Have We Got it All Wrong? Forecasting Mobile Data Use and Spectrum Exhaust

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Introduction

By most accounts, the current supply of licensed commercial spectrum is insufficient to meet the exponentially-growing demand for mobile data services.[1] Forecasts of future bandwidth demand paint a dire picture for the ability of carriers to satisfy demand, signaling a future of costly remediation efforts and higher prices. Governments across the globe are searching for ways to expand the amount of spectrum dedicated to the provision of mobile data by reallocating spectrum across uses. For example, here in the United States, Congress passed the Middle Class Tax Relief and Jobs Creation Act in 2012 to empower the Federal Communications Commission ("FCC") to hold a voluntary incentive auction to incent broadcasters to relinquish their spectrum for mobile broadband use.[2] Similarly, in 2013, the FCC allowed Mobile Satellite Service ("MSS") spectrum to be used for terrestrial broadband use.[3] And, of course, there are the on-going efforts to improve the use and management of government-held spectrum to potentially free up additional spectrum for mobile broadband use.[4] However, as spectrum is a scarce resource and there are many competing uses, these spectrum re-allocation and re-assignment efforts can be contentious.

As is typical of any adversarial process, there are (and should be) naysayers.[5] For example, a recent draft report entitled *Overestimating Wireless Demand: Policy and Investment Implications of Upward Bias in Mobile Data Forecasts* by Aalok Mehta and J. Armand Musey questions the urgency of the spectrum shortage by challenging the forecasts of mobile data demand and their use by policymakers to signal a looming crisis. Mehta and Musey claim that the predictions are plagued by "persistent errors" and "upward biases"[6] as evidenced by the fact actual mobile data usage is below forecast, due largely to traffic offloading (e.g., Wi-Fi), increases in spectral efficiency, and usage-dependent pricing.[7] As such, Mehta and Musey conclude that there is no serious crisis and that "[n]ew spectrum is only one mechanism among several for dealing with increasing mobile demand."[8]

> ***While Mehta and Musey are correct that there are always alternatives to procuring "more spectrum," it is exactly these alternatives that policymakers are attempting to avoid—including, primarily, the price rationing of limited capacity.***

Forecasting mobile wireless demand is not an enviable task. In recent times, the mobile industry has been highly dynamic, experiencing regular and significant shocks like the iPhone, tablet computing, and the explosion of data-intensive applications. These forecasts are, nevertheless, important and do play a role in guiding spectrum policy. The arguments made by Mehta and Musey reveal the need for some clarification on the economics of spectrum exhaust. While a number of fundamental errors contained in the Mehta-Musey study make its specific findings of limited policy relevance, it may serve as a useful template for clarifying some key aspects of spectrum exhaust and thereby help policymakers get a better handle on the issue. In this PERSPECTIVE, I discuss some of the underlying economics of spectrum exhaust using some of the arguments made in *Overestimating Wireless Demand* as a guide.

I will focus on three main issues: First, I demonstrate why Mehta and Musey's claim that demand forecasts over-estimate actual traffic largely misses the point. While Mehta and Musey assert that there are always alternatives to procuring "more spectrum," it is exactly these alternatives that policymakers are attempting to avoid—including, primarily, the price rationing of limited capacity. Forecasts of mobile data demand should, in fact, be higher than actual traffic, especially under spectrum exhaust, since actual traffic is affected by supply responses. Second, I will show that the FCC's prediction of a spectrum shortage is unaffected by Mehta and Musey's concerns. Third, I will briefly address the authors' erroneous claim that spectrum allocation is a zero-sum game.

Missing the Point

According to the title of their paper—*Overestimating Wireless Demand*—it appears that the authors intend to evaluate forecasts of wireless data *demand* and their policy relevance. Forecasting the global or regional demand for mobile data is an incredibly difficult task. Given the persistent dynamism of the market—including events like the release of the iPhone in 2007, the movement away from unlimited pricing in the United States in 2010, and even the widespread use of simple image-intensive applications like Instagram—a forecast of future demand is certain to have a wide forecast interval. More problematic is that demand is not directly observable; we see only actual traffic, which is a co-mingling of demand- and supply-side factors.[9]

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Whether a forecast is of demand or traffic is incredibly important. If the goal is to evaluate the accuracy of demand forecasts, then the standard by which accuracy is measured must be demand, not traffic. Demand is what consumers want, while traffic is a market outcome based on demand- and supply-side factors. As such, demand forecasts and market outcomes are generally not expected to be equal.

