrier-data-plan-pricing-2014-9 (until 2010 each of the four major U.S. carriers offered unlimited data plans to new customers; Verizon and AT&T have discontinued new unlimited data plans).

155 JR Raphael, *Smartphone Data Shake-Up: The End of 'Unlimited*,' COMPUTERWORLD (Feb. 8, 2012, 6:00 AM), http://www.pcworld.com/article/249532/smartphone_data_shake_up_the_end_of_unlimited.html.

156 Lisa Schifferie, *FTC sues AT&T for limiting "unlimited data*," FED. TRADE COMMISSION (Oct. 28, 2014), http://www.consumer.ftc.gov/blog/ftc-sues-att-limiting-unlimited-data.

157 Stenovec, *supra* note 154; Sinead Carew, *AT&T to end unlimited use mobile data plan*, REUTERS (June 2, 2010), http://www.reuters.com/article/2010/06/02/us-att-idUSTRE6513H120100602 (stating that AT&T eliminated unlimited data plans for new

plan was no longer free for most users.[158] Partially as a result, usage, particularly among heavy users declined significantly.[159] Evidence shows much of the decline was due to a reduction in usage in the top 1% of users, whose usage declined from 52% in 2010 to 18% in 2014.[160]

It is unclear, however, whether the carriers' primary motivation for ending unlimited data plans for new subscribers was spectral capacity. While the end of the unlimited data plans may have been implemented partly to control usage to ensure quality of service, it may also reflect a desire of the wireless carriers to increase revenue and leverage increase market power following several years of mergers that increased industry concentration.[161] Allowing existing customers to keep their unlimited plans (even if subject to potential throttling) also creates high switching costs for users who would lose those plans if they switched providers. This potentially lowers expensive subscriber churn for the carriers. At the same time, carriers have persisted in some policies that increase data usage, including the reintroduction of unlimited data plans.[162]

Analysts forecasting spectrum demand rarely have access to detailed information about carriers' business plans or technology rollout, and therefore must make assumptions that results in inaccurate data forecasts.[163] This puts them at a significant disadvantage when predicting demand induced by changes in technology implementation and/or pricing. However, none of these business plans were unforeseeable, and demand projections that employed proper risk

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customers on June 7, 2010); Carew, *supra* note 154 (stating that Verizon eliminated unlimited data plans to new customers on July 7, 2011); Tero Kuittinen, *AT&T and Verizon are about to put the squeeze on subscribers*, BGR (June 21, 2013), http://bgr.com/2013/06/21/att-verizon-fees-analysis (noting that AT&T and Verizon account for approximately 65% of U.S. subscribers); Eadicicco, *supra* note 154 (noting that T-Mobile and Sprint have retained their unlimited data plans).

158 Stenovec, *supra* note 154; Carew, *supra* note 154; Eadicicco, *supra* note 154 (stating that data plans no longer allowed for unlimited usage, but now provided fixed data plans, with the exception of T-Mobile and Sprint that still issue unlimited data plans).

159 J. Armand Musey, *Wireless Demand Projections- Elasticity of the Top-1% of Users*, GA GOLDIN ASSOCIATES (Jan. 26, 2014), http://www.goldinassociates.com/blogs/telecom-media-tech/wireless-demand-projections-elasticity-of-the-top-1-percent-users/; *see* CISCO, *supra* note 89, at 17 (stating that unlimited data plans dropped from 81% to 45%, while tiered data plans grew during a three year study from 2011-2013).

160 CISCO, *supra* note 14, at 2.

161 Jon Brodkin, *Analysis: Wireless data caps more about profit than congestion*, ARS TECHNICA (Oct. 8, 2014), http://arstechnica.com/staff/2014/10/analysis-wireless-data-caps-more-about-profit-than-congestion; Steven Musil, *AT&T completes $1.2B acquisition of Leap Wireless,* CNET (Mar. 13, 2014), http://www.cnet.com/news/at-t-completes-1-2b-acquisition-of-leap-wireless/.

162 Victor Luckerson, *Unlimited Data Plans: Are They Coming Back From the Dead?*, TIME (Aug. 23, 2012), http://business.time.com/2012/08/23/unlimited-data-plans-are-they-coming-back-from-the-dead.

163 Crowley, *supra* note 92.

analysis tools could have included the possibility of such business plan changes in their models, rather than consistently citing data projections from external sources or reporting only a single scenario.[164] Cisco, for example, cited the move to tiered business plans as one reason for its large downward revision of its 2011-2016 mobile demand forecasts.[165] In recent months, the U.S. wireless industry has begun to lower prices and embrace unlimited data plans once again, as well as more aggressively marketing data-share plans.[166] This is clearly not a move it would do if facing a situation of spectrum exhaust. As a result, we expect an increase in usage as zero-cost marginal pricing will encourage usage with minimal value.

More fundamentally, the definition of mobile "demand" is uncertain and can change depending on context. If the definition of demand is demand with no marginal cost, it is likely to be quite high.[167] From a policy perspective, it is questionable whether demand at no marginal cost is an appropriate measure of social need.[168] Supplying spectrum to mobile broadband based on demand at zero marginal cost encourages people to use spectrum for purposes with minimal value and risks, depriving allocation for other uses with much higher marginal value.[169] However, demand measured at a certain price per MB is also problematic. Future applications may require multiples of throughputs, just as today's applications require multiples of bandwidth of applications in use 5 to 10 years ago.[170] If projections assume the price per MB remains constant, aver-

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164 *Id.*

165 CISCO, *supra* note 89, at 4.

166 Luckerson, *supra* note 162.

167 William Spaulding, *Pure Monopoly: Demand, Revenue and Costs, Price Determination, Profit Maximization and Loss Minimization*, THISMATTER.COM, http://thismatter.com/economics/pure-monopoly-demand-revenue-costs-profits.htm (last visited Mar. 7, 2015) (referring to the Price Determination model, which shows high demand when marginal cost is at zero).

168 A similar argument can also be made for wireless demand for fixed applications (wireline substitution). Is it appropriate for such demand to be considered, for public policy purposes, as a measure of social need given that a wireline alternative is available? We do no attempt to resolve this issue in this paper, but flag it for future discussion.

