RADIO SPECTRUM FOR A HUNGRY WIRELESS WORLD

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Abstract

Radio spectrum is the mother’s milk of the Information Age. The wireless services it hosts are driving many developing countries into the modern economy, helping to make them global competitors and – soon, perhaps – wealthy nations. In the U.S., wireless is unleashing a torrent of mobile devices and applications, stirring innovation and creating impressive new efficiencies in business, government, health, and social networking. Consumer gains from mobile phone calls (voice) are alone estimated to top $190 billion annually. Social benefits from emerging data services appear poised to eclipse these magnitudes. We have only yet to scratch the surface of this rich, deep vein.

All mobile services rely on the infrastructure of wireless networks. These assets, in turn, rely on both man-made capital – radios, base stations, high-capacity bit transport grids -- and natural resources, namely the frequency spaces through which their signals hop. Until such airwaves were licensed and the licenses assigned to mobile carriers in the 1980s, mobile network development was pre-empted. Until additional bandwidth rights were assigned in the 1990s, the transition from analog to digital systems was stymied. When FCC allocations went dormant, circa 1995-2005, wireless broadband (“3G”) was deterred.

Liberalizing the use of airwaves and allowing secondary markets mitigated the impact of spectrum drought. 3G networks were constructed in the U.S. despite the absence of 3G licenses. Two major mergers reconfigured the market in 2004. FCC auctions in 2006 and 2008, along with reforms allowing 2.5 GHz frequencies to respond to market demands, finally infused new bandwidth into the market. Networks supplying high-speed data services – 3G and 4G – emerged, transforming the U.S. from laggard to leader in advanced wireless services. Today, smartphones, tablets, app stores, and a universe of devices that communicate “machine-to-machine” are transforming markets.

With these and such data-intensive applications as the high quality video streaming needed for medical, video conferencing and other enterprise purposes, the march of progress threatens to swamp existing facilities. The mobile data tsunami is not forming unexpectedly. Network managers seek to adjust to the rising tide. But relaxing spectrum constraints, a “free lunch” for policy makers, will ease the crunch, expand network capacities, intensify competitive forces, and quicken the pace of economic innovation. To leave spectrum allocations overly conservative will intensify trade-offs, squandering vast opportunities. The hopes of all will be dashed unless generous new dollops of radio spectrum are made available to the market.

Thanks to historic allocations of fragmented, restrictive, uneconomic frequency rights, broad swaths of un-productive bandwidth lie virtually fallow. Were such spectrum to be assigned through an open, transparent auction to the entities that value it the most (and therefore to those who will put it to the most productive use), policymakers would provide the U.S. mobile marketplace with an extremely useful asset. Mobile networks would dramatically expand in scope, coverage, and carrying capacity. Such policy options are clearly appealing to expert observers, but political stasis – the “tyranny of the status quo” – is a drag on progress. Strategies to break regulatory gridlock are vitally needed.
I. A MOBILE DATA TSUNAMI?

**Summary** There is fear of a “looming spectrum shortage.” Smartphones, netbooks, e-readers, and dongle-connected notebooks are driving huge increases in wireless network data use, video applications in particular. But the actual threat is not looming, it is here. The problem is not a shortage, but artificial constraints that suppress the networks and technologies that would emerge under a more generous regime. Spectrum use that has been liberalized demonstrates the vast scope for game-changing economic growth. Exploding machine-to-machine (M2M) services, including potentially game-changing applications in mobile health, energy resource management, and public safety, highlight the possibilities. To the degree that spectrum is available, these innovations will grow, offering breakthrough social advances. But historical regulatory barriers may yet stifle exciting developments now on the horizon.

The mobile sector is said to face a looming spectrum shortage. Great concern is expressed by policy makers over a coming crisis. The attention is all to the good; few measures would boost the U.S. economy, and improve the lives of consumers, more than a healthy dose of new mobile spectrum.

But markets easily avoid shortages -- prices rise. This discourages consumption while boosting production. Excess demand is eliminated and balance restored.

In mobile markets price mechanisms operate, but the supply of a key resource input – radio spectrum -- is controlled by regulators. It is impossible, nee illegal, for bandwidth under-utilized in one market to be bid into use for mobile networks starving for bandwidth. That forces demand to be more tightly rationed.

Because spectrum is an intermediate good, an input into retail service outputs, the effect is not seen so clearly. Shortages do not reveal themselves as retail free-for-alls, consumers jousting for bandwidth, wireless black markets emerging. Instead, operators shift their network offerings. They deter deployments and delay new technologies. Network growth is stunted, new applications blocked. It is the silent heart attack.

And it strikes, ironically, in the best of times, when the market has exploded, supplying more than 71 million high-speed wireless data users. The smart-phone revolution has triggered exciting new uses and applications; over 350,000 Apple App Store programs are available – while Android, Blackberry, Symbian, and Microsoft users have thousands of their own to choose from. Voice is no longer the sole product offering of the mobile network, as text or multi-media messages, email, web surfing and video streaming have jumped aboard

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3 Federal Communications Commission Chair Julius Genachowski, for instance, has taken on the issue, calling repeated attention to "unsustainable demands on our invisible infrastructure—spectrum." More Spectrum, Please, WALL STREET JOURNAL (Mar. 23, 2011).

the platform. New networks are forming for machine-to-machine (M2M) applications, like the emergency phone call from an OnStar car installation, the book download from a Kindle, or the medical monitor running as a cell-phone app. All these innovative uses of wireless gobble bandwidth. See Fig. 1. The trend is pushing networks to expand coverage, split cells, upgrade technologies, and acquire all the new frequency space regulators make available.

Each of these coping mechanisms costs society precious resources, save one. When regulators allow additional bandwidth to be bid into more productive employment, the entire economy gains. Failing to do that, keeping spectrum bottled up in allocations determined by regulators decades ago imposes a tax that deters growth in perhaps the most dynamic sector of our economy. The government gets no revenue from the burden, while consumers and businesses lose valuable services. The approach is penny stupid, pound foolish. So, to the question, Is a mobile data tsunami building? – the correct answer is: Yes, if we let it.

It is clear that we might not. That is the problem. If networks are given little opportunity to acquire new bandwidth rights, they must then take measures to limit usage more sharply than would be the case if additional spectrum resources were available. Something has to give. Indeed, many innovations will.

![Industry Forecasts of Mobile Data Traffic](image)

**FIG. 1. MOBILE BROADBAND DATA DEMAND, INDUSTRY FORECASTS (AS PER FCC\(^5\))**

Through pricing, tiering, queuing and other methods, networks distribute shared resources. Carriers naturally seek to protect valuable applications, keeping access open and reliable for customers. In managing the ecosystem, operators deploy a complex array of technologies, etiquettes, and economic incentives. Improving the subscriber experience creates the opportunity to maximize the service provider’s profit.

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Additional bandwidth loosens constraints. Whatever level of service might be supplied when a minute of network access costs five cents can now be supplemented by a range of new outputs when that cost drops to, say, three cents. A price shift signals the existence of more abundant capacity. Volumes increase, quality of service improves. More applications launch. Video clips that streamed to a subscriber’s handset in one minute, might now do so in 5 seconds, making new business models viable. Mobile health applications that were uneconomic become profitable. Insert unforeseen innovation here.

Inquiries that attempt to discern, “How much bandwidth does the mobile sector need?” miss the point and divert focus. The primary solution is not to have government listen harder, study markets more carefully, or better forecast the future. It is to permit competitive operators to buy spectrum resources, using what they can afford to bid away from alternative employments, while adjusting their networks and spectrum resources in response to changing conditions. This economic activity reveals optimal deployment patterns. Allocating as much bandwidth as possible to liberal licenses with flexible use rights enables and extends this information discovery process, making this approach the pro-consumer policy strategy.

The Federal Communications Communication has documented a building “mobile data tsunami.” The agency performs an extremely useful function in emphasizing the intense demand for additional radio spectrum already visible. Yes we can avert this incoming tide. But why would we want to? Given that large frequency spaces (in the TV band and elsewhere) are substantially under-employed, the increasing value that customers are placing on high-bandwidth mobile applications represents an excellent social opportunity. By permitting spectrum to be bid into more productive tasks, society can arbitrage past allocations, paving the way for pretty amazing new stuff, improving living standards for millions.

The tsunami is really not a forecast; the future is here. The smart-phone revolution, officially launched with the Apple iPhone in mid-2007, has already transformed the mobile marketplace. Each carrier competes with its rivals to attract users on the basis of its coverage and performance, particularly with respect to the speed and quality of its data flows. Large video files are now flowing copiously through the mobile network space. Subscribers are consuming bandwidth – wherever it can be purchased.

This is forcing networks to upgrade and expand. Growth is seemingly inevitable, but at what pace? A 10 percent annual growth rate results in a 159% increase over a decade. A 25 percent annual growth rate delivers 831%. Cisco and other industry experts forecast mobile data growth at rates well exceeding 25 percent per annum over the coming decade. Stretching networks from a standing start is expensive and difficult. Allowing new spectrum resources to be moved into place blows wind into the sales of operators, giving new momentum to evolving networks.