To illustrate why, consider the basic supply-and-demand graph with an upward sloping supply curve as illustrated in Figure 1. In the first period, demand is D_1, the supply curve is S, and the market equilibrium is the pair (P_1, Q_1). In the second period, demand increases to D_2, which is an increase in demand of ($Q_3 - Q_1$) units. However, because supply curve is upward sloping, market quantity only rises to Q_2 units, for a change equal to ($Q_2 - Q_1$), which is less than the demand change of ($Q_3 - Q_1$). Plainly, with an upward sloping supply curve, increases in demand (and its forecast) will always exceed the actual changes in market quantities.

Figure 1. Demand v. Equilibrium Forecasts

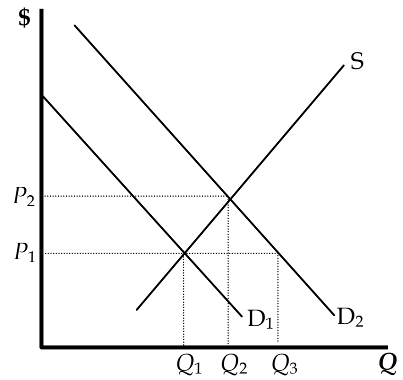
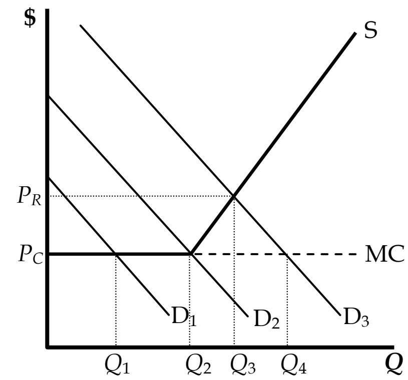


Figure 2. Forecasts and Spectrum Exhaust



This supply-and-demand analysis, while rudimentary, is fundamental to the problem of spectrum exhaust. If mobile carriers are short of spectrum, then the supply curve for mobile data will be upward sloping, reflecting the increased costs of expanding capacity. Practically, to the extent capacity cannot be expanded quickly enough, a shortage manifests as remedial measures to control or divert consumer demand to ration the scarce capacity. Today, the dominant supply-side mechanisms are Wi-Fi offloading and usage-dependent pricing, both of which are in heavy use and motivated by necessity and not necessarily by consumer preferences.

A slightly modified supply-and-demand model illustrates the problem of spectrum exhaust and the difficulty with demand forecasting. In Figure 2, we have a supply curve (labeled S) that is flat at marginal cost (labeled MC) up to quantity Q_2; an interval for which there is plenty of spectrum to satisfy demand. After Q_2, however, the supply curve is upward sloping. In the mobile data context, we can think of Q_2 as the point of spectrum exhaust; the upward sloping supply curve resulting from additional investments in towers and Wi-Fi networks, along with other means by which to increase capacity using relatively expensive means.

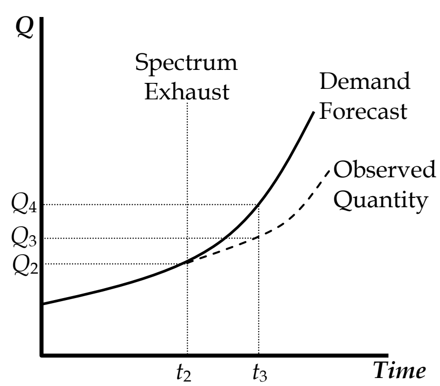
There are three demand curves in Figure 2, representing demand over time (D_1, D_2, D_3). Demand is growing so the vertical intercept of the demand curve is shifting up from year to year (that is, demand is growing by shifting up and to the right). In Period 1, with demand D_1, the equilibrium price is P_C (equal to marginal cost). In the next period, demand shifts up to D_2, but since there is plenty of capacity, the price remains at P_C. The change in output ($Q_2 - Q_1$) is equivalent to the increase in demand ($Q_2 - Q_1$). With plenty of spectrum, a forecast of demand could be reasonably evaluated for accuracy by looking at changes in actual marketplace quantities.