169 At zero marginal cost, individuals would use bandwidth until marginal benefits are zero, for example, by using mobile broadband even when comparable Wi-Fi networks with less capacity restrictions are available. *See* Austin Frakt, *Simply put: Marginal cost/benefit*, THE INCIDENTAL ECONOMIST (Feb. 18, 2011), http://theincidentaleconomist.com/wordpress/simply-put-marginal-costbenefit (relating a similar dynamic in health care, where if the cost of medical care was $0, individuals would use medical services indiscriminately without regards to overall or societal cost until the marginal benefit also equals $0).

170 *In the Matter of Inquiry Concerning the Deployment of Advanced Telecommunications Capability to all Americans in Reasonable and Timely Fashion and Possible steps to Accelerate Such a Deployment Pursuant to Section 706 of the Telecommunications Act of 1996 as Amended by the Broadband Data Improvement Act,* 2015 Broadband Progress Re-

age consumer bills would increase to many multiples of current bills. This would clearly be unaffordable for most consumers, and does not take into account properly both increasing spectral efficiency and increasing cell site densification, which both reduce overall spectrum need[171] and have led to steadily decreasing per-unit costs in the mobile industry.[172] Clearly, demand modeling needs to assume some marginal cost, but one that declines over time to match the increasing availability of technology to deliver throughput at reasonable prices.

4. Offloading and Other Technological Developments

a. Rapid growth in Wi-Fi offloading

Offloading to small cells or Wi-Fi networks is another significant driver of wireless demand changes. Globally, traffic offloaded onto fixed networks increased from 31% (14.3 PB/month)[173] in 2010 to 46% (1.2 EB/month) in 2014.[174] This traffic bypasses the carriers' networks, reducing the carriers' need for dedicated spectrum to accommodate mobile traffic.[175] Given the increasing ease of Wi-Fi deployment[176] and growing consumer expectation of Wi-Fi availability,[177] it is likely the trend towards increasing Wi-Fi offloading will increase. Additionally, the FCC has proposed adding up to 195 MHz in the 5 GHz band of spectrum for unlicensed access that supports Wi-Fi and similar transmission technologies, and 100 MHz in the 3.5 GHz band for small-cell

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port, 30 FCC Rcd 1375 para. 29-32, *available at* https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-10A1.pdf.

171 *See* FED. COMMN'CS COMM'N, *supra* note 34, at 6.

172 Roger Entner, *Entner: What is the price of a megabyte of wireless data?,* FierceWireless, http://www.fiercewireless.com/story/entner-what-price-megabyte-wireless-data/2011-04-13.

173 CISCO 2010-2015, *supra* note 149, at 2.

174 CISCO, *supra* note 14, at 22.

175 Kyunghan Lee et al., *Mobile data offloading: how much can WiFi deliver?,* 21 IEEE/ACM TRANSACTIONS ON NETWORKING 536, 536 (2012), *available at* http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6353239.

176 *iPass Wi-Fi Growth Map Shows 1 Public Hotspot for Every 20 people on Earth by 2018*, IPASS, http://www.ipass.com/press-releases/ipass-wi-fi-growth-map-shows-one-public-hotspot-for-every-20-people-on-earth-by-2018/ (last visited May 8, 2015) (estimating that Wi-Fi hotspots will increase from 47.7 million hotspots globally at year-end 2014 to more than 340 million by 2018).

177 *Total Wi-Fi® device shipments to surpass ten billion this month*, WI-FI ALLIANCE (Jan. 5, 2015), http://www.wi-fi.org/news-events/newsroom/total-wi-fi-device-shipments-to-surpass-ten-billion-this-month (noting that roughly 4.5 billion Wi-Fi products are in use as of January 2015). Many contemporary devices, such as certain tablets, laptops, and smart entertainment devices, can access broadband service only through Wi-Fi.

use on a shared basis.[178] More than 1000 MHz of additional spectrum currently used or shared by the U.S. federal government is under consideration for repurposing, much of it on a shared basis.[179] This additional spectrum is likely to facilitate additional offloading from wireless carriers' networks, particularly in urban environments where demand is highest and small cell sites most effective.[180]

Offloading was another major factor in Cisco's large downward revisions of its 2011-2016 demand estimates, although the company also cited a slowdown in new mobile laptop connections.[181] However, Cisco has been tracking offloading trends since at least 2010,[182] and such a large trend towards offloading again could have been predicted using reasonable risk management techniques and multi-scenario forecasting.

It is important to note that offloading does not represent a true supply-side adjustment in the larger context of spectrum policy.[183] Offloading is still wireless data transmission that uses spectral resources, albeit in an alternate, more socially optimal, configuration, especially in certain densely populated areas.[184] Moreover, offloading allows for the stratification of different types of mobile data; for many consumer applications with low quality-of-service requirements, Wi-Fi offers comparable service with no noticeable degradation, allowing exclusive-use mobile spectrum to better serve highly sensitive needs.[185] Thus, offloading represents the most tangible and important example of the direct tradeoff that regulators must make when allocating spectral resources and highlights alternative arrangements to exclusive-use licenses that can satisfy increases in mobile demand.

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178 *In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 13-49, 28 FCC Rcd 1769 para. 2 (Feb. 20, 2013).

179 U.S. DEPT. OF COMMERCE, *supra* note 124, at 6, 19.

180 WIRELESS 20/20, CARRIER WIFI OFFLOAD: BUILDING A BUSINESS CASE FOR CARRIER WIFI OFFLOAD 2-3 (2012), *available at* http://www.wireless2020.com/docs/CarrierWiFiOffloadWhitePaper03202012.pdf (noting that return of investment for offloading scales with population density).

181 CISCO, *supra* note 89, at 2-3.

182 CISCO 2010-2015, *supra* note 149, at 2.

183 *See* Ford, *supra* note 13, at 3.

