INNOVATION IN THE WIRELESS ECOSYSTEM: A CUSTOMER-CENTRIC FRAMEWORK

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Introduction

The Federal Communications Commission's Notice of Inquiry in GN 09-157 Fostering Innovation and Investment in the Wireless Communications Market is a significant event at an opportune moment. Wireless communications has already radically changed the way not only Americans but people the world over communicate with each other and access and share information, and there appears no end in sight to this fundamental shift in communication markets. Although the wireless communications phenomenon is global, the US has played and will continue to play a major role in the shaping of this market. At the start of a new US Administration and important changes in the FCC, it is most appropriate that this proceeding be launched.

The title of the proceeding has been chosen wisely. Innovation and Investment are two sides of the same coin; new ideas, new technologies and new business methods cannot happen without investment, and neither investment nor innovation will happen without incentives for innovators and investors to perform their roles. The focus on market is also a wise choice; some might view wireless as a technology, or perhaps a social phenomenon, and of course it is all of these. But it is the market which brings all of this to fruition and certainly it is the market that determines what innovations and investments customers really want. Of course, this is not enough; key resources such as spectrum must be readily available in order for markets to play their role in eliciting innovation and investment.

Some analysts and pundits have suggested that the market for wireless communications is flawed, controlled by a few large firms that suppress new technologies and limit the market.[1] They call for FCC intervention to fix these flaws via regulation, and many of the issues raised by these analysts and pundits are raised in the NOI. But good policy requires that intervention in markets must be based on empirical evidence of market failures and the likelihood of a proposed remedy's efficacy in correcting that failure. Unless interventions are based on rigorous analysis of market failure and the efficacy of the remedy, the most likely

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outcome is increased cost, reduced customer choice, reduced incentives to invest and reduced incentives to innovate.[2]

In earlier work, Faulhaber (2009) argued that FCC policy must be *customer-centric*; ensuring that key decisions about products and services should be made by customers in the competitive marketplace , not regulators, legislators, pundits, self-styled advocates, lobbyists or even academics. The job of the FCC is not to make decisions about "approved" business models but rather to ensure that customers are able to make such choices in markets which are competitive, innovative and transparent. The customer must be at the center of decision-making; it is the job of the FCC to make that happen. We take the same perspective in this paper.

In this paper, we review the wireless industry's past performance in three dimensions: (i) the rate of innovation; (ii) how competitive the industry is; and (iii) how competitive *wireless innovation* is. We do so by examining the record of three key layers in the industry's vertical chain: software applications, devices (handhelds), and the core wireless distribution networks. We find it useful to compare and contrast the wireless ecosystem (including Internet access) with the personal computer/Internet ecosystem, both in terms of innovation and in terms of market structure.

To preview our results: we find that the three segments of the wireless marketplace (applications, devices, and core network) have exhibited very substantial innovation and investment since its inception. Perhaps more interesting, innovation in each segment is highly dependent upon innovation in the other segments. For example, new applications depend upon both advances in device hardware capabilities and advances in spectral efficiency of the core network to provide the network capacity to serve those applications. Further, we find that the three segments of the industry are also highly competitive. There are many players in each segment, each of which aggressively seeks out customers through new technology and new business methods. The results of this competition are manifest: (i) firms are driven to innovate and invest in order to win in the competitive marketplace; (ii) new business models have emerged that give customers more choice; and (iii) firms have opened new areas such as wireless broadband and laptop wireless in order to expand their strategic options.

Having found that all three segments are highly competitive, we ask, where is the market failure? If none, then the principle of customer-centric applies: let *customers* make the key decisions regarding which products, services, open vs. managed business models, net neutrality, *et al.* will survive in the marketplace. While there is no shortage of pundits, advocates, lobbyists and academics advising the FCC that it, rather than customers, should be making these decisions and advising the FCC what those decisions should be, a customer-centric FCC must leave these decisions to customers in a competitive marketplace. Should the FCC decide to preempt customers and make choices for them, it follows as does night from day that the result will be (i) less customer choice, and therefore reduced customer well-being; (ii) higher costs for producers and therefore customers; (iii) lower incentives to invest and

innovate, harming customers, producers and the American economy. In this case, economics and technology are on the same page: economists advise intervention only in the case of demonstrated market failure, and then only if there is evidence that the intervention will do more good than harm. The technologist's advice is more pithy and down to earth: if it ain't broke, don't fix it!

We then consider potential problems raised in the NOI as possible targets for FCC intervention. The subsequent sections of the paper explore whether or not there are market failures in wireless communications, and, if so, what appropriate interventions might be. We are mindful, and ask that the FCC be mindful, of the potential negative effects of well-meaning interventions that are unsupported by hard evidence.

We explicitly ask if there is a proactive role for the FCC in fostering innovation and find that indeed there is. In fact, the FCC can and must play a crucial role in making available much more licensed spectrum for use in wireless communications. Only if sufficient spectrum is made available will innovators and investors have the critical input they need to keep up the rate of innovation the industry has so far exhibited.

Specifically, we address issues in the NOI regarding whether the FCC should

- mandate spectrum sharing of licensed spectrum, with the view of encouraging "non-interfering" uses such as cognitive radio.[3]
- adopt network infrastructure policies that foster the deployment of 4G and future technologies for wireless broadband, as well as explore alternatives to traditional network architectures, such as mesh networks.
    - Adopt alternative dispute resolution processes for resolving interference disputes
- consider "openness" regulation, so that all applications can run on all compatible devices.
    - We focus on the network neutrality regulations proposed recently by Chairman Genachowski
- consider how different business platforms and different business models affect innovation.

Lastly, we raise an issue not addressed in the NOI, and that is transparency. In the body of the paper, we make the consistent argument that competition in all segments of the industry has driven innovation and can continue to do so. But it will only do so if customers understand what they are buying and can make informed and intelligent purchase decisions. This requires all producers (application providers, device makers and core network providers) to be transparent in their dealings with customers concerning all matters that are relevant to

customers' purchase decisions. Part and parcel of a customer-centric policy must be ensuring the transparency of all wireless markets, a charge that government must take very seriously.

To preview our conclusions, we find all wireless segments to be demonstrably innovative, with competition driving this innovation. We find there is no market failure which would necessitate market intervention by the FCC. Indeed, we strongly support a customer-centric policy: put the customer at the center of decision-making. Let the customer, rather than regulators, legislators, pundits, advocate or academics, decide among open or managed business models, various network management options, and the degree to which they demand network neutrality and interconnection. Firms that don't satisfy customers' needs will lose out to firms that do. The job of the FCC is to put the customer in the driver's seat. This leads us to make two specific policy recommendations to the FCC: (i) make more spectrum available for licensed use; and (ii) ensure that customers have the information they need to make informed decisions.

Wireless Innovation –The Story Thus Far

Virtually anyone anywhere in the world is aware of the speed of innovation of wireless handsets over the past decade. New handsets of ever-increasing functionality appear weekly, in every country in the world.[4] But rapid innovation has occurred throughout the vertical chain of the wireless industry: applications, devices and core network. Although the innovation in handsets/devices (and applications) has been most obvious to customers, innovation in the core network has been just as rapid if not as visible.

In this section, we review recent innovations in applications, devices and core network. The innovation record in the first two segments is unsurprising, but certainly worth studying. The innovation record in core networks should not be a surprise, as networks have become much more capable over the past five years. But the innovation process is less obvious, more behind-the-scenes, and yet it is perhaps the most important *situ* of innovation because network innovation enables all the innovation in the other segments. We discuss how innovation must necessarily be integrated across all three segments in this industry, which is in stark contrast to innovation in the PC/Internet ecosystem.