At Q_2, however, there is spectrum exhaust so that expanding output becomes costly. When demand shifts to D_3 in the next period, the consumer demand cannot be met at price P_C. To ration the costly capacity, price increases to P_R and quantity rises to Q_3. Now, increases in "demand" and increases "traffic" diverge. Demand has risen by the amount ($Q_4 – Q_2$), but the market quantity has risen only by the (smaller) amount ($Q_3 – Q_2$). If the upward sloping supply curve could be avoided (say, by giving more spectrum to the carriers), then Q_4 could have been provided at a price of P_C.

Now consider the implication of this simple supply-demand logic to the task of forecasting mobile *demand*. If we had naively forecast quantity in the third period based on an extrapolation of the earlier two periods (or many prior periods), then the forecast would have been too large in the third period because it ignored (or could not foresee) the influence of the upward sloping supply curve in the third period. The forecast would not over-state demand, but rather over-state traffic which has been suppressed by a rising price.

Figure 3 illustrates the difference between a demand forecast and the market outcome based on the logic of Figure 2. After spectrum exhaust (at Q_2), when the supply curve begins sloping upward, the demand forecast (or forecast based on extrapolations of historical data) exceeds the market outcome. Persistent over-estimates of demand relative to market outcomes are, therefore, a symptom of spectrum exhaust, not sufficient spectrum capacity.

Figure 3. Demand Forecasts, Market Outcome



Why is this important? Because if policymakers ignore prices, then there is no spectrum crisis and there never will be. By choosing price, carriers can always make sure that demand and supply are equilibrated (i.e., the carriers raise price to control usage rather than increasing capacity by activating additional spectrum). But, policymakers generally view higher prices as the problem, not the solution. In the same way life-saving surgery and death are substitutes, we normally don't treat the two as equals, yet Mehta and Musey would have us do so.

This brings us to the point of the pencil: *what constitutes spectrum exhaust*? Spectrum exhaust occurs when insufficient spectrum exists to accommodate the service demands of consumers and, as such, a carrier must ration the available spectrum among its users by some mechanism such as service price increases, off-loading, blunt quantity rationing (dropped calls or choked speeds), or the like. Such steps, though, are not the most efficient response when a reallocation of spectrum from less-valued uses is feasible. It is socially preferable that all spectrum be used in its most valuable way, rather than that some spectrum be wasted while other users are starved for it.

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Evidence of Overestimates

In some cases, the influence of supply-side counter measures is detectable in available data. We see an example of this in *Overestimating Mobile Demand*, when Mehta and Musey compare the FCC's assumed data growth rates to CTIA's reported U.S. data traffic.[10] Table 1 replicates portions of Chart III-5 from *Overestimating Mobile Demand*.

Table 1. Effective Data Demand
(Pedabytes "PD" per Year)

	2009	2010	2011	2012	2013
FCC Growth Factors	1.00	2.53	5.89	11.99	21.82
Predicted Traffic (M&M)		468	1,090	2,219	4,038
CTIA Reported Traffic	185	389	867	1,468	3,230
Predicted Offload	15%	15%	15%	15%	15%
Actual Offload	15%	20%	30%	40%	43%
Eff. Data Demand		409	1,020	1,957	4,486

The first row of the table provides the Commission's assumed growth rates from the 2010 FCC staff study supporting the National Broadband Plan—*Mobile Broadband: The Benefits of Additional Spectrum*.[11] These growth rates are based on an average of third-party (global) forecasts including the forecasts from Cisco's 2009 VNI Report.[12] The row "Predicted Traffic" is Mehta and Musey's traffic levels computed using the FCC's growth rates and CTIA's reported data figure for 2009.[13] A word of caution: CTIA's figures are not actual data use, but rather figures based on responses to its regular survey of commercial mobile carriers. Not all carriers report data figures to the CTIA, so these figures are at best lower bounds on data traffic in the U.S. market.[14]