184 *See, e.g.*, MONICA PAOLINI, SENZA FILI CONSULTING, THE ECONOMICS OF SMALL CELLS AND WI-FI OFFLOAD 2 (2012), *available at* http://www.senzafiliconsulting.com/Portals/0/docs/Reports/SenzaFili_SmallCellWiFiTCO.pdf (noting that small cells and Wi-Fi can allow mobile operators to reduce total cost of ownership by 50%).

185 *See* SHUO DENG ET AL., WIFI, LTE, OR BOTH?: MEASURING MULTI-HOMED WIRELESS INTERNET PERFORMANCE, PROCEEDINGS OF THE 2014 CONFERENCE ON INTERNET MEASUREMENT 181 (2014) (noting that WiFi outperforms LTE 40% of the time for mobile data transfers of various sizes).

b. Compression/Network Management Technology Improvements

Wireless compression technology has improved dramatically since the inception of the industry.[186] For example, LTE is approximately forty times as spectrally efficient as early second-generation (2G) wireless technology.[187] The impact of this compression has allowed carriers to increase the amount of traffic (in conjunction with densification) that they can accommodate on a given amount of spectrum.[188] Moreover, small cell deployments have significantly helped manage traffic in dense traffic areas.[189]

c. Combined Impact of Offloading and other Technologies is Significant

The combined impact of increased spectral efficiency, Wi-Fi offloading, network management, and densification are significant. A detailed technical analysis of these issues is beyond the scope of this paper.[190] However, consider an illustrative example of their combined implications on spectrum demand. Verizon's LTE network, which carries approximately 20% of U.S. wireless network traffic,[191] ran on only 22 MHz of spectrum (in the Upper 700 MHz C-Block using two 10 MHz channels) until the end of 2013,[192] while being generally considered one of the strongest U.S. networks, including in major metro areas.[193] This would imply a total need of only 100 MHz to handle the coun-

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186 FED. COMMC'NS COMM'N, *supra* note 3, at 41.

187 *See id.* at Exhibit 4-F.

188 *See id.* at 135 (explaining that, despite growth in industry speed requirements, compression and customer usage patterns may possibly slow growth in bandwidth needs).

189 *See* Kinney, *supra* note 84 (noting 10.2 million small cell units being used by 75 mobile network operators; of these, only 17,000 deployments were in rural or otherwise remote areas).

190 For a more detailed analysis of spectrum and network efficiency improvements, see LS TELECOM AG & TMF ASSOC., MOBILE SPECTRUM REQUIREMENT ESTIMATES: GETTING THE INPUTS RIGHTS 33 (LS Telecom 2014), *available at* http://www.lstelcom.com/fileadmin/content/marketing/Press_releases/IMT_Spectrum_Requirements_Final_Report_v107.pdf.

191 *Id.*

192 Farrar, *supra* note 129.

193 *See RootMetrics Issues First-ever National RootScore® Report on Consumer Experience of Mobile Carrier Performance*, PRWEB (Mar. 5, 2014), http://www.prweb.com/releases/2014/03/prweb11640701.htm (ranking Verizon with best overall performance in how each major MNO "network performed across data, call, and text testing, as well as which network was the most reliable and which was fastest overall"); Press Release, J.D. Power McGraw Hill Fin., Wireless Network Data Quality Performance Has Improved Considerably as 4G Service Coverage Becomes More Universal (Mar. 6, 2014), *available at* http://www.jdpower.com/press-releases/2014-us-wireless-network-quality-performance-study%E2%80%94volume-1 (noting that Verizon ranked highest in wireless network quality performance in all regions of the U.S.).

try's traffic, well below the FCC's 2010 projection that more than 524 MHz of spectrum would be needed to handle the same traffic.[194] Other carriers also have large blocks of unused spectrum or spectrum that is reserved for older, less efficient technologies.[195] Current LTE technology operates at a theoretical maximum downlink capacity of approximately 1.7 to 2.7 bits/Hz/cell, depending on antenna configuration.[196] The next generation, LTE-Advanced, is expected to operate at between 2.4 and 3.7 bits/Hz/cell, which would represent a capacity increase of roughly 40% for similar devices, in addition to providing significant increases in uplink capacity.[197] It is not clear that carriers will truly face spectrum exhaust once they properly refarm existing allocations to utilize the latest, most efficient transmission technologies. Moreover, while conservative policies regarding spectrum allocation for mobile broadband may create capacity shortages of services in periods of rapid demand growth,[198] the greatest shortages are likely to be in highly populated cities where terrestrial alternatives are most widely available.[199]

B. Economic and Psychological Explanations

If pure methodological issues, technological changes, or business developments were the primary explanations for forecasting bias, one might expect that estimates would improve over time. The long history of inaccuracy and revision in demand estimates, including major recent revisions, suggest other underlying explanations.[200] Moreover, if estimates were neutral, the number of projections that overestimate demand should be roughly equal to those that underestimate demand. This suggests a systematic tendency for overestimation. At least two major categories of psychological factors can help explain why demand estimates tend to show directional skew: optimism bias and stra-

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194 LS TELECOM AG & TMF ASSOC., *supra* note 190.

195 *See id.* (stating that not all of the 547 MHz of spectrum allocated in 2010 has even been deployed).

196 *See* Ian F. Akyildiz et al., *The evolution to 4G cellular systems: LTE-Advanced*, 3 PHYSICAL COMM. 217, 219, tbl. 1 (2010).

197 *See id.* at tbl. 1.

198 Hazlett & Leo, *supra* note 61, at 1099.

199 *See* FED. COMMC'NS COMM'N, NAT'L BROADBAND MAP, BROADBAND STATISTICS REPORT: BROADBAND AVAILABILITY IN URBAN VS. RURAL AREAS 6, 8 (2015), *available at* http://www.broadbandmap.gov/download/Broadband%20Availability%20in%20Rural%20vs%20Urban%20Areas.pdf (noting differences in broadband availability between rural and urban areas).