It is widely feared that new pricing structures will curtail the consumer’s mobile fun. One pundit recently wrote in *Bloomberg Businessweek*:

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The era of unlimited plans does have to end. The best way to allocate finite goods is through transparent, efficient markets. As traffic increases on mobile networks—it nearly tripled this year, and Cisco expects it to grow twenty-six fold by 2015—consumers will be forced to make smarter choices about how they use mobile data. Perhaps parents will be forced to download the toddler-pacifying Elmo videos at home rather than on-demand in the car. That's not a tragedy; it's what markets do.7

Pricing is important, and mobile carriers—who generate more than $160 billion in annual revenues—are keen to get their schedules right. Each pricing rule has costs of its own. Sometimes the bother of charging for minutes of talk time is not worth the trouble, particularly as customers do not like having to worry about how much a given minute of use is costing them. That is partly why buckets of minutes, available for a fixed monthly fee, became so popular. It is also why carriers are keen to extend “free unlimited” off-peak or on-net minutes to subscribers. Where the marginal cost of usage is low, the trick is to entice customers to support network costs via a monthly subscription fee, extending access without (further) charge.

How far this offer extends, and how much opportunity for consumption exists, is complicated. It requires billions of dollars in network construction, maintenance, and management dollars to answer. One thing is clearly known: the more spectrum that is available for the network to deploy, the lower bandwidth cost to customers will tend to be.

So it is not literally the case that at one moment, a year, five years, or 8.453 years into the future, mobile networks will be swamped by a data tsunami. But it is precisely true that, to the degree that more spectrum is available, wireless networks will operate—on each of those dates—more efficiently and capaciously. Indeed, to the degree that investors in today’s marketplace think that future resources will become available, more innovation will flow into applications, services, and network development.

Networks are not built overnight. Spectrum made available to the market takes time to deploy. Substantial lags are at work, so network owners plan ahead. When they see substantial new resources becoming available, they develop applications and new technologies designed to seize those opportunities. Conversely, a regulatory system that blocks access to valuable airwaves depresses investment in a raft of development activities that depend on those airwaves. Why bother with ambitious, risky, research and development when the bandwidth needed to support new wireless activities will not likely be allocated?

In 1992, regulators finally signaled the end of the long PCS allocation logjam. Experiments for new digital telephone services came pouring into the marketplace. As Robert Pepper, a top FCC official, observed at the time:

When the FCC opened a Notice of Inquiry into personal communications

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services, a little more than three years ago now, most of the activity in PCS was being done in Europe… What has happened since has actually been quite remarkable. We have in excess of two hundred experimental licenses out there… Without the first signal that the Commission was interested [in allocating spectrum], there was a real chicken and egg problem… [I]ndustry was not willing to invest in the technology, the trials, the experiments, the lawyers, the consultants, and the whole process necessary to deploy a new technology… Merely the fact that we opened up a proceeding, and said we are interested in a new technology to provide these kinds of services, and are interested in questions about where in the spectrum these services ought to be, unleashed an enormous amount of activity within the U.S. telecommunications and electronics industries.8

Spectrum supply effectively creates its own demand. Once the inputs are available, markets race to configure the outputs. To cautiously dribble fixed increments into the market restrains the flow of resources, thwarting the dynamics of innovation, freezing productive investments that would uncover new uses and create unforeseen demands.

Network carriers form expectations about how much spectrum they will be able to utilize, and craft business strategies accordingly. Hence, at any given moment, carriers will volunteer – perhaps with exactitude – responses to the how much spectrum is needed? question. But these answers themselves reflect underlying spectrum policies that have led carriers to plan network trajectories. So the remarkable aspect of the “mobile data tsunami” consensus is that it forecasts that carriers are headed for the abyss even as they plan to avoid it.

An essential tension is that mobile systems are being transformed from voice-only platforms to multi-media, multi-network platforms. The rise of text messaging has been one aspect of this transition (see Fig. 2), but this conversion has been innocuous for carriers as SMS (short message service, or “texts”) claims little network capacity. Ensuing progressions of the market have not been so gentle. In particular, smart-phone subscribers are eager for more and more bandwidth-intensive applications, driving up network infrastructure costs even as carrier revenues remain relatively flat. See Figure 3. Wireless networks incur heavy capital costs to bring the new capacity to customers, and current trends suggest that revenue/gigabyte will fall below total cost/gigabyte (for Canadian and U.S. carriers) sometime in 2013.

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9 CTIA (2010).
Leveraging existing assets is expensive and risky for operators, who are themselves constrained by capital markets. To the degree that additional spectrum resources are not available to help expand network capacity, such investments become even riskier. Enthusiasm for capital expenditures will wane. There is a magic bullet available in the form of under-utilized spectrum resources. By permitting additional bandwidth to be bid into its most productive use, the mobile data tsunami can be not only accommodated, but promoted.

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II. PROLIFERATING MOBILE NETWORKS

Summary While consumer use of mobile networks is rapidly growing, the exponential growth in business applications is less visible. Entrepreneurial firms are now deploying a wide range of mobile devices to spur economic efficiency and improve quality of life. Safety, energy, and environmental payoffs are already large. The prospects for revolutionary change in the emergence of such fields as tele-medicine are, however, truly breathtaking. Yet the rate of innovation is linked to the expansion of networks and, in turn, the availability of radio spectrum.

A. 6 Billion Subscribers, 50 Billion Devices

Most people think of mobile networks as cell-phone companies like Verizon Wireless, AT&T, Sprint, T-Mobile, MetroPCS, or Leap. Others see the emergence of a new wireless broadband competitor Clearwire as part of the mix. But the vertical growth in wireless services is sometimes less obvious.

Vertical services are those applications hosted by a given network that go beyond traditional, carrier-supplied voice calls. These take a variety of shapes and forms. Mobile virtual network operators (MVNOs) have formed, for example, buying wholesale access to physical networks. TracFone and Consumer Cellular, among several others, offer retail phone services using the infrastructure of other companies. This allows multiple systems (and their subscribers) to share a given platform, accessing spectrum and network resources.

Such sharing intensifies when new services are added to the product menu. SMS, MMS (multimedia messaging service – texting with pictures or videos), and high-speed data are the most popular mass market services. When a carrier upgrades their network from first generation analog voice (1G), to second generation digital (2G), to third generation broadband data (3G), the platform becomes capable of hosting a new range of possible applications. Upgrades to fourth generation (4G) standards are now underway. With the improved speeds and capacities they bring, still more options become feasible.

Even with the rich mix of networks and services now provided by mobile carriers, it is likely that we have yet to even scratch the surface of what lies ahead. The emergence of machine-to-machine – M2M – devices is already proceeding at breakneck pace. In-vehicle telematics services from ATX, SYNC, and OnStar automatically place 911 calls when a car crashes and airbags deploy. The Amazon Kindle and Sony e-reader offer downloads of millions of books, a function provided seamlessly via arrangements between e-reader vendors and mobile networks, unseen by the user.

M2M apps abound. Truck fleets use them to monitor available transport slots, to track merchandise, and to optimize logistics. Vending machines report sales to computer servers, reducing inventory costs. Power meters do not have to be read by meter readers (expensively) trekking from door-to-door, but automatically report via wireless links. Automobiles, guidance-assisted, can be steered clear of traffic accidents. Electronic payment systems have already become mass market successes in developing economies, where banking
infrastructure is relatively under-developed, and are now making major strides in advanced economies.

Excitement is building over the Internet of Things. The optimistic scenario is that networks will support billions of new M2M devices. Industry experts predict that by 2020, six billion cellular phone subscribers will co-exist in a world of 50 billion connected mobile devices. They imagine everything from heart sensors to location finders implanted in the family dog.

B. Emerging M2M Apps

When calculating the value of wireless services, economists generally focus on the consumer surplus received from making voice calls. The numbers derived from these calculations are very large. Yet they examine only part of the social benefits associated with the growth of wireless networks. There are impressive second-order and third-order innovations taking place all through the “mobile ecosystem,” and the direct welfare measures of usage capture but a fraction of the gains that these applications create. It is as if we are measuring the importance of the transcontinental railroad by examining how many people ride the trains, leaving out the economic development of the American West made possible by the new infrastructure.

There is a reason for this omission, of course. It is extraordinarily difficult to measure the gains in markets that are only now emerging. Moreover, it is unclear how we attribute those gains; radio spectrum is one of many inputs. That issue is quite vexing for statisticians and economists. But in a broader sense, there is not much scope for confusion. The simple fact is that such markets will be stunted if additional spectrum is not made available; reducing bandwidth available to market innovators will reduce services available to customers. While quantification of social benefits may await better data and more sophisticated models, we now have all the information we need to motivate an important conclusion: spectrum policy is key to unleashing an exciting array of new product spaces in the mobile ecosystem. The following examples are illustrative.

i. Vehicle Tracking and Collision Avoidance

One of the best developed family of mobile applications rides the road. By connecting cars and trucks to wide-area cellular networks, a host of social improvements can be achieved. Some of these are already commonplace on new vehicles.

Among the earliest such devices are from OmniTRACS by Qualcomm. Launched in 1988, the system relies on satellite radio links to communicate the location of vehicles. Specifically, the service is used by truck fleets, with on-board radio devices connected to computers with keyboards adjacent to the driver’s seat. “The system consists of wireless devices installed on semi-trailer trucks that ‘talk’ to computers located in a network operations center (NOC), enabling transportation carriers to monitor driver performance;

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schedule and plan vehicle maintenance more effectively; and improve customer service.” In addition, trucks are efficiently routed via information generated about local conditions and last-minute variations in pick-ups or deliveries, saving time and fuel consumption.