By comparing the "Predicted Traffic" to CTIA's reported total traffic, Mehta and Musey conclude that the Commission's demand forecasts were too generous, thereby exaggerating the extent of a looming spectrum shortage. Indeed, as the table shows, CTIA's figures are well below the forecasts, by about 20% on average. Notably, the FCC's staff paper concluded that "if the current deficit curve for 20% over-estimate of data traffic is extrapolated into the future, it appears that the need for 200 MHz will follow shortly after 2014, and 300 MHz will be needed no more than one or two years after."[15] Thus, even if the forecast is an over-estimate, then a spectrum shortage remains a problem.

If market outcomes are below predictions of data "demand", then supply-side responses may be to blame. Significantly, the same table in *Overestimating Mobile Demand* includes data on the Commission's prediction of and actual off-loading rates. These figures are also provided in Table 1. As the data show, off-loading has increased dramatically over time. In fact, this supply-side response accounts for the discrepancy between the FCC's forecast and traffic outcomes. Holding the off-loading rate at 15% over time, as the Commission assumed, and adding the excess off-loaded traffic back onto mobile networks brings the demand forecasts (labeled "Eff. Data Demand") very close to the predicted levels.[16] In 2013, for example, the predicted traffic was 4,038 PB and the adjusted traffic level of 4,486 PB.

Spectrum exhaust occurs when insufficient spectrum exists to accommodate the service demands of consumers and, as such, a carrier must ration the available spectrum among its users by some mechanism such as service price increases, off-loading, blunt quantity rationing (dropped calls or choked speeds), or the like. Such steps, though, are not the most efficient response when a reallocation of spectrum from less-valued uses is feasible.

Another factor affecting mobile data consumption is the movement away from pricing plans with unlimited mobile data. This change in mobile data pricing began in earnest in 2010 and should reduce, ceteris paribus, the market quantity of data consumed over mobile networks by placing a positive price on marginal use (though often only at high quantities of data consumption).[17] Since off-loading closes the gap between the demand forecast and market outcomes (i.e., traffic), it is arguably the case that the demand forecast used by the FCC is too low since observed data consumption has also been reduced by the move away from unlimited data plans. In light of these countermeasures, Mehta and Musey's argument that the demand for mobile data has been exaggerated is weak and of no policy consequence.

The FCC's Spectrum Analysis

No doubt, forecasts of data demand in relation to spectrum supply are driving spectrum policy. If demand forecasts are over-stated, then the significance of the spectrum crisis may be overblown. This logic lies at the core of the Mehta-Musey study. The study fails to demonstrate, however, that any "bias" in the forecasts points to a fundamental change in the present trajectory of spectrum policy.

In the *National Broadband Plan*, the Commission called for an additional 300 MHz of spectrum for mobile data use by 2015, and a total of 500 MHz by 2020.[18] These spectrum figures were apparently influenced by a 2010 FCC staff study supporting the plan—*Mobile Broadband: The Benefits of Additional Spectrum*.[19] This study, using forecasts of data demand, tower construction, and spectral efficiency predicted a shortage of 275 MHz of spectrum by 2014, with a spectrum shortage materializing in 2013. The results of the study are presented in Table 2. Negative entries indicate "too little spectrum" to satisfy demand.

Table 2. Net Spectrum Requirements (MHz)

	2009	2010	2011	2012	2013	2014
FCC Model	377	322	225	87	-90	-275
Data Growth A	377	341	268	203	14	-134
Data Growth B	377	336	239	126	-149	-389
Data Growth C	377	318	202	151	42	-144

Note. Negative values imply a spectrum shortage.