200 *See* Bent Flyvbjerg, *From Noble Prize to Project Management: Getting Risks Right*, 37 PROJECT MGMT. J. 5, 5 (2006) (detailing a new APA endorsed method of forecasting resulting from a study of inaccuracy in demand forecasts).

tegic misrepresentation.[201] Optimism bias is "a cognitive predisposition found with most people to judge future events in a more positive light than is warranted by actual experience," and represents a kind of forecasting blind spot.[202] Strategic misrepresentation is much more likely in cases where "where political and organizational pressures are high," and forecasters stand to gain direct benefit from overestimates.[203] It is difficult to think of a more politically charged forecasting issue than spectrum, given the strong statutory oversight of licenses and the large amount of revenue that spectrum auctions can generate.

1. Structural Issues May Exacerbate Psychological Biases

Spectrum policy faces structural issues that exacerbate psychological biases, oftentimes through subtle organizational dynamics and regulatory processes that unconsciously influence behavior. First, the analysts who create spectrum demand estimates are often wireless industry veterans, dependent on the industry for their livelihoods.[204] These estimates are often funded by companies with an interest in seeing greater amounts of spectrum allocated to wireless carriers, and who have preferences for a single large number absent of qualifiers or nuance.[205] Moreover, government officials often become dependent on corporate-provided data.[206] Even government-produced estimates are often outsourced to industry consultants with a client base that benefits from having more spectrum allocated to wireless broadband.[207] Professionals who have worked in the industry also often staff government telecommunications regulatory agencies.[208]

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[201] *Id.* at 6.

[202] *Id.*

[203] *Id.* at 7.

[204] *See* Allan Holmes, *Wireless Companies Fight for Their Futures*, THE CTR. FOR PUB. INTEGRITY (Mar. 21, 2014), http://www.publicintegrity.org/2014/03/21/14433/wireless-companies-fight-their-futures (illustrating the influence that companies like Verizon and AT&T exercise over spectrum demand estimates).

[205] *See id.* (illustrating the influence that companies like Verizon and AT&T exercise over spectrum demand estimates).

[206] *See, e.g.*, Statement of Michael J. Copps, Commissioner, Fed. Commc'ns Comm'n, Before the Senate Committee on Commerce, Science, & Transportation (Jan. 14, 2003), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-230241A4.doc.

[207] *See, e.g.*, In the Matter of Policies Regarding Mobile Spectrum Holdings, Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Report and Order, WT Docket No. 12-269, WT Docket No. 12-268 at para. 23, n.70 (June 2, 2014). Using statistics from a study sponsored by Cisco Systems, Inc. in a Report and Order, the FCC evaluates whether current allocation of spectrum promotes and preserves competition. *Id.*

[208] *See* Mark Green & Ralph Nader, *Economic Regulation vs. Competition: Uncle Sam the Monopoly Man,* 82 YALE L.J. 871, 876 (1973) (noting "a kind of regular personnel inter-

These professionals may be subject to some of these same biases as those who currently work in the industry.

Second, the most powerful industry players are MNOs, who benefit when there is more available spectrum because it allows them to spend less on infrastructure.[209] In contrast, groups favoring amateur or unlicensed allocation of spectrum are generally smaller and less established.[210] As such, they face significant organizational challenges in advocating for particular spectrum policies, many are not aware of the importance of spectrum to their interests, and they often have few resources to spend on advocacy.[211] MNOs, on the other hand, spend heavily to influence government telecommunications regulatory bodies on spectrum issues, both through formal lobbying and through informal methods such as commissioning academic studies, funding think tanks, and conducting general public relations campaigns.[212] Even when spectrum is real-

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change between agency and industry blurs what should be a sharp line between the regulator and the regulated, and can compromise independent regulatory judgment. In short, the regulated industries are often in clear control of the regulatory process"); *see generally* Jeffrey E. Cohen, *The Dynamics of the "Revolving Door" on the FCC*, 30 AM. J. OF POL. SCI. 689 (1986); *see* William Gormley, *A Test of the Revolving Door Hypothesis on the FCC*, 23 AM. J. OF POL. SCI. 665 (1979); *see generally* J.H. Snider, *The Art of Spectrum Lobbying: America's $480 Billion Spectrum Giveaway, How it Happened, and How to Prevent It From Recurring*, (New Am. Found., Working paper No. 19, 2007), *available at* http://www.newamerica.net/files/WorkingPaper19_SpectrumGiveaway_Snider.pdf; *see also* Timothy M. LaPira & Herschel F. Thomas III, *Revolving Door Lobbyists and Interest Representation*, 3 INT. GRP. & ADVOCACY 4, 6 (Jan. 21, 2014), *available at* http://www.palgrave-journals.com/iga/journal/v3/n1/pdf/iga201316a.pdf (noting that Commissioners of the FCC have previously worked in the broadcast industry).

209 *See* Yochai Benkler, *Unlicensed Wireless vs. Licensed Spectrum: Evidence from Market Adoption*, 26 HARVARD J. L. & TECH. 69, 141 (2012) (noting that "[l]icensed services use the exclusivity they acquire in auctions as a substitute for capital investment in physical infrastructure").

210 For example, the Wireless Internet Service Providers Association is the leading trade group for small wireless Internet service providers ("WISPs") that often use unlicensed spectrum. It has a membership of 800 WISPs, and estimates all WISPs service approximately 3 million people. Even if every WISP was a member, the average WISP would serve 3,750 members. The actual average size is likely considerably smaller since not every WISP is a member. These WISPs would have collective organizing problems in advancing preferred policy positions, and collectively would have far fewer revenues than major MNOs.

211 Benkler, *supra* note 209, at 161.

212 *See* Holmes, *supra* note 204

> The four biggest carriers together spent $37.3 million in 2013 trying to influence lawmakers and the FCC on a host of policy issues ranging from taxes to cyber security as well as spectrum . . . . But the carriers led by AT&T and Verizon likely have spent at least twice as much more on behind-the-scenes influence campaigns — hiring Ivy-league academics, giving cash to think tanks, associations and universities, and employing public relations firms — all part of a synchronized effort to sway the FCC to establish rules that favor them.