The service became a “killer app” for trucking firms not only in the U.S., but around the world. In 1993 Irwin Jacobs, the co-founder and CEO of Qualcomm, was deemed “The Man Who Changed Trucking” by Fleet Magazine. While OmniTRACS is satellite-based, such services also face spectrum constraints. Indeed, these commercial services were non-existent until the Open Skies policy was implemented in the mid-1970s, ending the COMSAT monopoly and permitting private firms to use radio frequencies in competitive satellite ventures.

Passenger vehicles also benefit from M2M applications. The well-known OnStar service, developed by General Motors, has been available as a factory installed feature on GM cars for several years. It not only notifies public safety authorities in the event of an accident emergency, it provides locational information and other services to subscribers. Competing vehicle M2M devices have been developed by ATX and SYNC. Given new opportunities with faster 4G networks, being developed with airwave rights purchased in a 2008 auction, such services are able to extend coverage and features. A new ‘stand alone’ OnStar service is newly available to all cars (not just GM models) in an after-market appliance sold at retail store Best Buy. The device, which is installed as a rear-view mirror replacement, gives the customer “automatic crash response, turn-by-turn navigation, stolen vehicle location assistance, one-button access to emergency and roadside services and hands-free calling.”

Since, 1986 the LoJack (opposite of “hijack”) vehicle location tool has been sold to vehicle owners wanting to recover their property in the event of a theft. The wireless device, which uses a police band frequency, is small (about the size of a cigarette box) and emits a tracking signal when activated by remote radio communication. The company boasts a 90% recovery rate for stolen cars. Such wireless applications have already had a profound impact in reducing criminal activity:

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The fact that fewer vehicles were stolen in 2008 than 1980, despite the doubling in the number of vehicles on the road, is at least partly the result of the great improvement in locking devices built into modern vehicles… And owners who choose to equip their vehicles with an electronic tracking device like LoJack or OnStar greatly enhance the ability of the police to track them if stolen and arrest the thief or a chopshop owner.15

Interestingly, the benefits of crime-preventing equipment deters car thefts generally. Because criminals do not know which vehicles are equipped with tracking devices and which are not, they attempt to steal many fewer cars overall. This spreads the benefits of such wireless innovations far beyond those households that purchase the technology.16

Where are these vehicle-based M2M apps headed? One exciting path is collision avoidance. Advanced telematics are being tested using devices that monitor the environment surrounding a vehicle as it travels. Using computer projections, it can detect possible accidents before they occur, alerting the driver and/or taking evasive action.

Computers can respond to a situation in approximately 0.3 seconds, as opposed to the human reaction time of one-half to one full second… If these sorts of telematics can be integrated into automobile systems to not only keep people connected, but to also help them avoid deadly traffic accidents, then society may be well on its way to living up to science-fiction standards.17

ii. Energy Conservation

The most cost-effective “green technology” measures tend to involve energy conservation. Hence, the optimization of truck routes discussed above can improve not only competitiveness and the standard of living, but induce substantial energy savings, cutting pollution.

Many M2M fleet management solutions… help reduce emissions. Fleet management solutions can issue alerts when a vehicle exceeds predetermined limits for idle time or speed… reducing carbon emissions. M2M solutions help devise the best routes for truck deliveries to avoid unnecessary idling and to cut down on left-hand turns. According to UPS… between 2004 and 2008 this simple technique shaved nearly 30 million miles off delivery routes, saved three million gallons of gas and reduced emissions by 32,000 metric tons of

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CO2 - the equivalent of removing 5,300 passenger cars from the road for an entire year!18

Electric utilities are primary users of energy. They face challenges in responding both to high fuel prices and government mandates for reduced consumption. Metering usage to encourage greater efficiency is a key strategy. Where consumers can be enticed to shift to off-peak usage, existing power generation facilities stretch much further; expensive new plants need not be built. M2M metering robustly expands opportunities. Vodafone, the largest international mobile carrier, notes that wireless phone technology (in the form of SIM cards) are being installed inside electricity outlets, so that M2M applications can both monitor consumption and communicate price changes in real time, incentivizing customers to respond more efficiently.

During times when energy prices fluctuate rapidly, customers will transparently know what prices they are paying, precisely how much energy and utilities they are using, and where specifically it is being used.19

Smart Grids have great potential. In both homes and businesses, using computer technology to regulate the consumption of power can dramatically reduce draws, while achieving equivalent economic outputs. Computers can be programmed to manage particular machines, and then embedded within them. The savings in energy consumption – in refrigerators, TV sets, or air conditioning units – have been considerable. The next step, however, is to alter these sophisticated management techniques according to changing conditions in the external environment. That requires a communications link. As wireless networks expand in scale and capacity, they have aggressively sought to extend their verticals to improve Smart Grids.

The power industry also uses cellular M2M technology to monitor risky environmental operations... M2M remote monitoring lets utility and gas companies manage equipment in the field and detect oil and gas pipeline problems before costly and dangerous leaks occur. M2M can also manage fields of solar panels and wind turbines and respond in real time to output changes due to changing weather, equipment failure or cleaning or maintenance issues. This helps maximize energy production and further reduces the need for carbon burning energy sources.20

iii. Public Sector

Myriad M2M applications have emerged in the public sector, helping to substantially improve performance in areas from law enforcement to education to national security. For instance, in New Hampshire, 50 school districts contract with a bus company to transport some 1,500 special needs children daily. Prior to M2M devices, essential coordination was

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20 Hansmann, op cit.
often lacking: “Dispatching the company’s 178 buses was tedious and cumbersome, requiring the use of a radio and constant manual checks to ensure buses with wheelchair lifts” were available where needed. Combining mobile network-connected devices with GPS services aided efforts. According to a case study by KORE Telematics, the following results were obtained:

- $400,000 annual savings reported by reducing driver overtime
- 50% less time in routing the right bus to the appropriate location
- improved on-time performance through more efficient routing
- increased child safety achieved by monitoring driver speeds and rapid response to bus breakdown.

Police departments have an intense, real-time demand for up-to-date information from large databases. When a potential felon is stopped and questioned by officers, for example, the ability to access the individual’s criminal record and to sort through various alerts, bulletins, or “wanted” posters can be the difference in solving – or preventing – a serious crime. M2M applications transfer such data over cellular networks.

A solution being implemented in San Jose, California, the state’s third-largest city, makes each police patrol car a broadband-connected office. Officers in the field have instant access to police databases via high-speed Internet connections. The system, developed by Feeney Wireless and run over the Sprint mobile network, has been created with added

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security features. Benefits of the new system include “cost and times savings… on-demand access to real-time information… [and] enhanced emergency response.”

In Austin, Texas, the police department acquired, in early 2011, one hundred mobile devices that scan fingerprints. The radios then automatically identify the prints, and check for any outstanding arrest warrants. In just three months, the devices were used 340 times, resulting in the arrest of forty suspects. Not only do the devices deter the use of fake names and phony IDs, they keep officers in the field. Previously, a suspicious individual who failed to produce adequate identification would have to be taken to police headquarters for fingerprinting, and then (often) taken to a local jail for booking. The process typically consumed several hours. Now police patrols stay in the field, ascertaining actual identities instantly.

Other services greatly improve police surveillance. Prior to recent improvements in M2M networks, cameras used to record potential criminal activity had to be manned and located within a few hundred yards of a backhaul link. This exposed surveillance operatives to potential discovery, and consumed vast amounts of police officers’ time. New systems developed for a Southern California police department, however, have produced remote, cellular network-connected cameras that are movement-activated (eliminating data flows when there is nothing suspicious to observe) and controlled by police officers in a command center -- or traveling with a notebook computer – miles away. “Before deploying the wireless solution eight months ago, the coastal public safety organization used significantly more resources – both cars and officers - to undergo a surveillance mission, and the agency already sees a cost savings simply from reducing the amount of overtime previously required by officers.”

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C. Mobile Health

Consider the fact that market forces have distributed mobile phones to virtually everyone, child or adult. Consider, too, that the mobile handset is hardly a “phone” anymore. It is a network-connected personal computer. It has considerable processing capability, and can access virtually unlimited computing power via its carrier link. This powerful machine is carried, on (or near) one’s person, 24/7. We even sleep with these devices, recharging our batteries as they lay on the nightstand, charging theirs.

This ubiquity of mobile communications devices combines with the march of medical science and the ever-climbing cost of healthcare to suggest a new universe of high-valued apps. Medical services have already found their way onto some mobile phones, providing patient monitoring, health alerts, and generating physiological data of importance for doctors, hospitals, and individuals. But we have only seen the first puffs of smoke from this volcano, which may be about to explode.

i. Overview

Perhaps the most exciting of all M2M opportunities lies in the field of mobile health (aka, “wireless healthcare,” “connected health,” or “mHealth”). This burgeoning field holds tremendous promise in its potential to help improve health while reducing healthcare costs. From securely delivering a critical patient’s cardiac information to a doctor’s smart-phone – wherever s/he is - to pill bottles that remind you to take your medication with an SMS message, innovative mHealth applications are almost without bounds.
A broad array of applications is conveyed over both licensed and unlicensed bands. Network connections involving mobility tend to be supplied by wide-area networks (provided by cellular carriers), while fixed communications needing short-range links typically access unlicensed bands. The latter may involve signals sent between devices implanted within the human body, forming BANS – body area networks.