Innovation in Applications

Software applications for wireless phones have gone from essentially zero a few years ago to tens of thousands of applications today. Software vendors, device vendors and carriers offer apps stores, each offering hundreds or thousands of applications for download, some free, some for a fee. A current list of apps stores:

Device Manufacturer	**URL to App Store**
Apple's App Store	http://www.apple.com/iphone/apps-for-iphone/
BlackBerry's App World	http://na.blackberry.com/eng/services/appworld/
Palm's App Catalog	http://www.palm.com/us/products/software/mobile-

	applications.html
Nokia's Ovi Store	https://store.ovi.com
Samsung's Application Store	http://www.samsungapps.com
Sony's PlayNow arena	http://www.playnow-arena.com
LG's Application Store	http://www.lgapplication.com
Software Developers	
Google's Android Market	www.android.com/market
Microsoft's Windows Mobile Downloads	http://www.microsoft.com/windowsmobile/en-us/downloads/default.mspx
Carriers	
AT&T's MEdia Mall	http://mediamall.wireless.att.com
Verizon Wireless' Tools & Applications	http://products.vzw.com/index.aspx?id=fnd_toolsApps_all
Sprint's Software Store	http://softwarestore.sprint.com
US Cellular's easyedge	http://easyedge.uscc.com/easyedge/Home.do
Cellular South's Discover Center	http://www.cellularsouth.com/DiscoverCenter/phones-apps/index.html
Cricket's Downloads	http://www.mycricket.com/cricketfeaturesdownloads/
Independent Stores	
Handango	http://www.handango.com
GetJar	http://www.getjar.com

Table 1
Current Application Stores/Websites

What demonstrates the extremely rapid pace of innovation in the applications segment is the fact that the Apple's *affiliated app store* was established in *July, 2008*; almost all of the rest of the affiliated stores have started up in only the last year. (Some stores are older; Handango was founded in 1999 and GetJar in 2004, and AT&T's in 2004.)

The range of applications available is also worth a look, as nothing like this existed a decade ago, and demonstrates the extraordinary inventiveness of software developers. A few selected applications, from the useful to the social to the wacky:

Application & URL Link	**Function**
AroundMe	lists critical services based on your location
Pandora Internet Radio	creates your own personal music station
iLightr	creates a realistic photo of a flame).
Loopt http://appworld.blackberry.com/webstore/content/763	uses device's GPS technology to not only identify their current location, but also identify their proximity to friends using the same application
Shazam www.android.com/market/free.ht	identify songs they hear on the radio through applications that tie into their device's

ml#app=shazam	microphone
X-Plane 9 Flight Simulator http://www.x-plane.com/pg_Meet_Mobile.html	play games that use the device's accelerometer to control characters and vehicles

Table 2
Selected Applications

Many of these applications are specifically designed to take advantage of particular features in the devices, operating systems and networks for which they were designed. The lesson here is clear: innovation in applications often depends critically on innovation in other segments of the industry.

And customers are using apps, particularly on the most capable devices. Stone (2009) reports that Apple has sold more than 30 million iPhones since their introduction and customers have downloaded more than 2 billion apps (from an inventory of 85,000). This works out to 66 apps per iPhone. Communications Daily (2009) quotes Cole Bradman, Chief Technology and Innovation officer of T-Mobile, which sells the Google/Android phone, that they support 10,000 apps for the Android and their customers download an average of 40 apps for their Android phones.

The outpouring of applications over the last 15 months mimics the outpouring of applications that occurred in the decade following the introduction of Windows on the personal computer and the outpouring of applications in the decade after the widespread use of the Internet. Some have argued (Wu (2007)) that applications were more difficult to write and have accepted in the wireless ecosystem than in the Internet/PC ecosystem. It is certainly true that applications that are sold in device vendor or carrier app stores usually must pass stringent compatibility tests,[5] which is not the case in the PC/Internet applications market. However, the number of applications available belies the assertion that these compatibility tests were a barrier to innovation. In fact, the pace of introduction of new applications seems to be overwhelming to customers. CNET (2009) quotes Brodman of T-Mobile stating that "T-Mobile hasn't 'cracked the code' on how to expose customers to applications among the many offered for Google Android smartphones … The importance and difficulty of aiding users' 'discovery' of apps have grown as the Android Market online has expanded to more than 10,000 offerings."

Innovation in Devices

In a recent *ex parte* filing with the FCC, CTIA documents that there are at least 33 device manufacturers selling over 630 different handsets in the US. The worldwide figure is even higher, and device manufacturing is a worldwide business. US customers can thus tap into ingenuity and invention of manufacturers in Europe, Canada, East Asia and elsewhere, as well as the US in the handset market.[6]

We take a direct approach to demonstrating innovation in handsets: we list some of the many major handset launches over the past several years:

Date	Product	Announcement
6/29/07	AT&T Apple iPhone	http://en.wikipedia.org/wiki/IPhone
11/19/07	VZW LG Voyager	http://news.vzw.com/news/2007/11/pr2007-11-19.html
4/1/08	Sprint Samsung Instinct	http://newsreleases.sprint.com/phoenix.zhtml?c=127149&p=irol-newsArticle_newsroom&ID=1124417
7/10/08	Apple iPhone 3G	http://www.att.com/gen/press-room?pid=4800&cdvn=news&newsarticleid=25146
7/11/08	AT&T HSDPA iPhone 3G	http://www.att.com/gen/press-room?pid=4800&cdvn=news&newsarticleid=25923
9/23/08	T-Mobile Android G1	http://www.t-mobile.com/company/PressReleases_Article.aspx?assetName=Prs_Prs_20080923&title=T-Mobile%20Unveils%20the%20T-Mobile%20G1%20–%20the%20First%20Phone%20Powered%20by%20Android
10/21/08	AT&T Samsung Epix	http://www.informationweek.com/news/personal_tech/smartphones/showArticle.jhtml?articleID=211300247
11/4/08	AT&T Blackberry Bold	http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=9117804&intsrc=news_ts_head
11/20/08	Sprint HTC Touch Diamond	http://www.rcrwireless.com/article/20081120/WIRELESS/811199960/1081/blackberry-storm-flying-off-verizon-wireless-shelves/htc-s-touch-diamond-sprint-nextel-adds-to-its-high-end-offerings
11/21/08	VZW Blackberry Storm	http://news.vzw.com/news/2008/11/pr2008-11-20.html
2/24/09	AT&T Matrix Pro	http://www.phonenews.com/att-launches-matrix-pro-6888/
2/26/09	VZW LG Versa	http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=9128679&intsrc=news_ts_head
3/2/09	Sprint Palm Pre	http://www.rcrwireless.com/article/20090302/WIRELESS/902279975/1081
4/1/09	MetroPCS Samsung Finesse	http://investor.metropcs.com/phoenix.zhtml?c=177745&p=irol-newsArticle&ID=1272139&highlight=

7/13/09	VZW & Sprint Blackberry Tour	http://hothardware.com/News/Verizon-Wireless--Sprint-Launch-BlackBerry-Tour/
9/21/09	Cellular South HTC Hero (Android)	https://www.cellularsouth.com/news/2009/20090921.html
EOY 2009	LG Watch Phone	http://ces.cnet.com/8301-19167_1-10137452-100.html

Table 3
Selected Handheld Device Launches

Note that while the headlines focus on high-end phones, especially those that compete with the iPhone, new low-cost phones continue to be introduced with new features and functions. Device innovation benefits the entire product range, not just the high end.