Id.

located to new entrant wireless carriers, incumbent users are less likely to argue about whether the wireless carrier actually needs the spectrum.[213] Rather, they are likely to argue their rights under their existing licenses.[214] As a result, regulatory bodies typically do not receive balanced input from all affected parties.[215] In addition, equipment providers have incentives to assist the efforts of MNOs, since equipment companies typically develop new hardware to take advantage of reallocated spectrum.[216]

Finally, most large companies want to look successful to their investors and to banks supplying them with capital. A need for more spectrum implies a rapidly growing and successful industry. For these reasons, it is often in the best interest of wireless veterans to be overly generous in their estimation techniques and methodologies.

2. Potential Countervailing Influences to Consider

In addition to economic and psychological factors that can cause estimates to be inaccurate, there are also factors that can improve the accuracy of estimates that would otherwise be inaccurate. Demand estimates can become self-fulfilling if the industry organizes to prepare to them. If the wireless industry invests in capacity to handle a certain level of demand, then it faces little marginal cost for supplying that level of bandwidth, and it may then lower prices to minimize excess capacity from going to waste. We are likely seeing this trend today. Demand is lower than prior projections and unlimited data plans and aggressive data plan discounting are making a comeback with major carriers.[217] In this way, the process of measuring demand may, to an extent, shape that demand.

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213 *See* Benkler, *supra* note 209, at 157.

214 Benkler explains that when auctions are uncapped, large carriers are able to buy so much spectrum as to have a market foreclosure effect on other carriers. When bidding, large incumbents are not just paying for the right to use that spectrum, but are willing to pay a higher value if the aggregate effect of buying such a large proportion shuts out other competitors. Thus, incumbents may feel their licenses should protect not only their spectrum rights, but their right to certain market dominance as well. *See id.* at 158.

215 *Id.* at 161.

216 *See* Mobile Spectrum Holdings, *supra* note 207, at para. 71 (noting that the amount of spectrum available for auction depends on "suitability," which is partially determined by the availability of compatible equipment technology).

217 *See* In the Matter of Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993, Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services, Seventeenth Report, WT Docket No. 13-135 at para. 135 (Dec. 18, 2014) (acknowledging the industry-wide price cuts for certain data tiers among all four nationwide wireless service providers).

Countervailing influences and the tendency towards "self fulfillment" of projections are not dominant. Projections used by policy makers seem, on the whole, to exceed actual demand results, despite factors that may help shape demand to meet projections. Policymakers may have legitimate reasons for wishing to stimulate wireless demand, such as increasing overall social welfare, but the appropriate manner to do this would be through transparent processes, not through adoption of flawed demand projections to justify policy decisions.

IV. METHODS TO MITIGATE BIAS

The issue of biased estimates is common in many industries, such as transportation and supply chain planning.[218] Inaccurate traffic estimates are particularly well documented in the area of government-funded transportation infrastructure projects such as roads and rail.[219] In many of these projects, costs are underestimated while benefits are overestimated.[220] This may, in part, be due to the political nature of many transportation funding debates, a process not unlike that seen in spectrum policy debates.[221] In order to garner support for an infrastructure project, it is often necessary to illustrate dramatic beneficial results.[222] At the same time, many of these projects have long timeframes for planning and buildout,[223] delaying the process of comparing impacts against initial and interim predictions. By this time, the analysts who issued these reports, or politicians that utilized them to advance a project, may be in other positions where they are unlikely to be affected by the inaccuracy.[224]

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218 *See* Soora Rasouli & Harry J.P. Timmermans, *Uncertainty in Travel Demand Forecasting Models: Literature Review and Research Agenda*, 4 TRANSP. LETTERS: INT'L J. TRANSP. RES. 55, 56 (2012) (identifying the bias in "travel surveys"); Anshuman Gupta & Costas D. Maranas, *Managing Demand Uncertainty in Supply Chain Planning*, 27 COMPUTERS & CHEM. ENG'G 1219 (2003).

219 *See* Flyvbjerg, *supra* note 200, at 6 (noting that in transportation projects "[m]ore often than not, the information that managers use to decide whether to invest in new projects is highly inaccurate and biased, making projects highly risky," and that "transportation projects are no worse than other project types in this respect").

220 *See* Bent Flyvbjerg, *Policy and Planning for Large Infrastructure Projects: Problems, Causes, Cures* 2 (World Bank Policy Research, Working Paper No. 3781, 2005), *available at* http://core.ac.uk/download/pdf/6521546.pdf.

221 Rasouli & Timmermans, *supra* note 218 (noting that uncertainty is present in numerous fields, and becomes particularly relevant when, among other factors, a strong political division exists and financial risks are high).

222 Flyvbjerg, *supra* note 200, at 13.

223 *See* Flyvbjerg, *supra* note 220, at 1,7 (noting that large infrastructure project have long planning horizons and long construction periods, and are also typically delayed).

224 *See* Flyvbjerg, *supra* note 200, at 13.

Attempts in other industries to mitigate similar issues suggest a path forward for spectrum policy as well.[225] Planners have developed several tools and methods that help mitigate bias in estimates.[226] One well-known example of an industry attempting to tackle biases in estimates and projections was when the U.S. Securities and Exchange Commission brought enforcement action against ten Wall Street brokerage firms in 2002-2003.[227] Regulators were concerned that Wall Street research analysts were producing overly optimistic estimates to curry favor with investment banking clients, and developed a set of rules that may benefit spectrum planners as well.[228]

A. Improving Forecasting Processes

The American Planning Association, based on the results of a 2005 study of inaccuracies of demand forecasts for public works projects, endorsed a new forecast method called "reference class forecasting."[229] Conventional forecasting takes an insider's perspective, relying on industry-specific knowledge and processes.[230] The idea behind reference class forecasting is to take the "outside view" of the events being forecast based on the results of similar projects.[231] In particular, reference class forecasting considers the distribution of the accuracy of prior projections from similar events.[232] It then evaluates and "de-biases" the initial results of the subject by overlaying average error ranges found in the earlier reference projections.[233] By these means, the method reduces optimism bias and reduces psychological, political, and organizational pressures.[234] Experimental evidence has shown that this process produces better results than conventional methods.[235]

Spectrum managers might also benefit from such a method. However, one challenge of using reference class forecasting in a rapidly changing industry, such as wireless communications, is that the factors underlying forecasting

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225 *See, e.g.*, Gupta & Maranas, *supra* note 218, at 1226 (incorporating demand uncertainty into supply chain management).