The demand for wireless medical services is projected to increase by 58 percent annually over the next five years.27 The digital health market (which includes mobile applications) is estimated to have been $1.7 billion in 2010, and is expected to grow to $5.7 billion by 2015.28 More than 200 million downloads of mHealth applications are in use today, and that number is expected to increase threefold by 2012.29 Currently, U.S. mHealth revenues are approximately $100 million annually, but the rapid evolution in mobile devices coupled with physician demand and the need to improve quality while reducing healthcare costs is forecast to result in a $1.7 billion market by 2014.30

The focus is extremely diverse. The top ten medical conditions being targeted for wireless health applications are: breast cancer, heart failure, Alzheimer’s, COPD, sleep disorders, depression, asthma, diabetes, hypertension, and obesity.31 Mobile health devices can be used for monitoring patient behavior, patient symptoms, or device performance (keeping heart pacemakers running properly). Usage can lower costs and increase quality of life.

Almost all mHealth solutions require the partnership and collaboration of a collection of players and innovators with diverse competencies. The cross-disciplinary nature of the products and services demands it. Typical is the example of MedApps, a company specializing in “remote health monitoring.”32 The business strategy is focused on “establishing a strategic Eco-System [as] a highly effective way to bring remote patient monitoring to the world.”33 See Figure 5. Applications providers resemble system aggregators, herding medical device, healthcare and pharmaceutical companies,
telecommunications carriers, hardware, network, chip, and software developers. Radio spectrum lies at the heart of this ecosystem.

ii. Examples

*Biometric Sensors*

Biometric sensors placed in mobile handsets transmit data to remote medical teams, generally at hospitals. These may be neighborhood facilities, or hospitals hundreds of miles away. Multiple wireless technologies convey data from small sensors such as glucose meters or blood pressure monitors to servers located in data centers. These data are monitored and recorded for further analysis.

In a typical pathway, a body sensor collects key biometric data. The sensor may be implanted in the body or embedded in the handset. Using a mobile broadband network, the portable device transmits the data for analysis – wherever such monitoring can best be done, anywhere in the world. Think of it as the patient’s biometric data telecommuting instead of the patient commuting to the doctor’s office or lab. And imagine the scale and scope economies that are possible to exploit. Think further of the feedback loop gains, as scientists learn how human bodies are performing, now with millions of data points in real world (outside of the doctor’s office or hospital) circumstances. Figure 6 depicts the general service structure.

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34 Ibid.
Remote Monitoring and Diagnostics

Wireless technologies are being integrated into many traditional medical procedures, freeing physicians to perform their monitoring and diagnostic services anywhere, anytime. These particular applications became possible with smartphones and tablets, devices with sufficient memory, CPU “horsepower,” and screen resolution to manage the computational and data demands associated with high-resolution MRIs or ECGs. The new applications are integrated with existing monitoring and diagnostic equipment in hospitals, reducing costs. Two scenarios illustrate:

Obstetrics  Airstrip Technologies’ AirStrip OB™ service\(^{35}\) sends critical patient information (such as fetal heartbeat and maternal contraction patterns) directly from monitoring systems in the delivery ward to a clinician's smart-phone or tablet. Data are transmitted securely in real time, allowing busy doctors to continuously monitor patients regardless of their physical location.


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**FIG. 6. BIOMETRIC SENSORS TRANSMIT TO REMOTE MEDICAL TEAM**

[Image: ResolutionMD http://www.calgaryscientific.com/products/resolutionmd-clinical.html]
Radiotherapy / Neurology  Calgary Scientific’s “ResolutionMD Mobile” service\(^\text{36}\) provides remote access to CT and MR images through the clinician’s iPhone, iPad or iTouch. (Support for Android-based devices is in development.) This information permits clinicians to closely observe and diagnose, 24/7, while attending other patients. One of the more compelling applications is used for acute stroke, when a patient’s outcome very much depends on the speed of medical attention: *time lost is brain lost*. This diagnostic tool yields immediate access to brain scans for clinical assessments, no matter where doctors may be located. This can markedly improve the quality of critical care.

**Medication Monitoring**

Wireless applications are being used that remind patients to take their medicine. This is an emerging solution to a huge, if under-appreciated, healthcare problem. “Poor medication adherence in all of its manifestations costs the United States upwards of $290 billion per year in unnecessary health care spending not to mention illnesses and deaths that could be otherwise prevented. Unless we find innovative ways to address the adherence crisis these negative impacts will likely worsen.”\(^\text{37}\)

One solution is proffered by a device called “GlowCaps,” developed by Vitality.\(^\text{38}\) It is a wirelessly embedded pill bottle that generates refill alerts and also reminds patients to take their medications via light or sound pulses, phone calls or text messages. Using a blinking light and then a ringtone, GlowCaps signals the user when it is time to take a pill. If the cap of the pill bottle is not opened within a given time, a phone call reminds the patient to take their medication. Each time the bottle cap is opened, data are relayed wirelessly to Vitality; the information is used to compile adherence tabs. Progress reports are issued for patients, family members, and caregivers. AT&T announced that it will be partnering with Vitality to sell the product on Amazon.\(^\text{39}\)

\(^{36}\) ResolutionMD Mobile, Calgary Scientific Website; http://www.calgaryscientific.com/products/resolutionmd-mobile.html.


\(^{38}\) Introducing GlowCaps, Vitality Website; http://www.vitality.net/glowcaps.html.

### III. SPECTRUM ALLOCATION AND CONSUMER WELFARE

**Summary**  
Strong economic evidence shows that increasing the spectrum available to mobile networks results in a rising number of applications available to consumers at steadily falling prices. Conversely, withholding bandwidth stunts the growth of networks and punishes users. A 2009 study published in the *RAND Journal of Economics* (Hazlett–Muñoz) estimated that an eight-year delay in the FCC’s assignment of PCS C-block licenses (allocated 30 MHz of spectrum) ultimately cost consumers about $66 billion. While auctions are generally the best way to allocate new bandwidth, the real gain to society is not in the capture of license bids – some $53 billion has been claimed by the U.S. Government since 1994 – but in the infusion of new spectrum into the marketplace. Annual consumer surplus generated in U.S. mobile markets easily exceeds $190 billion, far outstripping the total take from FCC auctions, which are one-time exactions. Auctions should be conducted expeditiously and efficiently, with license rules allowing spectrum to be flexibly used and hence free to be deployed in its most productive use.

Formal economic analysis has reached the same conclusions offered in the narrative above: more spectrum in mobile markets reliably produces lower prices for consumers. Indeed, this research identifies two key outcomes. First, mobile networks operate more efficiently when there is more bandwidth available. The opportunity cost of a given call is lower when the capacity (bandwidth) of a mobile network is greater, all else equal. Second, enlarging the spectrum allocation increases competitiveness in the market. Hence, when more spectrum is available consumers reap the benefits of enhanced market rivalry.

The pro-competitive impact of more liberal spectrum allocations shows up in the international data measuring mobile market outcomes. Moreover, statistical analysis can quantify the effects. The key set of output variables comes from retail markets: how much do consumers pay (average price per minute of use), and how many minutes of use do they “consume”? With standard economic theory, it is predicted that lower prices and higher quantities are good for consumers – “welfare enhancing.”

In a study published in the *RAND Journal of Economics* in 2009, Roberto Muñoz and I compared 28 markets around the world to find out how different spectrum allocations ultimately impacted consumers. Econometrically, we found that additional allocations of radio spectrum strongly influenced economic efficiency. Making bandwidth inputs more abundant resulted in lower prices for consumers and higher outputs. These effects were due to both better performance by carriers and the effect of the extra bandwidth in enhancing competition between them.

Given the estimated results in this study, which link spectrum policy choices to operating market outcomes, we were further able to forecast the effects of different policy approaches. Specifically, we projected the economic effect of enhancing or reducing the flow of spectrum inputs. One particular simulation we created used the empirical parameters in our

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40 Hazlett & Muñoz (2009).
global study to forecast the impact that an additional 30 MHz of spectrum would have on the mobile market in the U.S.

This increment was of particular interest due to policy delays in issuing PCS C block licenses, allocated 30 MHz. An auction ending in May 1996 was to have assigned 493 of the licenses (exhaustively covering the entire U.S.). The FCC subsidized small businesses and rural telephone companies, so-called “designated entities” (DEs), by extending two forms of bidding credits. One allowed a $1 bid to count as more than a $1 bid in the auction. The other permitted any winning DE to pay for its license over ten years, paying only the interest rate on ten-year Treasury bonds (and interest-only for the first four years).\(^\text{41}\)

Given these incentives, DEs bid extremely aggressively. Over $10 billion (net of credits) was pledged by license winners, easily exceeding the $7 billion total paid for the A and B block PCS licenses sold the previous year and allocated twice as much total bandwidth.\(^\text{42}\) The use of DE preferences and, in particular, long-term credit subsidies, encouraged such optimistic valuations.