What is most compelling about this list is how rapidly new handsets are introduced, each one offering features undreamed of five years ago. And the pace continues: Richtel (2009) of the New York Times reports that Google has announced 18 new Android handsets will be introduced by EOY 2009 by device makers. Clearly, innovation is alive and well in the handheld device segment of the wireless marketplace.

Innovation in Core Networks

The carrier segment of the wireless industry is least understood by the general public, in that their service, while at the core of the business, is largely invisible. We hold handset devices in our hand and use them every day. Similarly, we experience applications very directly when we use them. But the radio signals, the receivers, the processors, the backhaul networks are simply invisible to us. Of course, we spot the occasional cell tower as we drive, but that is usually the extent of our awareness. We know, of course, that what makes our cell phones work is radio, connecting us to the phone network and the Internet via controlled and directed electromagnetic radiation, together with the processing at both the handset and the cell tower, but what is it that really goes on? If we are in a "dead zone," we know we are out of our carrier's coverage area and cannot make calls. We know we may drop calls if the capacity of the closest tower is exceeded by lots of voice or data traffic. But most of us know little or nothing about the "magic" that happens between our cell phones and our carriers.

At its most basic, carriers are assigned radio frequencies over which our voice and data signals are sent to carrier receivers. Many customers may be using a given tower/receiver, sharing frequencies to do so. The more frequencies (more "bandwidth") the more capacity that cell tower has to move voice and data traffic. Carriers obtain these frequencies in different parts of the country by bidding in an FCC auction for licenses to use the bandwidth they need to move traffic. Of necessity, this resource is quite limited, and the FCC has limited the amount of licensed spectrum available for mobile wireless (Commercial Mobile Radio Service, or CMRS) communications. In spite of this scarcity of spectrum, carriers have been able to utilize this

resource with ever-increasing efficiency to offer more voice services and more recently more data services over mobile phones.

Innovation in the core network, therefore, can be conceived as *increasing spectral efficiency*. Increased spectral efficiency is manifest to customers as increased capacity to make voice calls and increased speeds by which our phones access the Internet, download our e-mail, and allow us to watch video on our handsets, based on the very limited resource of spectrum. Innovation in spectrum use takes place in laboratories[7] and research centers and real world networks around the world, and consists of scientists and engineers determining better, more efficient protocols for sending and receiving information over the air using less spectrum. In its simplest terms, spectral efficiency is about how many bits (i.e., information) can be successfully transmitted per megahertz (Mhz) (i.e., bandwidth) of spectrum.

Innovation in core networks often takes the form of standard-setting, as new means of using the carrier's spectrum must be accompanied by new devices, and device manufacturers must have standards to which they build their handsets or else they won't work on the network. Therefore, we often see core network innovation manifest in an alphabet soup of protocol initials: CDMA, GSM, WiMAX, 3G, 4G, EV-DO Rev A, HSDPA, UMTS, and LTE, to name a few. Each is a network protocol, and each represents an advance in spectral efficiency:

Service	**Standard**	**System Spectral Efficiency[8] (Bits/sec)/Hz**
2G	GSM 1993	0.17
2.75G	GSM+EDGE	0.33
3G	CDMA 2000	0.172 (fully loaded)
3G	1x EV-DO Rev A	1.3 (average load)
3G	WCDMA	0.51
3.5g	HSDPA	2.88
WiMAX	IEEE 802.16	1.2
4G	LTE	16.32 max
WiFi	IEEE 802.11b/g	2.4

Table 4
System Spectral Efficiency of Selected Network Standards
(from Wikipedia, Spectral Efficiency)

Overall, how does US carriers' spectral efficiency measure up? Campbell (2009) finds that the US leads all OECD countries in subscribers served per Mhz of spectrum allocated. US carriers are more efficient than Japan, more efficient than Korea, and more efficient than any European country. US carrier innovation in networks allows our networks to be far more efficient than any other country. Could this be because US customers use less voice and less data? As it turns out, the same report shows that US customers use far *more* voice and data than customers in other countries. So yes, innovation in the core network has made us a world leader in managing the scarce resource of spectrum and providing capacity to meet the world's most demanding customers.

How does this innovation in spectral efficiency affect customers? Again, we list announcements of major deployments of network innovations:

Date	Action	Link
11/29/07	VZW announces LTE as 4G Broadband Direction	http://news.vzw.com/news/2007/11/pr2007-11-29.html
2/6/08	AT&T to expand 3G Broadband, then LTE	http://www.att.com/gen/press-room?pid=4800&cdvn=news&newsarticleid=25146
2/8/08	Stelera Wireless launches network using AWS spectrum	http://www.stelera.com/Portals/0/docs/2.08.08%20Stelera%20Wireless%20Launches%20Inaugural%20Wireless%20Network,%20Providing%20High%20Speed%20INternet%20in%20Rural%20America.pdf
5/5/08	T-Mobile begins 3G rollout in NYC	http://www.t-mobile.com/company/PressReleases_Article.aspx?assetName=Prs_Prs_20080505&title=T-Mobile%20USA%20Begins%20Commercial%203G%20Network%20Rollout
9/18/08	T-Mobile announces 3G in 21 markets (HSDPA)	http://www.t-mobile.com/company/PressReleases_Article.aspx?assetName=Prs_Prs_20080919&title=T-Mobile%20USA%20Announces%20Commercial%203G%20Network%20Availability
9/29/08	XOHM WiMAX 4G introduced in Baltimore	http://newsreleases.sprint.com/phoenix.zhtml?c=127149&p=irol-newsArticle_newsroom&ID=1203014&highlight
10/17/08	T-Mobile expands 3G network coverage	http://www.t-mobile.com/company/PressReleases_Article.aspx?assetName=Prs_Prs_20081017&title=T-Mobile%20USA%20Further%20Expands%20Commercial%203G%20Network%20Availability%20in%202008
10/28/08	US Cellular Launches EVDO Broadband	http://www.uscc.com/uscellular/SilverStream/Pages/x_page.html?p=a_press081028
11/4/08	nTelos upgrades 70% of sites to EVDO Rev A	http://ir.ntelos.com/releasedetail.cfm?ReleaseID=345339
2/19/09	VZW details 4G plans	http://www.washingtonpost.com/wp-dyn/content/article/2009/02/18/AR2009021800747.html

2/24/09	AT&T 3G to expand to 850 Mhz	http://www.intomobile.com/2009/02/24/att-3g-network-going-850mhz-nationwide-by-2010.html
7/31/09	BendBroadband enters Voice and Internet (HSPA+)	http://www.bendbroadband.com/press/BendBroadband%20Wireless%20Announcment%20--%207-31-09.pdf
8/19/09	Sprint/Clearwire deploy WiMAX 4G in Baltimore, Portland, Atlanta & Las Vegas	http://www.slashgear.com/sprint-4g-wimax-reaches-las-vegas-portland-and-atlanta-1852602/
9/5/09	MetroPCS announces vendor for 4G LTE Launch	http://investor.metropcs.com/phoenix.zhtml?c=177745&p=irol-newsArticle&ID=1331809&highlight=
9/20/09	T-Mobile rolls out 21Mbs 3G in Phila	http://gizmodo.com/5363254/t+mobile-launches-21mbps-3g-service-in-philadelphia