226 *See, e.g.*, *id.* at 1220 (outlining a framework for incorporating uncertainty about demand in supply chain programming).

227 *SEC Fact Sheet on Global Analyst Research Settlements*, U.S. SEC. EXCHANGE COMMISSION, http://www.sec.gov/news/speech/factsheet.htm (last updated Apr. 28, 2003).

228 *Id.*

229 Flyvbjerg, *supra* note 200.

230 *See id.* (comparing to reference class forecasting which has an "outside view").

231 *Id.*

232 *Id.*

233 *Id.* at 8.

234 *Id.* at 7.

235 Dan Lovallo & Daniel Kahneman, *Delusions of Success: How Optimism Undermines Executives' Decisions*, HARV. BUS. REV., July 2003, at 56, 61.

errors can change over time.[236] In one case it might be price changes by carriers; in another, changes in the rate of Wi-Fi offloading; and in a third, miscalculations about the impact of new applications.[237] As a result, the errors of the past might not be relevant for understanding the errors in the current subject forecasts. In addition, other than historical demand for telephony and wireline broadband, which developed in significantly different regulatory and technological environments, it is difficult to identify relevant reference classes for wireless broadband.

Nonetheless, reference call forecasting might be useful in identifying potential psychological, political, and organizational biases in forecasts. At minimum, considering historical errors alongside current forecasts can give users a better idea about the likely accuracy of forecasts.[238] In the case of spectrum demand forecasts, this would mean including other, similar projections in analyses, especially those conducted by external parties.[239] Analysts would be free to explain differences in their methodologies that might make their analysis more accurate, but including this information would give users a much better appreciation of the likely limits of the forecast they are reading.

B. Increased Transparency

Spectrum demand estimates also suffer from a lack of methodological transparency. As noted above, industry associations and companies often do not disclose sources or methods for competitive reasons.[240] Cisco, in addition, removes from easy access prior estimates when it releases new versions of its VNI report.[241] This hinders people from evaluating the accuracy of projections in the prior report and considering them in the context of and against changes in methodology in the current report. Moreover, Cisco, like Worldcom, is

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236 For example, the Apple App Store had grown to 1 million apps and more than 60 billion total downloads in late 2013, just five years after launch. *See* Nathan Ingraham, *Apple announces 1 million apps in the App Store, more than 1 billion songs played on iTunes radio*, THE VERGE (Oct. 22, 2013), http://www.theverge.com/2013/10/22/4866302/apple-announces-1-million-apps-in-the-app-store.

237 For example, in 2013 Cisco cited the implementation of tiered mobile data packages, a slowdown in new mobile-connected laptop growth, and increases in offloading, in lowering previous year traffic estimates. *See generally* CISCO, *supra* note 89.

238 Flyvbjerg, *supra* note 200, at 9.

239 *Id.*

240 U.S. GOV'T ACCOUNTABILITY OFFICE, *supra* note 19, at 16-17.

241 For example, as of the time of publication, only the most recent VNI report was posted online at Cisco's VNI website. *See* CISCO, *supra* note 14, at 39-40.

uniquely positioned within its industry and may be able to lend additional credibility to its reports by maintaining their proprietary nature.[242]

Other industries use historical "batting averages" to evaluate the claims of forecasters.[243] One example, as mentioned above, is 2002-2003 government-led reforms in the financial sector when regulators became concerned that Wall Street research analysts were publishing biased research that inflated company prospects.[244] In particular, regulators found that Wall Street research analysts at brokerage firms had inflated the prospects of the companies they followed.[245] This put investors at risk.[246] Part of the resulting global settlement the major brokerage firms entered into with the government was to require each research report to contain a graphic of the history of the firm's recommendations for that company's stock.[247] In this way, investors could evaluate the recommendation in context with the analyst's "track record."[248]

It is difficult to measure whether or not the inclusion of a prior forecasts' track record helps improve accuracy of forecasts. However, it provides the user with some context about the historical reliability of the projections.[249] Such information should not be difficult for a spectrum analyst to provide and could be helpful to policy users of the information.

C. Accountability

Another method for improving reliability of data (as well as to address a multitude of other issues) is to make specific individuals accountable for the accuracy of their reports. In the case of spectrum demand projections, they are often published without individual author names, so that a reader has little idea who conducted the analysis or signed off on results.[250] Thus an analyst has little

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242 Sidak, *supra* note 58.

243 *See SEC Fact Sheet on Global Analyst Research Settlements*, *supra* note 227 (noting that "[a]n analyst's compensation will be based in significant part on the quality and accuracy of the analyst's research").

244 Gretchen Morgenson, *Wall Street's Analysis Put on the Defensive at a Hearing*, N.Y. TIMES, June 14, 2001, at C4.

245 *See SEC Fact Sheet on Global Analyst Research Settlements*, *supra* note 227.

246 Morgenson, *supra* note 244.

247 *See SEC Fact Sheet on Global Analyst Research Settlements*, *supra* note 227 ("Each quarter, each firm will publish on its website a chart showing its analysts' performance.").

248 *See id.* (setting out the requirements of the analyst's "track record").

249 *See id.*

250 *See, e.g.*, CISCO 2010-2015, *supra* note 149, at 1 (noting the lack of named authors); *see, e.g.*, CISCO, *supra* note 89, at 1 (noting the lack of named authors); *see, e.g.*, CISCO, *supra* note 100, at 1 (noting the lack of named authors); *see, e.g.*, CISCO, *supra* note 14, at 1 (noting the lack of named authors).

fear of being "caught" or called out if their projections are widely off the mark.[251]

Standard procedure in many areas of finance is to require analysts to sign reports indicating that their contents reflect the analyst's views.[252] Some analysts are also required to attest that they met various standards of independence and followed certain professional standards in developing estimates.[253] Analyst accountability does not guarantee accuracy.[254] However, without accountability, as is currently the standard with spectrum demand forecasts, the odds for negligence or abuse increase.