But the credit subsidies also left the federal government holding the risk. Were the licenses to prove less valuable than the debt owed, the bidders could suspend payments to the Treasury. That is what happened – with a twist. Winning licensees found that they could declare bankruptcy and then gain protection from the FCC; the government would be a creditor in the queue. A bankruptcy court could reduce the bidder’s debt obligation. In the course of events, including litigation of the largest cases,\(^\text{43}\) the winning bidders succeeded in getting the federal courts to leave them in possession of their licenses while slashing payments they owed to the U.S. Treasury.\(^\text{44}\)

From a social standpoint, the problem was not so much that the payments to the government went uncollected as that there were long delays imposed on spectrum allocation. The C-block licenses, allocated 30 MHz, did not generally host productive use until at least 2005. That is when the financial issues were resolved by the U.S. Supreme Court and the FCC held a license re-auction. (In settling obligations with the FCC, many rights ended up back with the regulatory agency.) The spectrum allocated to PCS had been set aside by the FCC in 1989-1992; a licensing plan was ready in 1994; license auctions had begun in 1994; the original C license auction had ended in May 1996. The cost of such an outcome was conservatively estimated in our model, which projected the value that an extra 30 MHz of spectrum in the U.S. mobile market would have yielded if deployed 1997-2003. The extra

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\(^{44}\) The grounds, as set forth in the first case (GW), were that the government had used its regulatory powers over spectrum allocation and wireless licenses to create a “constructive fraudulent transfer.”
bandwidth would have lowered prices and expanded volumes, producing consumer welfare gains of about $66 billion.

These gains (losses) are listed, year by year, in Table 1. Price is proxied by “revenue per minute of use,” or RPM. Usage is quantified as millions of minutes of voice service per month, or TOTMIN. And market concentration is measured in the standard way, using the Herfindahl-Hirschman Index, $HHI$. Adding the new capacity (30 MHz) to the market lowers prices, increases output, and decreases concentration. These changes lead to increases in consumer welfare of, annually, some $8 billion to $10 billion.

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial Estimated Equilibria</th>
<th>Final Estimated Equilibria</th>
<th>Welfare Changes ($bil.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RPM</td>
<td>TOTMIN</td>
<td>HHI</td>
</tr>
<tr>
<td>1997</td>
<td>0.1888</td>
<td>27,276</td>
<td>1,664</td>
</tr>
<tr>
<td>1998</td>
<td>0.1848</td>
<td>29,909</td>
<td>1,729</td>
</tr>
<tr>
<td>1999</td>
<td>0.1813</td>
<td>32,902</td>
<td>1,788</td>
</tr>
<tr>
<td>2000</td>
<td>0.1775</td>
<td>35,619</td>
<td>1,856</td>
</tr>
<tr>
<td>2001</td>
<td>0.1734</td>
<td>36,306</td>
<td>1,949</td>
</tr>
<tr>
<td>2002</td>
<td>0.1697</td>
<td>38,315</td>
<td>2,029</td>
</tr>
<tr>
<td>2003</td>
<td>0.1662</td>
<td>39,909</td>
<td>2,115</td>
</tr>
</tbody>
</table>

These results strongly suggest that policy makers should focus on quickly getting more spectrum into the marketplace. In particular, they should be careful to avoid the ‘auction revenue trap,’ which measures the success of a spectrum allocation by the amount raised via license sales. Even as Washington D.C. was excited over the high bids for PCS C block licenses in 1996, for instance, some argued that DE preferences were a useful device for increasing government revenue collections.\(^{46}\)

To be clear: there are sound reasons for auctioning licenses. There are efficiencies that result from reducing rent-seeking costs (including licensing delays) and from distributing licenses to the firms that can most productively use them. Market bids do a far better job than regulators, under the beauty contest method, of determining the efficient assignment of licenses.\(^{47}\) Prior to assigning licenses by competitive bidding, FCC regulators held hearings in which they attempted to discern which of a group of competing applicants should be

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\(^{45}\) Hazlett & Muñoz (2009), p. 436, Table 5. RPM is average revenue per minute of use (voice phone calls). Dollar amounts are in constant 2000 SUS. Total Minutes (TOTMIN) are in millions/month. HHI is the Herfindahl Hirschmann Index, 0 – 10,000.


\(^{47}\) As a general matter, this implies that auctions should be open to all and that results should not be altered by government bidding credits.
awarded the rights in “the public interest.” Given that the rights were valuable, each of the applicants spent considerable sums to acquire and present a “public interest” story.

Such processes did not advance the interests of consumers, citizens, or the U.S. economy. Competitive bidding for licenses could eliminate this wasteful gamesmanship, and had been put forward as an efficiency-creating solution by economists for decades.48 When finally adopted by U.S. regulators after a Congressional statute authorized the reform in 1993, auctions proceeded smoothly, proving themselves capable of rapidly getting licenses to operators likely to create the highest social value.49

Another advantage of license auctions is that they capture rents for the Treasury. If the revenues raised by government offset other revenues (i.e., government spending is constant, and lesser tax collections are thereby required), then the distortions associated with those unneeded tax collections are saved. Public finance research suggests that, in the U.S., a dollar raised via the tax system tends to cost society about $0.33 over and above the dollar transferred from private to public sector.50 Using this rule of thumb, a billion dollars in auction revenues, then, may eliminate about $333 million in social costs.

This gain is an important aspect of license auctions, but it is typically far from the largest consideration. The consumer surplus generated by spectrum allocated to popular services such as mobile cellular easily outweighs the profits captured by service providers, and it is these (anticipated) profits that auction bidders are willing to, partly or wholly, bid away in order to receive valuable wireless authorizations. Not only is the big picture dominated by efficiencies in wireless markets where services generate value for consumers and businesses, but efforts to squeeze more revenues out of auctions reliably prove to be ‘penny wise, pound foolish.’51

Regulators have many tools at their disposal to artificially increase auction bids. They may delay license sales, making the market more desperate to obtain bandwidth rights. They may reduce the number of licenses auctioned, or the bandwidth allocated, making assets more precious due to greater scarcity. They may impose high reserve prices, refusing to sell licenses unless such specified prices are bid. Or they may favor certain weak bidders with bidding credits, forcing stronger bidders to raise their prices. The problem with each of these tactics is that they carry the prospect of reducing efficiency or competitiveness in the resulting market, hampering network development and raising retail prices to customers. In such instances, the higher prices received by governments are offset by inefficiencies in the

49 Thomas W. Hazlett, David Porter, & Vernon Smith, Radio Spectrum and The Disruptive Clarity of Ronald Coase, 54 JOURNAL OF LAW & ECONOMICS (forthcoming, Nov. 2011).
51 Hazlett & Muñoz (2009).
marketplace. In the Hazlett-Muñoz (2009) study, we found that the losses imposed generally far outweighed any benefits gained.

![Diagram showing annual consumer surplus in U.S. mobile voice (2008)](image)

**FIG. 7. ANNUAL CONSUMER SURPLUS IN U.S. MOBILE VOICE (2008)**

The basic logic, however, is gleaned from the knowledge that the social value of mobile networks is almost entirely generated on the demand-side of the market. Consumer surplus (the benefit to consumers buying a product, over and above what they pay) in a given year is very conservatively estimated to be about $190 billion, as shown in Figure 7. This forecast is derived from historic price-quantity pairs. These are not points on a demand curve, as much changed in the market between 1991 and 2008, the period over which these price-quantity outcomes are observed. But it is safe to assume that the key factors driving demand (other than mobile service prices) uniformly influence demand for mobile minutes in a positive direction. These include income, the price of handsets, the quality of handsets, the quality of networks, and preferences for using mobile technology. This implies that the historical price and output data pictured in Figure 7 define a lower-bound for the U.S. demand curve for mobile minutes (2008). Consumer surplus, graphically shown as the area between the demand curve and the market price (about four cents per minute), is then estimated at approximately $190 billion per year.

The receipts garnered in FCC license auctions are, including all sales since 1994, about $53 billion. The two numbers – annual consumer surplus and total license revenues -- are not directly comparable. Much of the spectrum used for mobile wireless was allocated to cellular or SMR licenses not initially awarded by competitive bidding, and most of the licenses sold via auctions have not been for mobile service. To provide comparability, values can be stated in “price/MHz/pop,” as license bids routinely are. Averaging across mobile wireless licenses sold by the FCC, 1994-2008 (there have been no sales since), produces a mean price of about 63¢/MHz/pop. The lower-bound estimate for annual consumer surplus

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52 Taken from Thomas W. Hazlett & Roberto E. Muñoz, What Really Matters in Spectrum Allocation Design, paper presented to the Georgetown-U.C. Berkeley Mobile Impact Conference (U.C. Berkeley, April 16, 2010). The 2006-2008 minutes of use data are augmented by including text messages at the rate of 1 SMS = 1 MOU. Revenues include voice and texting, but exclude mobile broadband subscriptions.

53 Ibid.
(of $190 billion) is approximately $3.17/MHz/pop. The former is a lump sum amount, realized one-time in a sale of future rights. The latter is an annual flow. That the flow is five times the magnitude of the stock value implies that the latter – measured apples to apples – is perhaps 100 times as large.

Once it is seen that the overwhelming proportion of benefits are delivered to consumers, not producers, it becomes clear that license auctions – if done correctly – cannot capture for the Treasury any but a very small part of the total social surplus created. It then becomes obvious that the efficient path is for the government not to engage in strategic games to goose up bids, but to focus on smoothly assigning more bandwidth rights to competitors.

Wireless licenses, after all, are inputs. The objective is not to maximize the value of inputs, or costs, but of the relevant outputs – the retail services that licensees supply to end users. As spectrum is released to the market, fueling the creation of mobile services, consumer surplus and profits are generated. More spectrum, more gains.