Table 5
Selected Market Deployments of Network Innovations

Core network innovation has enabled US carriers to keep up with demand for voice traffic that is soaring:

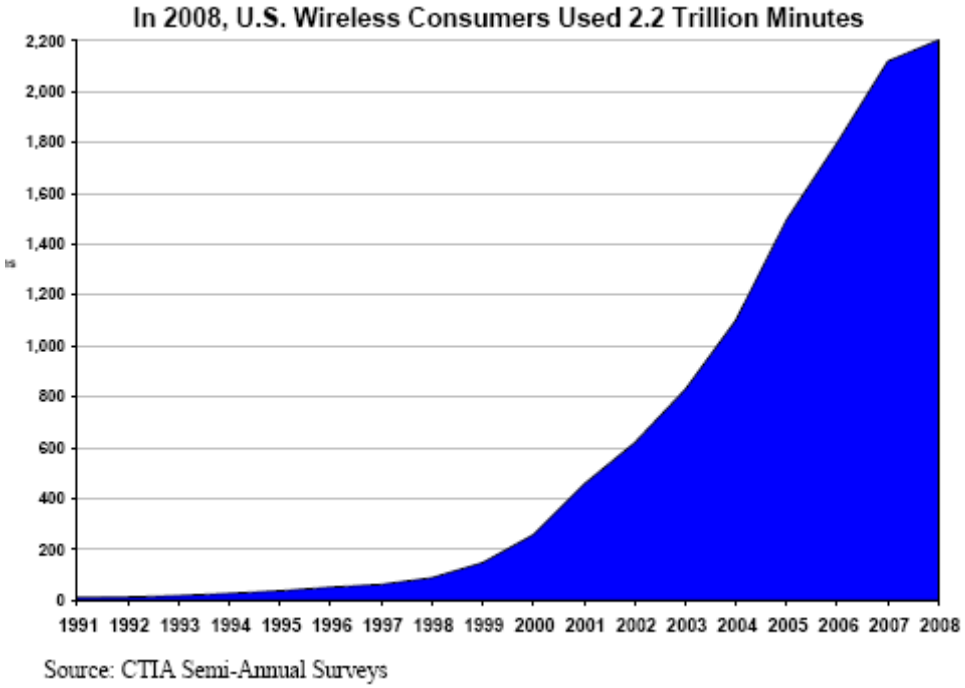

Figure 1
Growth in US Voice Minutes

And data traffic that is soaring; Cisco (2009) estimates mobile data traffic is increasing at the annual rate of 130% (both US and worldwide). Additionally, US data subscribers are soaring:

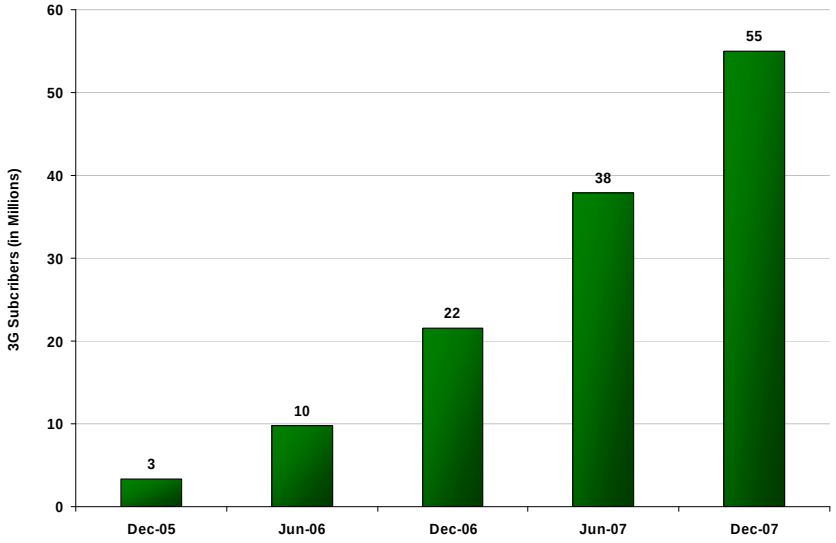

Figure 2
Growth in US 3G Subscribers

The one item that isn't soaring is spectrum licensed by the FCC to the carriers. So if capacity isn't increasing, how is it the carriers are handling vastly increased traffic? The answer is core network innovation which leads to substantially increased spectral efficiency. Carriers are doing more with less.

Wireless Innovation – A Collaborative Venture

In the previous subsection, we separately reviewed innovations in each segment of the wireless industry, noting rapid introduction and deployment of new technology for applications, devices, and the core networks. But the innovation process in wireless is not at all separate; it is a collaborative venture between and among the three separate segments. Innovations in devices depend crucially upon innovations in core networks, and innovations in applications depend crucially upon innovations in devices and core networks. And the applications that customers demand drive innovations in all three segments. Customers demand access to the Internet and other data services, so Internet applications are developed, devices become Internet-enabled, and core networks ensure that capacity is available for high-speed data through spectral efficiency innovation. All of this innovation is driven by customer demand; it is *customer-centric innovation.* To achieve this, cooperation and collaboration is required among all three segments.

Both device manufacturers and carriers establish standards and protocols that application developers must meet. Each advertises developers' toolkits (see for example AT&T's

developers' website devCentral at http://developer.cingular.com/developer/?_requestid=136448, and Verizon Wireless's developers' website at http://developer.verizon.com/jsps/devCenters/wireless/index.jsp). Carriers and manufacturers hold conferences and tutorials on how application developers can become certified to offer applications on their platforms, ensuring that developers can focus their efforts on applications that work with their target platforms.

Manufacturers of handsets and carriers must work closely to ensure that the phones and the networks function as they must to maintain quality transmission and use the spectrum efficiently. Since they are innovating in a competitive environment, they must tightly control both costs and power drain. As carriers develop new protocols to increase network performance, they must work with device makers who will build the handsets that use these protocols and do so with the device makers' needs in mind. The alphabet soup of standards are developed jointly in standards committees with carriers and device makers both party to the development of these standards, each representing the needs of their firm to enable innovation on both sides of the market to move forward. Without devices to use standards such as 4G LTE, networks need not bother with building ultra-high-capacity data networks, and without the networks to transmit 4G LTE the device makers need not bother building the next generation of ultra-high-speed broadband handsets. And without these collaborative innovations, developers need not bother building the applications such as IP TV that can use these ultra-high-speed connections.

A current example from McKeough (2009) brings this techno-speak down to earth. "AT&T is developing a software tool and networking platform that will use wireless devices to record a patient's health measurements at home and send the data to the doctor…[using a wireless technology] named ZigBee, which receives data from medical sensors. ZigBee consumes considerably less power, so monitoring devices, including thermometers, pill dispensers, blood-pressure monitors, and pulse oximeters, can use small batteries to transmit data over long periods of time….If a physician notices, for instance, that a blood-pressure medication isn't working, or if the patient isn't taking the drugs regularly, she'll be able to arrange a videoconference with the patient to discuss solutions."