Using the Commission's methodology, it is possible to generate predictions of spectrum shortages under different demand-growth scenarios. For scenario "Data Growth A," I take the CTIA figures from Table 1, adding a 2014 figure of 5,168 PB as reported by Mehta and Musey. Roughly, the CTIA figures can be considered (a lower bound of) actual market outcomes. Even at these much lower growth rates, there is a spectrum shortage in 2014 (a net of -134 MHz of spectrum), and this shortage will worsen over time absent more spectrum and continued demand growth.

Scenario "Data Growth B" uses growth rates based on the Effective Data Demand figures from Table 1 (adding back in the increase in off-loading). As with the FCC's original case, there is a spectrum crisis beginning in 2013, with a shortage -149 MHz in that year and -389 MHz in 2014. Scenario "Data Growth C" computes growth rates using the first-year estimates of data demand reported in Cisco's VNI reports.[20] These figures are not long-range forecasts, but match the release date of the report and presumably are reasonably accurate measures of market outcomes in those years. Again, there is a spectrum crisis in 2014 (with a net of -144 MHz).

It appears that the FCC is correct in its efforts to increase the amount of spectrum for mobile wireless services. In all three scenarios, the FCC's model calculates a significant shortage of commercial spectrum, so even if Mehta and Musey's claims about forecast errors are valid they have no impact on the current direction of spectrum policy—more spectrum is needed for commercial data services and soon.

As another alternative, I extrapolate the CTIA figures to 2014 and 2013 using the Gompertz function (the familiar S-shaped curve of market growth):

$$y = ae^{-be^{-ct}} \quad (1)$$

where y is traffic and t is a time trend and e is the Euler's Number. The parameters of the function (a, b, and c) are estimated using non-linear least squares, and then used to extrapolate the series to the years 2014 and 2015. The forecast and the spectrum requirements of U.S. carriers are provided in Table 3. In 2014, a spectrum shortage of 183 MHz is computed, and in 2015 the shortage is 507 MHz. It appears that the FCC is correct in its efforts to increase the amount of spectrum for mobile wireless services. In all three scenarios, the FCC's model calculates a significant shortage of commercial spectrum, so even if Mehta and Musey's claims about forecast errors are valid they have no impact on the current direction of spectrum policy—more spectrum is needed for commercial data services and soon.

Table 3. Net Spectrum Requirements (MHz)

	2010	2011	2012	2013	2014	2015
FCC Model (MHz Required)	322	225	87	-90	-275	…
CTIA – Traffic	389	867	1,468	3,230	5,647*	9,443*
MHz Required	341	268	203	14	-183	-507

Note. Negative values imply a spectrum shortage.
* Forecast using Gompertz function.

Another way to look at the data is to consider the timing of the shortage. Looking back to Tables 2 and 3, we see that the shortages predicted in 2014 for Scenarios A and C are similar in magnitude to the 2013 shortages in Scenario B and the Commission's benchmark case. Scenarios A and B can be loosely viewed as implying the spectrum shortage occurs one-year later than implied by the FCC's scenario. In essence, the supply responses push the "demand" forecasts out one year. In light of the pace of spectrum policy, a forecast being too aggressive by one-year is a triviality.

A similar analysis can be done with Cisco's data. In Table 4, Cisco's forecast of (global) mobile data demand from the 2009, 2011 and 2013 reports is provided. The Commission's data growth rates were based on the 2009 report's global demand figures, and the 2011 report is chosen because it was the highest forecasted demand in the Cisco reports. The 2013 report is the last report available. The final row is the first-year forecasts from the various reports, which I assume are a reasonable estimate of actual data use. Demand levels for 2014 are all forecasts. As in Table 2, while the Cisco forecasts from 2009 and 2011 are a bit high (relative to the first-year estimates), they are only about one-year ahead in terms of magnitude, again a trivial matter in light of the time it takes to repurpose spectrum.

Table 4. Cisco's Global VNI Forecasts (PB/year)

	2009	2010	2011	2012	2013	2014
2009 VNI Report	91	220	536	1,150	2,162	3,565
2011 VNI Report			597	1,252	2,379	4,212
2013 VNI Report					1,480	2,582
Cisco First-Year	91	237	597	885	1,480	

Mehta and Musey's conclusion that forecast errors recommend complacency merely because the spectrum crisis begins one-year later than predicted is plainly unreasonable, especially considering how long it takes the Commission to reallocate spectrum. I suppose other governments face similar temporal challenges in allocating spectrum. Given the policy lag, it is arguably the case that governments need to address the spectrum shortage immediately, so that practically it will be dealt with at some point in the foreseeable future.