The bottom line is that it is highly efficient to expeditiously get abundant bandwidth into the marketplace via licenses assigned by competitive bidding. But it is highly inefficient for policymakers to then become pre-occupied with extracting higher auction revenues. In reducing allocated frequency space from, say, 3X to X, profits in the emerging industry (to operate using the licenses assigned) may increase due to reduced rivalry. These expected profits can be captured in a well designed auction. But the underlying spectrum allocation has been artificially constrained and the economy will suffer. Consumer welfare, which includes consumer surplus in addition to producer surplus, is reduced. While the social gains derived from the auction may be a substantial proportion of total revenues (one-third associated with the public financing bonus), the dominance of consumer surplus over producer surplus makes such gains a social welfare bust. Measures that stifle growth in wireless are an extremely expensive way to raise public funds. They constitute a perverse anti-industrial policy, targeting perhaps the most dynamic sector of the Information Economy.

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54 Hazlett & Muñoz (2010), Table 1. This incorporates annual consumer surplus of $190 billion, and assumes 200 MHz was used by U.S. mobile carriers. This is a bit more than the 194 MHz actually deployed at year-end 2008. See Peter Rysavy, Mobile Broadband Spectrum Demand, White Paper (Dec. 2008), p. 23; http://www.rysavy.com/Articles/2008_12_Rysavy_Spectrum_Demand_.pdf.


Summary The FCC estimates that it takes from 6 to 13 years for U.S. regulators to make new spectrum available for wireless services. These long lags erect barriers reducing competition and deterring innovation. In some instances, regulators abroad have allocated spectrum more expeditiously. European countries, by contrast, distributed 2G and then 3G licenses about five years, in either case, before the U.S. did. Ironically, however, U.S. regulators simultaneously crafted more liberal policies regarding the use of bandwidth already allocated, permitting markets to better cope with the lack of new allocations. Competing nationwide 3G networks were built without “3G licenses,” and now – with additional bandwidth finally released in 2006 and 2008 auctions – multiple 4G networks have emerged. Getting rules in place that authorize flexible use of spectrum use while also making much more spectrum available to the market is the challenge for policy makers.

It is well known that moving new spectrum allocations into the mobile market can take years or even decades, and that these long lags deter economic growth. The problem was specifically studied by the FCC’s National Broadband Plan Task Force, which issued its Report in March 2010. It concluded, “The process of revisiting or revising spectrum allocations has historically taken 6-13 years.” The statement is based on an analysis of key allocation episodes, summarized in Table 2.

The summary is forgiving in its measurements. The cellular telephone spectrum allocation, which it lists as beginning in 1970 and ending in 1981, took far longer. AT&T filed an application for cellular bandwidth in 1958; the FCC opened the official proceeding to do this in 1968. Licenses were assigned, not in 1981, but in multiple rounds (most using lotteries) between 1983 and 1989. The process could well be defined as lasting not 11 years, but 32.

The FCC is, however, accurate in presenting the basic problem: “Historically, the FCC’s approach to allocating spectrum has been to formulate policy on a band-by-band, service-by-service basis….” The Report describes this framework as being “criticized for being ad hoc, overly prescriptive and unresponsive to changing market needs.” The obstacle course an allocation must run is a gauntlet in which opponents of new allocations take free shots. Those attempting to move new bandwidth into the market, conversely, are forced to bear the burden of proof, showing how new services would enhance the “public interest.” That enhanced economic growth would benefit consumers and the U.S. economy is not a given. The regulatory process demands the proposition be proven anew – to a curiously skeptical jury – time and time again.

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56 NBP (2010), p. 79.
59 Ibid. (footnote omitted).
The alternative, socially efficient pathway is to proactively put additional bandwidth into the market, to be allocated and reallocated according to consumer demand. Questions about how such resources will best serve the public are best answered in the context of productive activity – namely, competition between networks and service providers who risk capital to gain sales. Indeed, to the extent that markets fail to achieve goals that can be elsewise accomplished through subsidy or regulation, the existence of robust, fully-developed spectrum markets assists government. It does this both by efficiently satisfying additional demands, and by developing additional tools for policy markets via market innovation.

A. How the U.S. Fell Behind the E.U. in 2G

No matter the very long lag in getting cellular telephone services to market in the U.S., no other nation was faster. This was not just because the U.S., via Bell Labs, had developed the underlying technology, but also because whatever the rigidities of the regulated (AT&T) monopoly, markets elsewhere operated under the thumb of state monopolies. These government enterprises, PTTs, extended the bureaucracy of the post office to telephones and telegraphs. They proved more of a barrier to competitive efficiency than did the relatively liberal regime in America.

But where the U.S. mobile market would pioneer an exciting new chapter in world economic development, America’s early lead would soon be squandered. Spectrum was parsimoniously distributed, and cellular licensees were restricted to deploying a particular analog technology. With the rise of digital communications, the approach was already becoming obsolete. Observers lamented the “rise and decline of U.S. leadership, from AMPS and 1G to digitization…”

The emergence of wireless phone service in the 1980s was a jolt to markets everywhere. The old “natural monopoly” market structure was no longer an unquestioned default. Private carriers were unleashed to compete in the U.S. and elsewhere, demonstrating

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**Table 2. NBP Summary of Key Spectrum Allocation Lags**

<table>
<thead>
<tr>
<th>Band</th>
<th>First Step</th>
<th>Available for Use</th>
<th>Approximate Time Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular (AMPS)</td>
<td>1970</td>
<td>1981</td>
<td>11 years</td>
</tr>
<tr>
<td>PCS</td>
<td>1989</td>
<td>1995</td>
<td>6 years</td>
</tr>
<tr>
<td>Educational Broadband Service (EBS)/Broadband Radio Service (BRS)</td>
<td>1996</td>
<td>2006</td>
<td>10 years</td>
</tr>
<tr>
<td>700 MHz</td>
<td>1996</td>
<td>2009</td>
<td>13 years</td>
</tr>
<tr>
<td>AWS-1</td>
<td>2000</td>
<td>2006</td>
<td>6 years</td>
</tr>
</tbody>
</table>

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60 NBP, p. 79.
61 George Calhoun, DIGITAL CELLULAR RADIO (1988).
a new dynamism never associated with state monopoly. Indeed, a privatization wave swept
the PTTs out into the market, and regulators looked to license additional wireless rivals.

European countries pursued a policy designed to favor European producers by issuing
mobile licenses that mandated deployment of a technical standard largely owned by European
firms. A consortium of firms, including Nokia (Finland), Ericsson (Sweden), Alcatel (France)
and Siemens (Germany), collaborated on “GSM” (based on a French derivation of Global
System for Mobile Communications). Regulators in Europe embedded the GSM mandate in
second generation (2G) licenses as a form of industrial policy. By establishing a large market
for the European standard, both in handsets and network equipment, economies of scale
would kick in and allow local manufacturers to compete successfully in the global electronics
market.

The social advantages of this approach are often overblown. Gaining economies of
scale is an important efficiency. But competition in the market for standards is, as well. In
2G, and particularly in 3G and 4G (broadband data) networks, the rivalry to the GSM
standard has proven exceedingly beneficial. In particular, the competing CDMA technology
pioneered by (American-based) Qualcomm has supplied an upgrade path allowing GSM and
other cellular systems to grow in scope and functionality. Without the openness allowing this
competition, the European standardization diktat would have proven far more costly.63

One highly successful outcome of the European standard-setting process, however,
was to create a political constituency for allocating spectrum quickly. As industrial policy,
European Union regulators strove to win a standards race. This prompted member states to
cooperate, quickly agreeing to harmonized pan-European policies. Licenses were then
expeditiously distributed. The U.S. is seen (in Table 2) to have engaged in a process for PCS
(2G) licensing that took from 1989 to 1995. In reality, this covered only the distribution of
licenses authorizing use of 60 MHz; the other 60 MHz of PCS spectrum was allocated to
licenses that were not finally assigned until 2005. In contrast, E.U. states were awarding
licenses beginning in 1989 (as in West Germany, e.g.).64 By the end of 1992, 12 European
countries had licensed GSM networks,65 and services were launched – with over one million
GSM subscribers.66

While Europeans licensed, American regulators dithered. While spectrum at 1.9 GHz
was made available for PCS services, and rules allowing operators to adopt digital
technologies were enacted in 1988, well before new licenses were issued, regulators were
confounded by how to handle existing users in the 1.9 GHz band. There are some 4,500
point-to-point microwave stations in the bands designated for licensed PCS.67 The great
majority of these radios were used for fixed applications, such that the links could be easily
transferred to either wired systems or higher (wireless) frequencies. Indeed, many of the

63 See, e.g., Neil Gandal, David Salant & Leonard Waverman, Standards in Wireless Telephone Networks, 27
64 Ibid., p. 328.
65 Laurent Benzoni & Eva Kalman, THE ECONOMICS OF RADIO FREQUENCY ALLOCATION (OECD; 1993).
licensees had already made such substitutions. Of course, each “relocation” of radio services involved an expense. And incumbent licensees found that they could hold up the entire PCS allocation by making various demands on regulators in negotiations over who paid, and how much existing licensees received.