In contrast, innovation in the wireline Internet can be highly compartmentalized. Innovation in transmission, either to the home or among backbone providers is largely focused on improved fiber optic links and improved cable standards such as DOCSIS 3, and innovation in routing is largely focused on faster Internet servers. At the customer end, hardware innovation is largely focused on PCs and other terminal devices (including WiFi), and is independent of network innovations. Applications developers need not concern themselves with network innovations or PC innovations, and so can innovate independently. Of course, each segment must be able to forecast the capabilities of the complementary segments, but they often don't need to actually collaborate to innovate. In the wireline Internet/PC ecosystem, innovation can proceed independently. In the wireless ecosystem, innovation proceeds only through close cooperation among all segments of the industry.

The rationale for this difference resides in the nature of the interfaces among the segments of the two industries. In the case of the Internet/PC ecosystem, many application developers choose to write code for a single operating system: Windows on which the vast majority of PCs run,[9] and one network protocol: TCP/IP. The interface between applications and the PC/OS is well-understood and time-tested; and TCP/IP has been the simple Internet standard for over twenty years. Similarly, PC manufacturers need only consider the simple TCP/IP interface when designing hardware to work with the Internet. In both cases, the interface between segments is straightforward, standardized and well-understood. In the wireless world, the interfaces among segments are far more complex. Devices and the core network must work together quite closely during a voice or data transmission in order to ensure that the carrier can make the most efficient use of the spectrum, and that the devices comply with the complex task of real-time spectrum management.[10] Applications as well must be vetted to ensure that they work safely with both the devices and the core network, as they can interfere with the proper functioning of the radio channel. No such concerns exist in the wired Internet/PC ecosystem. It is the complexity of these interfaces that demand collaboration of innovation in the wireless ecosystem which is simply not present in the wired Internet/PC ecosystem.[11]

Another difference between the Internet/PC ecosystem and the wireless ecosystem is that there has been much less competition in standards or operating systems in the Internet/PC world, while competition among standards and operating systems has been vigorous in the wireless ecosystem, and that competition has been an important driver of innovation. Handheld operating systems include Apple vs. Google vs Microsoft vs Symbian vs. Blackbery vs. Palm webOS vs. Nokia Maemo vs. Linux vs. ... In the PC world, there is, for all practical purposes, Windows. In the wireless core network high-speed data world, there is HSPA, EV-DO, WiMAX, and LTE. In the Internet/PC world, there is TCP/IP. Greenstein (2009) concludes that "because standards are extraordinarily important and valuable in introducing innovation to the value chain, their development and rollout anticipates new services and inventive activity. There are often multiple solutions to similar problems, so competition between standards proxies for multiple solutions for users." In short, "standards competition beats the alternative" and "standards designed in the absence of competition are usually much worse."

Experienced Internet pros often advocate the Internet model of innovation; we believe there are important lessons to be learned from the Internet, but innovation in the wireless ecosystem is very different from innovation in the Internet. Lessons from Internet innovation must be applied to wireless innovation judiciously, with due respect for these differences.

This is not to say that collaboration is all sweetness and light; firms in different segments have different needs, and when standards are being hammered out in committee meetings, conflict can be expected. Each application provider must deliver a different product for each device using a different operating system. Each device maker must deliver a different product for each carrier using a different network standard; the process is likely contentious. But

ultimately, in a competitive industry, all firms have a common interest in delivering what the customer wants and needs. Only if the innovation process is customer-centric will these firms survive. Collaboration is the necessary survival strategy.

Does this complex innovation process work? Can the competitive market deliver the goods when it comes to innovation? Tables 1-5 tells us the answer: the market has delivered innovation. Another measure of innovation is the number of patents granted related to CMRS.[12] The data show substantial and increasing patent activity in this industry:

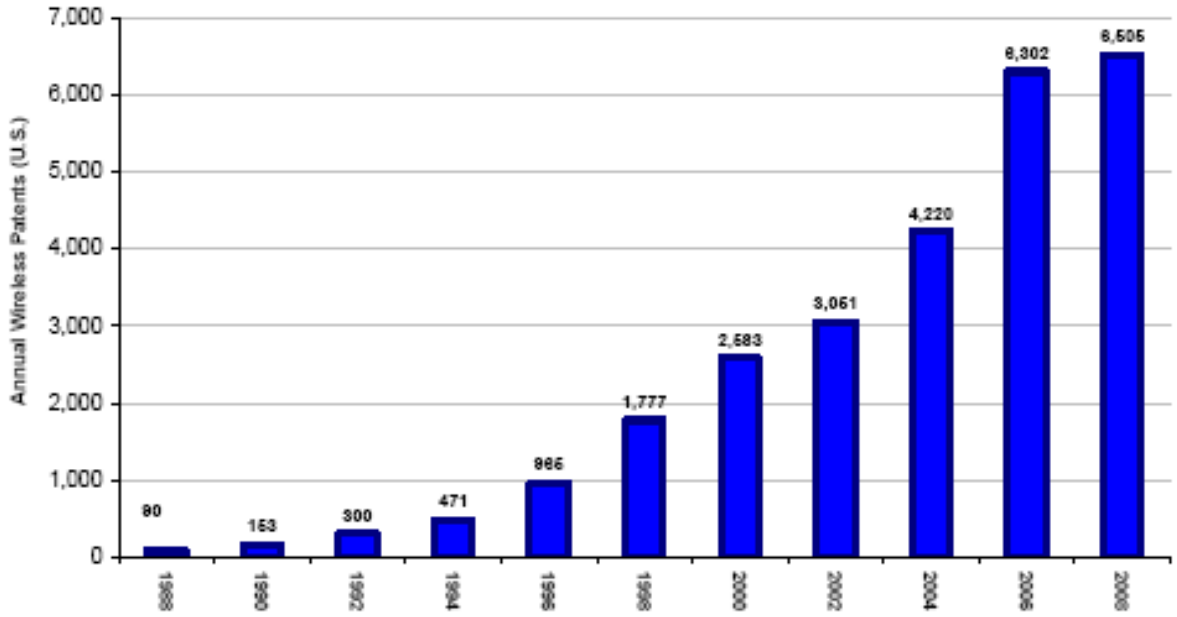

Figure 3
Licensed CMRS Patents Granted
Source: CTIA (2009)

The evidence tells a compelling story of innovation at breakneck speed in all segments of the industry. It also tells a story of collaborative innovation, a rather different story than has occurred in the wired Internet/PC ecosystem. It has been an ecosystem driven by customer-centric outcomes, to which we now turn.

Wireless Competition – In Products/Services and in Innovation

Wireless Competition is the subject of another proceeding, and the topic has been amply and expertly discussed by our colleagues Michael Katz (2009) and Bobby Willig (2009). However, the topic is particularly important to innovation in the wireless ecosystem, and so it bears a brief discussion in this paper. Our primary focus, however, is on competition in innovation; competition in product markets may lead to competition in innovation, but not necessarily. We ask: has innovation in wireless markets been related to competition in these markets?

Competition in Products/Services

Of the three segments of the wireless industry, both applications segments and device segments compete for customers worldwide with many players which are without question highly competitive. We need not belabor the obvious, so we focus our attention on core network providers (carriers). The carrier segment is rather different than either the applications or device segments. Although carriers can operate nationally and globally, there may be local variations. Customers tend to buy their cell service in the metro area where they live. Competition therefore can be more of a local issue; for example, is the carrier segment in Philadelphia competitive? How about in Pittsburgh? In principle, the answers to these two questions could be different.[13] It is also a capital intensive industry, requiring substantial investments in towers, radio equipment, switching and backhaul. This might lead one to expect that the carrier segment would be highly concentrated and not very competitive. We use several simple measures to show that this is not the case; the carrier segment is not concentrated and has resulted in lower prices and higher volumes than anywhere else in the world.