A Zero-Sum Game?

If the government licenses 10 MHz to commercial carriers, then it cannot also assign the same spectrum to some other use. Based on this fact, Mehta and Musey claim that "decisions about spectrum should not and cannot be made lightly due to the zero-sum nature of spectrum allocation."[21] This take on spectrum assignment is demonstrably false. Spectrum allocation is not a zero-sum game.

In game theory, a zero-sum game is a game where the payoffs of all the players add up to a constant. The implication of the definition is that no matter how the resource is divvied up, the payoff is always the same. In such a scenario, economic welfare would be the same whether the government assigned spectrum purposefully or randomly. Also, no beneficial trade could ever occur, since the payoff is a constant.

Plainly, Mehta and Musey's claim of a zero-sum game in spectrum assignment is preposterous. The social value of 10 MHz in one use need not be the same as in another, and the goal of spectrum allocation and assignment is to maximize the social value of the scarce resource.

Plainly, Mehta and Musey's claim of a zero-sum game in spectrum assignment is preposterous. The social value of 10 MHz in one use need not be the same as in another, and the goal of spectrum allocation and assignment is to maximize the social value of the scarce resource. Without question, some uses of spectrum are more valuable than others, and different licensees use spectrum with different efficiencies, even within a single type of use. Moreover, spectrum is bought, sold and leased routinely, something that would not occur in a zero-sum game. In fact, the government often stands in the way of such surplus-increasing transactions.[22]

Conclusion

There are many competing uses for spectrum, adding to the drama of spectrum assignments. Naturally, there will be some disagreements about the spectrum needs of various sectors of the communications industry. It is critical, therefore, to evaluate the various claims made with a sound framework.

In this PERSPECTIVE, I have provided some fundamental economic analysis on the issue of spectrum exhaust. Despite claims to the contrary, my analysis demonstrates that the Commission's focus on getting more spectrum for mobile broadband is justified, even accounting for some alleged disparities between the forecast and the actual levels of mobile data traffic. Over-estimates of mobile data demand, where they appear, can, in part, be explained by supply-side responses to spectrum shortages, including offloading and a reduction in the availability of unlimited data plans. Indeed, higher prices can always be used to ration scarce capacity, but higher prices are the problem and not the solution to spectrum shortages. Remedial measures like offloading and price hikes, while perhaps curbing mobile data traffic, are not an excuse to slow down spectrum repurposing, but rather a call for both Congress and the Commission to get busy on spectrum policy.

NOTES:

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1 T.R. Beard, G.S. Ford, L.J. Spiwak and M. Stern, *Wireless Competition Under Spectrum Exhaust*, 65 FEDERAL COMMUNICATIONS LAW JOURNAL 79 (2012).

2 Middle Class Tax Relief and Job Creation Act of 2012, Pub. L. No. 112-96.

3 *In the Matter of Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands,* FCC 12-151, 27 FCC Rcd 16102, REPORT AND ORDER AND ORDER OF PROPOSED MODIFICATION (rel. December 17, 2012), *see also* T.R. Beard, G.S. Ford, L.J. Spiwak, and M. Stern, *Taxation by Condition: Spectrum Repurposing at the FCC and the Prolonging of Spectrum Exhaust,* PHOENIX CENTER POLICY PAPER No. 44 (September 2012) (available at: http://phoenix-center.org/pcpp/PCPP44Final.pdf).

4 T.R. Beard, G.S. Ford, L.J. Spiwak and M. Stern, *Market Mechanisms and the Efficient Use and Management of Scarce Spectrum Resources,* 66 FEDERAL COMMUNICATIONS LAW JOURNAL 263 (2014).