A powerful political player, Sen. Ernest Hollings (D-S.C.), championed the incumbents’ cause. As Chairman of the Senate Commerce Committee, overseeing the FCC, he exerted considerable influence. He took the position that existing uses of the emerging PCS band were extremely valuable in terms of public safety. Loss of life might well follow from rules compromising microwave radios, which were operated by railroads, public utilities, refineries, and crude oil drillers (including offshore rigs). The incumbents commissioned a study that estimated it would cost as much as $1 billion for them to be safely relocated. FCC regulators were stymied for several years. While digital mobile services were taking off in Europe, U.S. regulators argued about the terms of spectrum reallocation. As late as 1992, Sen. Hollings was blocking PCS.68

B. Breaking Free for 2G

The logjam was broken in 1994. An overlay device was used, in which the bands were authorized for use by new PCS networks, but incumbent microwave licensees were allowed continued use of the frequencies. PCS licenses were then issued, assigned via competitive bidding in newly instituted FCC auctions. The licenses yielded the right to use the unencumbered bandwidth, and awarded secondary rights to the airwave space used by incumbents. This permitted the (new) overlay licensees to bargain with the (old) incumbents, arranging deals in which the incumbents were paid to relocate. To reduce bargaining costs, the FCC imposed an arbitration structure and mandated time limits. Within a few years, the incumbent users had been moved out, and had profited from their cooperation. More importantly, new PCS services, allocated some 120 MHz of licensed bandwidth, were made available to the public.69

The infusion of PCS A and B licenses in the mid-1990s, allocated 30 MHz each, was a huge shot in the arm for mobile services. New digital networks were built, and existing analog cellular networks soon had to upgrade to remain competitive. Outputs expanded and prices plummeted. New services, including data, came to complement “plain old” mobile voice. And innovative business models, including the revolutionary path blazed by Research In Motion’s Blackberry, attached useful wireless devices to networks using the enterprise and imagination of radio makers owning no FCC licenses. These vendors were to create applications surprising even the mobile operators with which the radio makers contracted, as seen in the current explosion of smart-phone competition – triggered by RIM, launched to

new heights by Apple iPhone, and veering off in new directions with Google Android-based devices.

The essential ingredient in this explosion of economic activity was spectrum. But it is not enough to cite the increase in the bandwidth available via mobile licenses alone. What was equally important, perhaps even more important, was that U.S. policy makers wisely opened the options for the use of the spectrum allocated to mobile licenses. Instead of extending the traditional licensing approach used in broadcasting, the FCC abandoned its “operating permit” template. Instead, it effectively deregulated the use of the radio spectrum allocated to cellular, PCS, and SMR licenses, which were unified under a “commercial mobile radio services” (CMRS) regime.

By the time PCS licenses were awarded, mobile operators could select virtually any service to offer, any technology to deploy, and any business model to operate. They were able to plan their networks as they saw fit, placing base stations where it was economically efficient, not where an FCC license specified. Power levels were similarly left for the mobile operator to optimize; where radios needed high power to jump long distances to the network, they could do so. Of course, operators and their technology partners quickly seized upon this freedom to exploit new margins of efficiency; today, radios in both CDMA and GSM networks search continuously for the lowest power levels they can use while still maintaining transmissions. They adjust power hundreds of times per second to minimize emissions, both conserving battery life in handsets and conserving bandwidth so as to accommodate additional users.

C. 3G Services Without 3G Licenses

The U.S. was slow to introduce 2G, and then slow to introduce the next generation of cellphones. While the E.U. was again licensing carriers with 3G authorizations in 2000-01, the U.S. was still mired in its 2G (PCS) licensing process. Not until 2006 and 2008 would new license auctions (for AWS and 700 MHz allocations) bring substantial new CMRS spectrum to market. While this regulatory lag was – and is – a serious problem, the U.S. benefited from a different set of policy choices far more favorable to economic growth: license liberalization.

The fact that cellular and PCS licenses constituted broad, flexible spectrum use rights meant that operators did not have to wait for 3G licenses in order to deploy 3G networks. It meant that the carriers, their vendors, or third-party application developers that utilized radio spectrum in innovative ways unforeseen by the market and not explicitly outlawed by regulators could introduce new devices. So it was that a small Canadian technology firm, RIM, introduced a pager, the “Inter@ctive,” in 1998, by contracting with mobile carriers. See Figure 8. This presaged the smart-phone revolution a decade later.

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Firms also had considerable leeway to acquire bandwidth in secondary markets. Networks pieced together licenses, affording bandwidth opportunities, by merger. Technologies and business models were little constrained by license terms. While more spectrum would have delivered further efficiencies, consolidation helped mitigate the overly conservative allocations.

The result is visible in terms of market growth. While the 2G licensing lag set back the development of U.S. services in comparison to the E.U., the emergence of third generation wireless broadband came to the U.S. in relatively timely fashion. Today, high-speed wireless services in the U.S. compare favorably with deployments in the E.U. See Figure 9. As recently as 2006, the U.S. mobile allocation of less than 200 MHz paled in comparison to the average E.U. allocation of 266 MHz. But liberal spectrum usage rules allowed the market to make lemonade, turning “1G” and “2G” spectrum into lively “3G” markets. Voilà!

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Perhaps one of the best examples of U.S. spectrum liberalization lie in the details of the 2.5 GHz – 2.7 GHz band, historically referenced as “ITFS” or “MMDS.” The acronyms relate to the video service licenses issued starting in 1963. Educational institutions, including school districts, junior colleges, and churches, were assigned Instructional Television Fixed Services licenses in order to distribute video programs services to classrooms. This was largely before the existence of videotape player/recorders, DVDs, cable or satellite television, let alone broadband data networks. Multipoint, Multichannel Distribution Service licenses were additionally issued to for-profit enterprises for the express purpose of supplying over-the-air subscription television services. For various business reasons, including the imposition of “pay TV” bans in states such as California and then the post-deregulation rise of cable TV networks, the services never gained much traction.

As time went by, the frequencies were little utilized. By the late 1980s, however, it had become clear that the very large amount of spectrum allocated to the licenses – nearly 200 MHz between 2.5 and 2.7 GHz -- was potentially quite productive. The band was close to the PCS frequencies, and had similar propagation characteristics. Entrepreneurs began acquiring the MMDS licenses in secondary trades, and acquiring use rights in leases arranged with the non-profit institutions owning ITFS licenses. The FCC was petitioned by wireless innovators requesting that new wireless services – specifically, for two-way broadband data – be permitted. A long reform process began; the FCC’s 2010 National Broadband Plan Report charts the duration of the reform period as lasting from 1996 to 2006. See Table 2.

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73 International Telecommunications Union.
74 The spectrum allocation process for this band is described in detail in Thomas W. Hazlett, Spectrum Tragedies, 22 YALE JOURNAL ON REGULATION 242 (Summer 2005).
The upshot, however, is that much of the spectrum has now been made available for productive use. Licenses to supply relatively low-valued, “specialized mobile radio” services — such as taxi and pizza delivery dispatch — were pieced together in secondary markets and (with the help of a key 1990 FCC regulatory waiver) redeployed in highly productive cellular telephone networks by industry entrant Nextel. Much of the 198 MHz originally allocated for ITFS and MMDS services now hosts state-of-the-art “WiMax” networks pioneered by U.S. operator Clearwire. A joint venture of several companies (Sprint, Motorola, Intel, Google, Comcast, Time Warner, Bell Canada, and Bright House), as well as public investors (following a 2008 IPO) and cellular entrepreneur Craig McCaw, Clearwire serves over six million customers. It is ambitiously attempting to construct a nationwide “4G” wireless network, deploying emerging technology, while competing with rivals offering fixed or mobile broadband Internet connections. See Figure 10.

It is not an easy gambit. Yet it is just such risk-taking that propels markets, disrupting established modes. Social progress is built on the scaffolding of such successes, which themselves sit atop the remains of so many daring business failures. In wireless, the enterprising efforts of either kind are blocked in the absence of bandwidth rights. Without the reforms freeing 2.5 GHz airwaves for more productive use, the billion-dollar investments of Clearwire would have been pre-empted; their customers would not enjoy the options they have availed themselves of; the customers of rival networks would themselves face one less competitive option. Win, lose, or draw, the Clearwire experiment is a worthy one. More spectrum, more entrepreneurial experiments.

\[\text{Fig. 10. Clearwire “4G” Subscribers, by Quarter 2006-2010}^{75}\]

\[\text{Company quarterly reports.}\]
The U.S. system has, despite too-tight bandwidth constraints, been free to deploy efficient technologies. Competitive markets have delivered far-reaching social benefits. Prices, appropriately measured as mean revenue per minute of voice use, are lower in the U.S. than in any other high-income country. See Figure 11. The result is that mobile voice usage is easily the highest per capita anywhere. See Figure 12.

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77 Ibid., p. 83.
These data tell a remarkable story. Just 15 years ago, the U.S. was tied up in regulatory knots, stuck with analog 1G services, unable to allocate new spectrum resources. But the deadlock over incumbent users in the PCS band was broken, thanks in large measure to reforms undertaken by both Republican and Democratic policy makers at the FCC. Market mechanisms were authorized, including liberal overlay rights and license auctions. Progress then came quickly. Competitive bidding awarded new licenses, and these were configured so as to convey broad, flexible use rights. Investors poured money into network development, and markets exploded with economic activity. A far-ranging array of business models, technologies, services and applications found their way to consumers. Driving this market evolution: bandwidth allocated via liberal licenses.

Today, Americans enjoy the lowest prices of any developed country, and consume the largest volumes of any nation. Yet we can do much better.\textsuperscript{78} Vast bandwidth continues to lie virtually idle. That represents a world of wasted opportunity. The intense growth in mobile services we have seen so far – Americans use over 2 trillion voice minutes per year, and send more than 2 trillion text messages – is simply the tip of the consumer welfare iceberg. Demand is already observed for far faster speeds, far greater capacities, and far more bandwidth-consuming applications. Emerging networks, including those hosting M2M applications, represent the future of mobile communications. Continued spectrum liberalization is the key to generously accommodating that future.