Do wireless customers have choices of carriers? In fact, 95% of the US population has access to three or more carriers, and 72% has access to five or more carriers (CTIA (2009)).

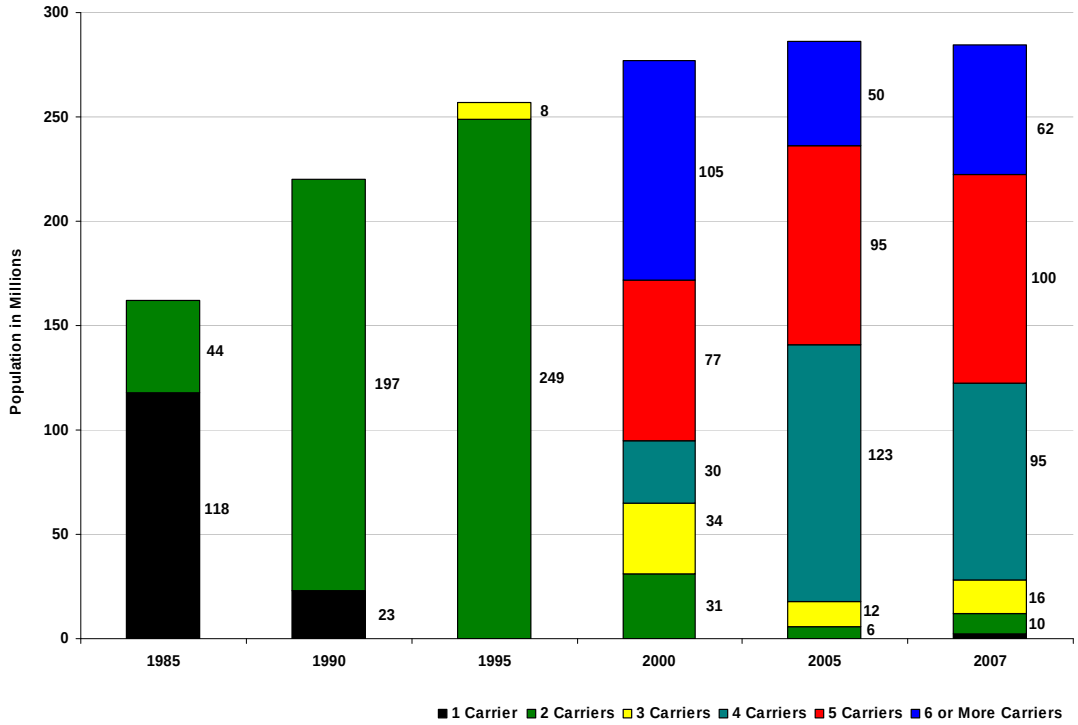

Figure 4
US Population with Access to Multiple Wireless Carriers
Source: Roche (2008)

And customers have no qualms about changing their carriers; the FCC (2009) found that between 15% and 40% of customers change carriers every year. With number portability, changing carriers is easy, and customers show that they are willing to move. It is no wonder that the FCC found in the same report (at ¶1) that CMRS services are effectively competitive.

Given the capital intensity of the industry, one might expect that traditional antitrust measures would show substantial concentration. In fact, the HHI (Herfindahl-Hirschman Index)[14] shows rather the opposite. The US CMRS segment has an HHI of 2280, barely above the threshold of 1800 (below which antitrust issues are dismissed out of hand) and is the *lowest HHI of any country in the world* (Campbell (2009)).[15]

But do these measures of competition impact customers? We use two simple measures of impact on customers, based on international comparisons. Average revenue per minute (our best proxy for *price) is lower in the US than in any other OECD country* (Campbell (2009)):[16]

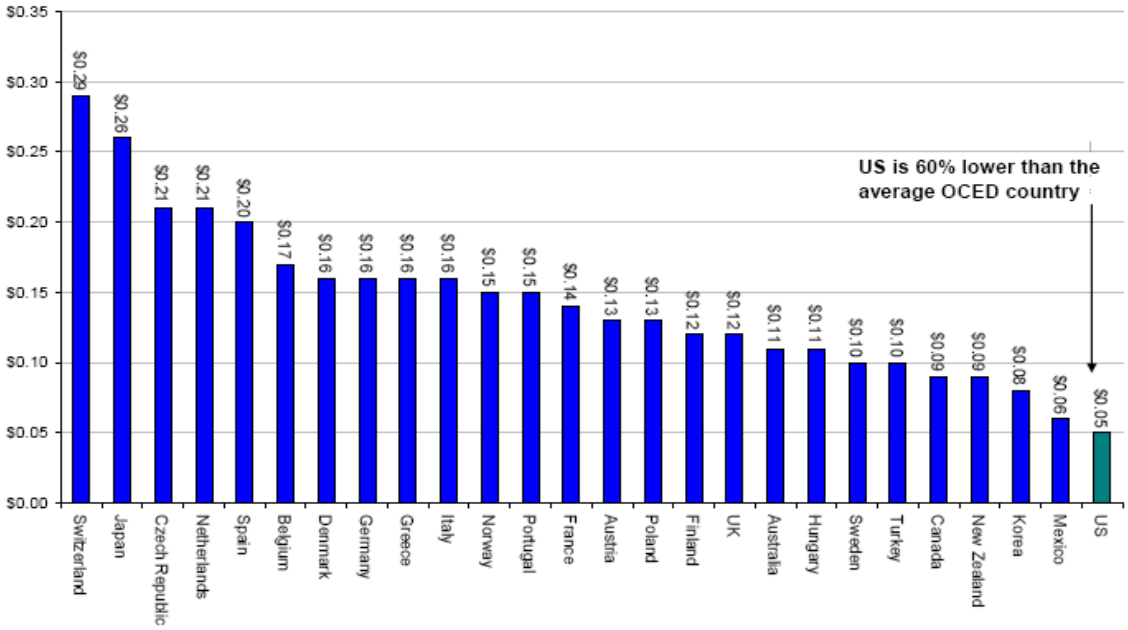

Figure 5
Revenue per Minute, OECD Countries
Source: Campbell (2009)

As might be expected, lower prices lead to greater demand, and the *US has more minutes of use per customer than any other OECD country*:

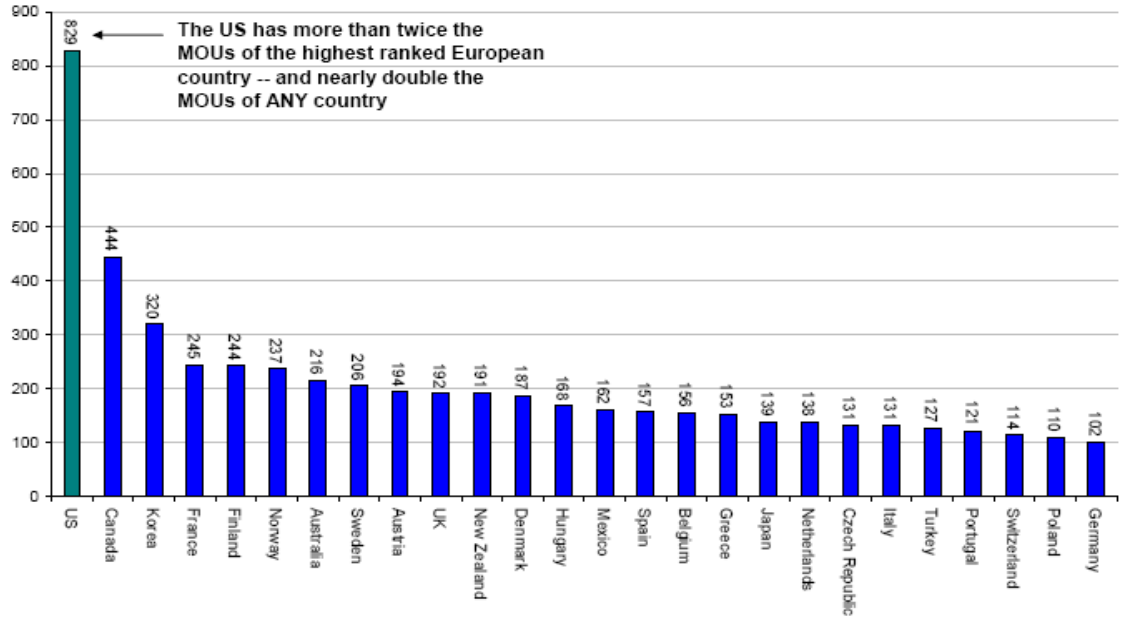

Figure 6
Average Minutes of Use per Customer, OECD Countries
Source: Campbell (2009)

Again, we defer to our colleagues Michael Katz (2009) and Bobby Willig (2009) whose work on CMRS competitiveness is definitive. Our efforts here are simply indicative, easy-to-understand measures of competitiveness, which we recognize as incomplete, if nevertheless quite suggestive.

Competition in Innovation

The previous subsection considered (quite briefly) *static* competition, and examines the effect of marketplace structure on prices and outputs. But a more important question in the wireless ecosystem is *dynamic* competition, or competition among firms to introduce new products, services and network advances.[17]

The analysis of the previous section provides us with the answers.

- In the *application* segment, we have gone from dozens of applications to over 100,000 applications in the past decade, and one recent event stands out as the driver of this explosion of innovation: the establishment of Apple's iPhone apps store. Previously, carriers were cautious about accepting new applications. Perhaps it took a new entrant (Apple) into the industry to show that customers really did want lots of applications and firms could turn a profit by encouraging applications. In the fifteen months since the introduction of the Apple App Store, dozens of stores have sprung up, driven by the competitive necessity of matching Apple's business model innovation. As noted, most app store launches followed very quickly after the launch of Apple's App Store.

- In the *device* segment, the technology race was already on prior to the introduction of the iPhone, but clearly the iPhone raised the bar for other device makers. Within months, manufacturers in East Asia, Canada and Europe were rushing to market with iPhone wannabe's, some quite successful. Would Blackberry have rushed the Storm and the Tour to market without the competitive push of the iPhone? Would Palm have rushed the Pre to market without the competitive push of iPhone (and Blackberry)? In the device market, we see a virtuous circle, in which innovation begets further innovation, as manufacturers innovate in order to stay in the game. Yesterday's cell phone[18] state of the art, e.g., the Palm Treo, is simply no longer salable; it is competition in innovation which has led to this cutthroat but dynamically efficient result. In his analysis of the device market, Levy (2009) states that US wireless customers are the beneficiaries of a "brutal technology competition that is making the chariot race in Ben Hur look like a stroll in the park."
- In the *core network* segment, competition takes place over network capacity and coverage. From our TV commercials, we know that "more bars in more places" is important to customers. But we also know that "the fastest 3G network" is also important. Both are related to the carrier's use of advanced networking standards that provide the spectral efficiency needed to ensure capacity for both voice and data. Table 4 and Table 5 demonstrate that network standards of ever-increasing spectral efficiency are a competitive necessity in the core network business. Both AT&T and Verizon Wireless have announced plans to deploy LTE, a true 4G technology which promises achievable wireless broadband speeds in the 8-12 Mbps range (Segan (2009)). Sprint/Clearwire has already deployed WiMAX in Baltimore, Portland, Atlanta and Las Vegas (Davies (2009)). Firms have found out that customers want bandwidth, and the firm that can deliver that bandwidth will get the business. Even as AT&T Wireless has invested billions of dollars to keep up with the data demands of its iPhone customers by expanding its 3G capabilities, it is planning for its 4G LTE in the near future. It simply cannot let its competitors open up a technological lead.

Innovation and Competition – Conclusion

The Federal Communications Commission has a long tradition of keeping hands off wireless (and the Internet) while ensuring it remains competitive. The results of this policy are evident: the most innovative industry in the US and the world, with lower prices, more usage, and more innovation. In fact, the competitive market has lifted the US from being a wireless laggard compared to Europe and East Asia, and the US is now recognized as the leader in the wireless industry (Strategy Analytics (2009)). The FCC has allowed the competitive market to work its magic, and that is exactly what it has done. As it turns out, that policy has indeed been customer-centric. Customers are in the driver's seat; when they want better handsets, manufacturers, sometimes in collaboration with network provider partners, innovate. When they want more bandwidth, carriers innovate. When they want more applications, developers (and the other segments) innovate. In this competitive wireless marketplace, firms survive by

giving customers their best value proposition, and this means innovation. We strongly recommend that this hands-off policy continue. We see no market failures in this market, so there is no rationale for government intervention. If it ain't broke, don't fix it!

Do We Need "Fixes"?

The FCC's Notice of Inquiry raises several issues which could be targets for FCC intervention. In essence, the NOI asks if there are market failures which it ought to fix. Since our previous analysis suggests that there are no market failures in this industry, the quick answer is (again): if it ain't broke, don't fix it! The FCC has had the wisdom in the past to let the competitive market develop without meddling, and this policy has been a successful customer-centric policy. If one carrier is not providing sufficient value by, say, encouraging application developers via an app store, then another carrier will be happy to take his business by giving customers what they want. Of course, this is precisely what happened with the Apple App Store; customers liked it, and competitors were forced to emulate it. This is precisely what happened with 3G in core networks; customers liked it, and competitors were forced to emulate it. Should the FCC opt for a more interventionist policy without rigorous justification of demonstrated market failure, the result will be clear: higher costs, less customer choice, reduced incentives to invest and reduced incentives to innovate.

We consider each issue raised by the NOI in turn.

Mandate Spectrum Sharing

On the basis of a study conducted in Washington, DC (McHenry et al. (2003)) some years ago that showed that spectrum in the 30 Mhz-3Ghz bands to be underutilized,[19] the NOI asks if sharing of licensed spectrum should be mandated. Some suggest that underlays (low-power uses of licensed spectrum) would create little interference and overlays (high-power uses such as cognitive radio that would be "smart" and not interfere with licensed use) would increase the efficiency of licensed spectrum.

We first address the issue of whether spectrum licensed for CMRS is underutilized; some critics have alleged that carriers are "warehousing" spectrum (that is, not leasing spectrum for which they hold licenses but are not currently utilizing) for anticompetitive reasons.[20] Our previous discussion concerning core network innovation spoke of the substantial efforts of carriers to increase spectral efficiency and operating procedures to increase capacity utilization. It would hardly make sense to undertake such capital intensive efforts if carriers had excess spectrum lying about. It would also hardly make sense that carriers who have paid billions of dollars at auction to buy the spectrum would allow it to go to waste. So on the face of it, allegations of underutilization of CMRS licensed spectrum[21] defy all economic logic.[22]

Several other studies conducted in Chicago by Illinois Institute of Technology researchers (McDonald (2007), McDonald et al. (2008)) found that CMRS spectrum was in fact efficiently utilized, although other spectrum was not. In fact, no one who has studied the potential for

spectrum sharing ever seriously considered using the heavily utilized CMRS spectrum, but focused on lightly used spectrum as potential targets for sharing.