5 *See, e.g.,* S. Crawford, CAPTIVE AUDIENCE: THE TELECOM INDUSTRY AND MONOPOLY POWER IN THE NEW GILDED AGE (Yale University Press, 2013) (arguing that spectrum exhaust is a myth perpetrated by the wireless industry as an excuse to facilitate additional consolidation ("the spectrum crisis did not exist (p. 242)") and that the wireless industry convinced President Obama to spread this lie to the American people in his 2011 State of the Union Address, an accomplishment to which she notes "you had to admire these guys (p. 233).")

6 A. Mehta and J. Musey, *Overestimating Wireless Demand: Policy and Investment Implications of Upward Bias in Mobile Data Forecasts*, Draft Paper, Presented at the 2014 Telecommunications Policy Research Conference (2014) (available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2418364). The authors suggest that this pattern of exaggeration could arise (among other reasons) from "deliberate misrepresentation" by equipment vendors (and other parties) that stand to financially gain from a spectrum crisis.

7 *Overestimating Wireless Demand*, *id.* at pp. 20-2.

8 *Id.* at p. 5.

9 Mehta and Musey devote much attention to the widely-used forecasts reported annually in Cisco's Visual Network Index ("VNI") reports (available at: http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html.). Cisco's estimates are based on complex, data-intensive methods using trends in mobile adoption, device adoption and upgrades, minutes of use, application data requirements, and so forth. Thus, these forecasts are arguably forecasts of demand, but a review of the Cisco reports does not make this clear. The terms "demand" and "traffic" appear to be used interchangeably, though "traffic" is used much more commonly than is "demand" (by a ratio of 30:1). For example, the Cisco's 2013 VNI Report states "[m[obile subscribers are growing rapidly and bandwidth demand due to data and video is increasing (p. 32)" and mentions "unmet demand (p. 33)," but the report is entitled "Global Mobile Data Traffic Forecast Update, 2013-2018." *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018*, White Paper, Cisco Corporation (February 2013) (available at: http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html). Communication with Cisco indicates that the forecasts are intended to reflect foreseeable supply-side effects.

10 http://www.ctia.org/your-wireless-life/how-wireless-works/annual-wireless-industry-survey.

11 *Mobile Broadband: The Benefits of Additional Spectrum*, FCC Staff Technical Paper, Federal Communications Commission (October 2010) (available at: http://transition.fcc.gov/national-broadband-plan/mobile-broadband-paper.pdf), at Exhibit 10.

12 http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html.

13 The FCC reports only assumed growth rates, which the authors of *Overestimating Mobile Demand* use to calculate a PB/year figure.

NOTES CONTINUED:

14 CTIA, *Year-end 2013 Wireless Industry Indices* at p. 12 ("Not every wireless company answers CTIA's survey, and not every company which responds to the survey answers every question. But the answers we are getting show the continued growth of the wireless industry, and we look forward to reporting the on-going evolution of the wireless industry.") (available at: http://store.ctia.org/wirelessindustryindicesreportyear-end2012.aspx).

15 *Mobile Broadband: The Benefits of Additional Spectrum*, *supra* n. 11, at p. 22.

16 Effective Data Demand is calculated by adding the amount (Actual Offload – Predicted Offload)*(CTIA Reported Traffic) to CTIA Reported Traffic.

17 S. Carew, *AT&T to End Unlimited Mobile Data Plan*, REUTERS (June 2, 2010) (available at: http://www.reuters.com/article/2010/06/02/us-att-idUSTRE6513H120100602); P. Ganapati, *Verizon Signals the End of the Unlimited Data Plan*, WIRED (June 21, 2010) (available at: http://www.wired.com/2010/06/verizon-signals-the-end-of-the-unlimited-data-plan).

18 CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN, Federal Communications Commission (2010) at p. 84 (available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-296935A1.pdf).

19 *Supra* n. 11.

20 For 2014, I use the Cisco's 2013 forecast of 2014 demand, which is very close to the relative growth assumed in *Overestimating Mobile Demand* for the CTIA data.

21 *Overestimating Mobile Demand*, *supra* n. 6 at p. 5.

22 *See*, *e.g.*, *Taxation by Condition, supra* n. 3.