\textsuperscript{78} One must be careful when playing the “global race” game. The key is not where America ranks, but how better policies might improve consumer welfare. Whether the U.S. is thought to rank #1 or #100, there are potential reforms that might improve performance. The confusion becomes even more pronounced when poor metrics are used for comparison, as so often happens in the vaunted “broadband race.” See Thomas W. Hazlett, \textit{We’re Number Two?} COMMENTARY (Dec. 2009).
V. LESSONS LEARNED

[E]normous economic value [will be] created by releasing 300 MHz of additional spectrum to meet growing demand for mobile data.


When describing the wireless industry, it does not take anyone – least of all the economic experts at the Federal Communications Commission or the U.S. Department of Justice Antitrust Division – long to get down to the question of radio spectrum. It is the essential ingredient. Its inefficient deployment, courtesy of a regulatory system that makes bandwidth artificially scarce, has frustrated economists – and wireless entrepreneurs seeking to innovate in the marketplace – for decades. Each and every allocation by regulators has been a long, hard slog.

The good news is that many of those slogs are now behind us. U.S. commercial networks have about 450 MHz of radio spectrum to deploy, using licenses that grant broad rights to use airwaves flexibly, without rigid rules or restrictions.

Daunting challenges remain, however. The first three decades of an unfolding mobile ecosystem have exposed the size of the opportunity. We see that the greatest possibilities for productive spectrum use are yet ahead of us. The wireless revolution is not cresting but rising. An economy of cellphones is giving way to a planet of smartphones, video-streaming, data transfer, and M2M. Five billion mobile subscribers have crowded into the marketplace; they will be joined, soon perhaps, by some 50 billion network devices. How soon the new connections arrive, and how much they improve social life or business efficiency, is largely a function of how imaginative we are in crafting new services – and getting the bandwidth in place to accommodate them.

To host the 302 million mobile subscribers in the U.S., something close to 450 MHz has been made available to the market. The regulatory processes involved have taken decades. We are now in a position to productively use (at least) all of it. The Federal Communications Commission projects that upwards of another 300 MHz would also be efficiently utilized by U.S. mobile carriers as of 2014. In contrast, the International Telecommunications Union (an arm of the United Nations), forecasts market demand, in

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79 Mobile Wireless Services Industry
Mobile wireless services allow customers to make and receive telephone calls and use data services using radio transmissions without being confined to a small area during the call or data session, and without the need for unobstructed line-of-sight to the radio tower. This mobility is highly prized by customers… To provide these services, mobile wireless services providers must acquire adequate and appropriate spectrum…


80 NBP (2010), Chapter 5.
countries like the U.S., for a total of over 1,700 MHz by 2020.\footnote{International Telecommunications Union, \textit{Estimated Spectrum Bandwidth Requirements for the Future Development of IMT-2000 and IMT-Advanced}, Report ITU-R M.2078 (2006), p. 25; \url{http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2078-2006-PDF-E.pdf}.} In truth, there is no magic number for “demand.” How much networks, and their subscribers, will gobble depends on the price they must pay for access. But there is a simple economic reality: mobile markets will produce far more value should input prices be lower. And the reliable way to lower those prices is for regulators to allow more spectrum into the marketplace.

The cellular telephone spectrum allocation officially began in 1968. Given that marker, the FCC has been at the task of putting spectrum into the mobile services for some 43 years now. At this rate – just about 10 MHz a year – we are destined to see little progress. It is time for bold steps and fundamental reforms. These measures should capture the lessons we have learned.

\begin{quote}
\textbf{Lesson 1: Spectrum creates its own wireless demand.} Policy makers need not worry about the precise amounts of bandwidth mobile carriers are going to utilize; they need simply to make copious amounts of bandwidth available to the marketplace. A more generous flow of spectrum will itself send the signal that technologists, carriers, and application innovators can profitably invest in developing the networks of tomorrow. Relieving spectrum bottlenecks by allocating substantially more frequency space will lower costs for consumers and entrepreneurs alike, encouraging competition and robust wireless growth.
\end{quote}

\begin{quote}
\textbf{Lesson 2: Spectrum markets need liberal licenses.} When bandwidth is allocated via licenses that permit operators to choose technologies, services, or business models, competitive markets replace administrative fiat. Licensees, given flexibility, have powerful incentives to build the most useful and popular networks, providing platforms that generate maximum economic value. Moreover, secondary markets are free to shift spectrum inputs from outmoded employments to more productive wireless applications. As technology options change, so do efficiencies – and networks evolve. Restrictions on spectrum use disrupt market forces, over-protecting the past and freezing out the future.
\end{quote}

\begin{quote}
\textbf{Lesson 3: The case-by-case spectrum allocation system is a barrier to progress.} Fundamental reform calls for moving to a more liberal regime where spectrum use rights are flexible, not fixed. The market should not have to wait for regulators to make specific determinations about the use of each frequency band, but be able to bid spectrum from one employment to another. Companies – wireless carriers, device makers, media producers, technology vendors, or daring upstarts – should be able to deploy new services, buying spectrum rights in markets without waiting for a 6-13 year FCC proceeding.
\end{quote}

A generic approach to airwave liberalization, as suggested in a formal letter to the FCC by “37 Concerned Economists” on Feb. 7, 2001, needs to receive the attention today it
failed to garner a decade ago. The signatories included a Nobel Laureate, 2 former members of the President’s Council of Economic Advisers, 6 former Chief Economists and Deputy Chief Economists of the Commission, and 10 former Deputy Assistant Attorneys General in the Department of Justice Antitrust Division. It read, in part:

Constraints on the use of spectrum cause both static and dynamic inefficiencies. At any moment, unnecessary restrictions prevent beneficial uses of spectrum. Over time, these regulatory rigidities can discourage innovation altogether. Instead of being able to bid for spectrum space to introduce a new service, an entrepreneur must submit to a formal rule making process. There, the entrepreneur’s counsel must convince the Commission that the proposed innovation warrants an allocation of spectrum and, if so, what rules should govern it. This process is typically lengthy, arduous, lawyer-intensive, and expensive. Moreover, it often necessitates revealing proprietary investment ideas (and business models) to gain a “public interest” determination. This taxes entrepreneurship. Better rules would be permissive, allowing wireless licensees flexibility to use spectrum subject only to limits on out-of-band emissions and anti-competitive concentration.

Much of this policy vision has permeated the FCC. The 2010 National Broadband Plan includes a very persuasive chapter on the importance of additional spectrum allocations, and appropriately focuses attention on the prospect of allowing TV band airwaves to be bid into the mobile market. This thinking needs to be stretched further. Beyond Five Year Plans that target specific bands for reallocation, provoking all-too-familiar FCC turf wars, our emerging Information Economy would be best supported by a systemic liberalization. Spectrum resources are precious, and should be – in every band, and through time – optimized. This does not and cannot happen under top-down administrative allocation. It requires economically-motivated asset owners facing competitive constraints.


83 See Thomas W. Hazlett, Putting Economics Above Ideology, BARRON’S (July 12, 2010). While the FCC is pursuing a plan, requiring new authority from Congress, to reassign TV airwaves via a two-sided auction organized by the Commission, I have proposed a much simpler and, I believe, more efficient transition plan for the TV Band. Unleashing the DTV Band: A Proposal for an Overlay Auction, Comment by Thomas W. Hazlett, submitted to the FCC in A National Broadband Plan for Our Future, GN Docket 09-5 (Dec. 18, 2009); http://mason.gmu.edu/~thazlett/pubs/NBP_PublicNotice26DTVBand.pdf. For a good summary, see Richard Thaler, The Buried Treasure in Your T.V. Dial, N.Y. TIMES (Feb. 27, 2010).
A “free lunch” is available. By allowing investors to bid under-used frequencies into more productive employments, society gains great new opportunities at virtually no social cost. Where additional airwaves are brought into busy wireless networks, expansion is possible for any given level of infrastructure investment. A system engineered to deliver phone calls for a million customers can host many more. A network offering data services of 1 mbps, may deliver Internet access at five or ten times that speed. Additional bandwidth has been a key driver at every stage of mobile sector development.

Big spectrum bumps jolt markets. In the 1980s, cellular bandwidth introduced a stunning new marketplace. In the 1990s, PCS licenses accommodated more competition, and digitization – per minute price reductions of more than 95% followed. Now carriers are scrambling to deploy AWS and 700 MHz bandwidth, bringing fresh bling to the smart-phone wars.

Today’s mobile market is developing a universe in which every person lives, works, and travels with a network-connected computer. Voice phone calls and text messages are only opening salutations in this developing relationship between man and machine. Governments can use such networks to air highly-targeted public safety alerts; doctors to monitor the health of their patients; enterprises to track their shipments. None of this is wondrous; the applications noted are already here. Yet, the paths they will take are as yet uncharted. They may quickly achieve critical mass and “killer app” status, or be delayed by the artificial scarcity of spectrum inputs.

Additional bandwidth is a force multiplier. The speed and quality of existing services increase; the scope of applications expands; the capacity for creative new products and business models grows throughout the wireless ecosystem. Efficiency is itself disruptive. The policy complements are there for the taking. There is no good reason to turn down a free lunch, particularly one this healthy and delicious.