D. Avoid Conflicts of Interest

Many industries have processes and procedures for avoiding conflicts of interest.[255] The separation of the business and journalism sides of newspaper organizations,[256] and the tenure system for academics[257] are probably among the best-known examples of attempting to assure independence from conflicts of interest within an organization. Similarly, the government's settlement with Wall Street brokerage firms in 2003 limited the ability of firms to pay analysts based on investment banking revenue.[258] However, it can be difficult to ensure the independence of analysts when a firm's business is so deeply involved in specific, esoteric industry issues.[259] A firms' likely response, even if this could

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251 Flyvbjerg, *supra* note 200, at 13.

252 *See* THE APPRAISAL FOUND., APPRAISAL STANDARDS BD., UNIVERSAL STANDARDS OF PROFESSIONAL APPRAISAL PRACTICE U-84 (2014-2015 ed. 2014), *available at* www.uspsp.org. Also note the attestation requirement for Wall Street research analysts ("Regulation AC"). *Responses to Frequently Asked Questions Concerning Regulation Analyst Certification*, U.S. SEC. EXCHANGE COMMISSION (Apr. 16, 2005), http://www.sec.gov/divisions/marketreg/mregacfaq0803.htm.

253 *See Responses to Frequently Asked Questions*, *supra* note 252 (discussing Regulation AC's analyst requirements).

254 *See* Brad M. Barber et al., *Comparing the Stock Recommendation Performance of Investment Banks and Independent Research Firms*, 85 J. OF FIN. ECON. 490, 516 (2007) (providing that analysts at investment banks and independent research firms are inconsistent in terms of accuracy when it comes to buy/sell/hold recommendations by the analysts in times of close regulatory scrutiny).

255 *See, e.g.*, Model Rules of Prof'l Responsibility R. 1.7 (1983).

256 *See, e.g.*, *Statement of Ethical Principles*, ASSOCIATED PRESS MEDIA EDITORS http://www.apme.com/?page=EthicsStatement (last visited Mar. 7, 2015) ("Advertising should be differentiated from news…[the newspaper] should not give favored news treatment to advertisers or special-interest groups.").

257 *See 1940 Statement of Principles on Academic Freedom and Tenure*, AM. ASS'N OF UNIV. PROFESSORS, http://aaup.org/report/1940-statement-principles-academic-freedom-and-tenure (last visited Mar. 7, 2015) (describing the "academic freedom" of teacher tenure).

258 *See SEC Fact Sheet on Global Analyst Research Settlements*, *supra* note 227.

259 Lori Richards, Director, Office of Compliance Inspections and Examinations, Sec.

be effectively done, would be to only hire analysts whose views tend towards the far end of the range that supports their goals.

Even before the Wall Street brokerage settlement, analysts covering brokerage stocks did not make recommendations on their own firm's stock.[260] This was seen an insurmountable conflict of interest.[261] The best way of insulating from conflicts of interest is to ensure they arise outside of self-interested firms.[262] Thus, projections from independent research firms are likely to be less susceptible to bias,[263] and governments should rely primarily on such estimates in developing national spectrum policy. As FCC Commissioner Copps said regarding using Internet traffic growth estimates from regulated carriers, "We must commit to doing the hard work of collecting our own data rather than relying on potentially misleading and harmful financial, accounting, and market information produced by corporate sources subject to clear biases and market pressures."[264]

V. POLICY ANALYSIS AND CONCLUSIONS

A. Reducing the Need to Use Unreliable Projections

In addition to more general process changes to mitigate bias, several alterations to how spectrum policy itself is conducted may reduce the need to rely on demand projections. In particular, in the face of rapidly evolving wireless technology and uncertain, unreliable estimates, spectrum regulators should maxim-

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and Exch. Comm'n, Speech to the Financial Women's Association: Analysts Conflicts of Interest: Taking Steps to Remove Bias (May 8, 2002) (transcript available at http://www.sec.gov/news/speech/spch559.htm) (citing a variety of undisclosed factors that the SEC believe affect the independence of analysts).

260 Based on co-author J. Armand Musey's experience working as a senior research analyst at several major Wall Street securities firms during this time period.

261 *See, e.g.*, Jessica Menton, *Regulators Fail to Police Conflicts of Interest Among Wall Street Analysts, Study Says*, INT'L BUS. TIMES, (Nov. 10, 2014, 3:41 PM), http://www.ibtimes.com/regulators-fail-police-conflicts-interest-among-wall-street-analysts-study-says-172151 (citing the case of Jenifer Jordan, who was fined for non-disclosure of a new job offer by the company who was subject to her reports).

262 *See* Richards, *supra* note 259 ("The rules prohibit research analysts from being supervised by the investment banking department…[a]nalysts will also be prohibited from sharing draft research reports with target companies.").

263 Barber et al., *supra* note 254.

264 Statement of Michael J. Copps, *supra* note 206.

ize flexibility to adjust rules and uses, to ensure timely and proportional adjustments to allocations in the face of novel developments.[265]

First, since wireless clearings are so expensive and time-consuming, there is strong pressure to begin reallocation procedures as soon as possible.[266] However, demand also changes rapidly, so regulators should build into spectrum policy a regular and periodic process for re-evaluating spectrum inventory and needs. This would involve closely examining trends in network technology, infrastructure deployments, and auction revenue to re-estimate the need and utility of additional clearing, rather than automatically assuming unlimited growth in demand.

Second, there is significant uncertainty about future application growth and traffic management. In particular, there is no consensus about how many applications will truly require the extremely high quality of service of licensed spectrum;[267] in real-world measurements, Wi-Fi continues to offer superior speeds over 3G and 4G wireless, and is more easily able to support key uses such as high-definition video streaming.[268] In the face of this uncertainty, regulators should take a default position of favoring shared spectrum bands—including unlicensed bands—requiring minimal incumbent relocation. Unlicensed bands, for instance, make licensed spectrum more valuable (offloading peak demand being just one example), facilitate diversity of applications, lower barriers to entry, and provide the government consistent long-term revenue (from unlicensed device and service innovation and sales tax) over the one-time proceeds provided by an auction.[269] Regulators have taken note of these factors. In its 2012 spectrum report, the President's Council of Advisors on Science and Technology ("PCAST") argued that spectrum sharing is the best (and in many cases, the only viable) method to allow greater overall utilization of federal spectrum.[270] The U.S. government currently has more than 1500 MHz of spectrum under investigation for repurposing, with a heavy emphasis on commer-

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265 *See* FED. COMMC'NS COMM'N, SPECTRUM POLICY TASK FORCE, *supra* note 11, at 7, 21, 26, 32-33 (suggesting the Commission's need to promote spectrum allocation flexibility).

266 *See* FED. COMMC'NS COMM'N, *supra* note 3, at 79 (noting that historically it has taken 6 to 13 years to reallocate spectrum, from first step to availability for use).

267 *See* Michael J. Marcus, *Spectrum Policy for Radio Spectrum Access*, 100 PROC. OF THE IEEE 1685, 1689-90 (2012) (noting that the "most rapidly growing sector of wireless use is not voice telephony with its strict latency requirements and constant throughput, but asymmetric data flows with widely varying rates").

268 See *U.S. Wi-Fi Report*, OPENSIGNAL (July 2014), http://opensignal.com/reports/2014/us-wifi/ (comparing download speeds of Wi-Fi vs. 3G and 4G).

269 *See* Werbach & Mehta, *supra* note 59 (detailing the benefits of shared spectrum).

270 PRESIDENT'S COUNCIL OF ADVISORS ON SCI. & TECH., *supra* note 75, at vi-vii.

cial-federal sharing, including some bands featuring unlicensed or general access usage rules.[271]

Third, regulators should immediately begin imposing stronger and more robust receiver standards on wireless devices, including more capable antennas and strong interference acceptance standards. This reduces interference issues that complicate repurposing of bands by minimizing the likelihood that adjacent users will be harmed by new types or patterns of interference.[272] Embedding advanced computational capacity into receivers would also facilitate subsequent changes to spectrum allocations, since wider-range antennas with advanced sensing and software capabilities can more easily share frequencies or relocate to adjacent bands.[273]

Fourth, to avoid the risks of spectrum allocation rules being overturned for being arbitrary and capricious, regulators are required to engage in "substantial inquiry" during rule-making processes.[274] The "presumption of regularity" cannot be used to prevent a "thorough, probing, in-depth review."[275] It is not clear whether basing a rulemaking on estimates that have proven inaccurate and have not been updated, meets this standard.[276] Continuing reliance on such forecasts raises particular concerns due to the financial impact of spectrum allocation decisions.[277] Moreover, agencies are required to justify their rule-making.[278] It is not clear that a justification based on such unreliable projections would be a sufficient agency defense, even under the *Chevron* standard of

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[271] U.S. DEPT. OF COMMERCE, *supra* note 124, at 6 (Table 2-1).

[272] *See* U.S. DEPT. OF COMMERCE, NAT'L TELECOMMS. AND INFO. ADMIN., REPORT 03-404 RECEIVER SPECTRUM STANDARDS PHASE 1 – SUMMARY OF RESEARCH INTO EXISTING STANDARDS iv (2003), *available at* http://www.ntia.doc.gov/files/ntia/publications/ntiareport03-404.pdf (providing that the FCC is considering such receiver standards and that the NTIA has receiver standards in place for federal users); *see also* MARK MACCARTHY, ASPEN INST., RETHINKING SPECTRUM POLICY: A FIBER INTENSIVE WIRELESS ARCHITECTURE 2 (2010), *available at* http://www.aspeninstitute.org/sites/default/files/content/docs/pubs/Rethinking_Spectrum_Policy.pdf (stating that there is a role for the FCC to play as a regulator in the development of minimum receiver standards).

[273] *See* PRESIDENT'S COUNCIL OF ADVISORS ON SCI. & TECH., *supra* note 75, at 31, 32 (noting new technologies that enable more dynamic, flexible spectrum sharing).

[274] Citizens to Preserve Overton Park v. Volpe, 401 U.S. 402, 415 (1971).

[275] *Id.*

[276] *See id.* (laying out the standard).

[277] *See Auction Summary*, FCC, http://wireless.fcc.gov/auctions/default.htm?job=auctions_all (last visited Apr. 10, 2014) (noting net bids of more than $120 billion since the FCC began auctioning spectrum licenses)

[278] 5 U.S.C. § 553(c) (2012).

agency deference.[279] Even if rules based on unreliable forecasts withstand challenges, they risk undermining the perceived credibility of agencies using them.

VI. CONCLUSIONS

Over time, government agencies may reduce their need for demand projections by facilitating more flexibility in spectrum bands. Currently, though, policymakers have little choice but to rely on some sort of projections of spectrum demand. Moreover, regardless of the exact demand, mobile broadband is growing, and political pressure to allocate more spectrum to MNOs is overwhelming. This reliance on projections is unlikely to completely disappear. Spectrum is limited and in high demand, so it must be allocated; this requires empirical input.

Government agencies, however, have a strong obligation to manage spectrum as efficiently as possible due to its finite, limited nature and public ownership. It is not just reasonable, but should be standard practice, for policymakers to use the best projections possible, to insist on high standards from those whose estimates they use, and to properly incorporate uncertainty and risk into their policy decisions. The current system falls far short of that goal, in our view. To the extent policymakers do not have confidence in projections, they should be more up-front about potential biases and errors and periodically reassess their decisions. This, in turn, requires governments to take measures to improve the quality of the forecasts they commission. Requiring outside experts to be transparent about data and method, to use and publish sensitivity analyses, to identify potential sources of error, to minimize conflicts of interest, and to avoid establishing a single projection as "fact" when it is known to be subject to uncertainty, are minimum first steps.

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[279] *See* Chevron U.S.A., Inc. v. Natural Resources Defense Council, Inc., 467 U.S. 837, 866 (1984).