But we need not depend only upon economic logic; we have facts to support the view that US carriers use their spectrum quite efficiently. As mentioned above, Campbell (2009) finds that US carriers serve many more customers per allocated bandwidth than any other country. The following is excerpted from that study:

	US	Japan	Germany	UK	France	Italy	Canada	Spain	S. Korea	Mexico
Efficient Use of Spectrum -- Subscribers Served per MHz of Spectrum Allocated	651,100	312,968	347,540	214,002	148,958	290,622	103,414	144,692	194,420	630,833

Table 6
Subscribers per Mhz of Spectrum Allocated
Source, Campbell (2009)

Both the logic and the evidence clearly indicate that spectrum utilization by US carriers is just fine; there is no evidence that suggests that a regulatory "fix" can have a positive effect; it is more likely to have serious negative effects.

We are generally of the view that low-power uses have shown their worth in practice and we encourage their deployment. In fact, it is for this very reason that the FCC established Part 15 unlicensed bands, so that low-power uses such as baby monitors, cordless phones, garage door openers and WiFi could flourish, as they have. In recent years, the FCC has designated large swathes of spectrum as unlicensed, and this is the appropriate location for low-power operations, as history has demonstrated. Imposing low-power applications in spectrum with existing licenses is totally unnecessary, as there is more than enough unlicensed spectrum available for such applications. If such uses are truly non-interfering and for some reason cannot find a home in the unlicensed space, then assuming the licensees are in the business of making money, they will surely permit such low-power uses for a market price. Mandating low-power sharing is simply regulating the price of low-power use of a licensee's spectrum at zero. Let the licensee decide whether or not it can tolerate interference; the market will set a competitive price that fully accounts for interference or lack thereof. This is not a suitable task for government.

We are also of the view that cognitive radio is a promising technology in its early experimental stage, and should be encouraged. It is not, however, a technology ready to be released in the valuable and fully utilized CMRS bands. While some engineers and legal scholars suggest it can be made non-interfering, it has yet to be field-tested and so remains experimental and untried. In other work, Faulhaber (2005, 2008) raises issues with cognitive radio that suggest much work needs to be done before we let the cognitive radio out of the regulatory box. In any case, even if cognitive radio eventually proves its worth, there is no reason that it should be *mandated* in any licensed spectrum, particularly the heavily utilized CMRS bands. If cognitive radio is a going concern, it can certainly pay its own way; licensees (who are no

doubt a profit-making bunch) will be happy to permit truly non-interfering uses for a competitively determined market price. There is no reason that this particular technology should get a free ride on spectrum.

In fact, carriers are quite comfortable with both transacting spectrum (there is an active secondary market in spectrum) and sharing spectrum. The entire Mobile Virtual Network Operator (MVNO) market is based on third parties using carrier spectrum in order to offer competitive mobile phone service. Indeed, virtually all the major carriers host at least one MVNO; Sprint is perhaps the most active in this market. It should be no surprise that if a carrier thinks it can make a buck sharing spectrum, it will certainly do so, as the MVNO experience demonstrated. Accommodating a truly non-interfering overlay or underlay should be fairly straightforward. As in the MVNO market, a market price will emerge and parties will find it in their mutual interest to transact. Intervening in this market by setting a zero price seems a totally unnecessary and highly distortionary regulatory intervention. There is no market failure here, and therefore no rationale for intervention. Should the FCC wish to mandate sharing of spectrum as a result of special pleadings at the expense of existing and future licensees and customers, there is no need to dress it up in the language of efficiency and innovation.

Develop network policies that foster wireless broadband

Are there policies the FCC can adopt to foster the deployment of 4G and future technologies? What are they? Yes, yes, yes there is a clear and simple policy the FCC can adopt to foster wireless broadband: *auction off much more licensed spectrum*. If there is one policy that the FCC should adopt in this proceeding, this is it. Carriers are now approaching the theoretical limits of spectrum capacity and yet traffic shows no sign of abating. As noted above, Cisco (2009) is forecasting wireless data annual growth rates of 130%, principally from the customer demand for TV to the handheld. At that rate, carriers will hit their maximum capacity in a few years.

A study by the ITU (2006) forecasts a "total spectrum requirement of as much as 840 MHz by 2010, 1300 MHz by 2015 and 1720 MHz by the year 2020. Even at a lower market development rate, the projections are 760 MHz by 2010, 1300 MHz by 2015 and 1280 MHz by 2020." Current spectrum available to CMRS is well under 500 Mhz (under 400 Mhz by some estimates (Rysavy (2008)). By any measure, the industry is approaching a licensed spectrum capacity crisis. The FCC must step up now and auction off lots and lots of spectrum.

Exactly how much is "lots and lots"? In earlier work, Faulhaber (2009a) suggested that an additional 1 Ghz would probably be a good starting point. The ITU estimates suggest that this guess was close, and we adopt this as our recommendation: 1 Ghz of spectrum put up for auction for licensed spectrum.[23]

Easy for us to say; what, the FCC might well ask, spectrum did we have in mind? Where do we think 1 Ghz of spectrum will come from, seeing as virtually all the usable spectrum has already been allocated to someone or something? This brings to mind the well-known criticism that much of the spectrum is unused most of the time, an argument the authors made

in Faulhaber & Farber (2003). Maybe it is time for the FCC to reclaim spectrum that is lying fallow; there will no doubt be a price to do this, but correcting past mistakes is never cheap. We have two solutions for finding spectrum; the "business as usual" solution and the "fundamental change" solution. Neither is new; both have been before the FCC for some time. But now is the time to end the procrastination and get this done.

The "business as usual" solution: spectrum that could be cleared and re-purposed for licensed wireless communications:

- First, get the AWS-3 spectrum (25 Mhz) into the market; the FCC has had this under consideration for some time; act now to find a paired band and auction it.
- Second, the World Radio Conference (WRC)-07 identified 400 Mhz in the following bands:
    - 450-470 Mhz (largely occupied in the US)
    - 698-863 Mhz (includes 700 Mhz which has already been auctioned in the US)
    - 2.3-2.4 Ghz (much of which is occupied in the US)
    - 3.4-3.6 Ghz (used by radar in US)
- Third, approximately 555 Mhz has been designated as mainly unlicensed U-NII spectrum for wireless broadband (although there are other users in these bands). There is minimal use of these bands for wireless broadband, the FCC's intended purpose for U-NII.
- Fourth, the FCC has recently freed up an *average* of 34-58 Mhz of the TV white space bands,[24] dedicating it to unlicensed uses. The evidence has shown that this is not likely to result in wireless broadband actually being offered to customers.

In bringing fresh spectrum to market, the FCC needs to be mindful of bandwidth assignments internationally. Spectrum assignments that don't correlate with worldwide assignments result in lost scale economies in handset production and unnecessary costs for carriers.

The "fundamental change" solution. In Faulhaber & Farber (2003), we argued that the entire FCC process of allocating spectrum was deeply flawed, resulting in vast underutilization of spectrum. We strongly advocated a Coasian market-based solution, in which property rights are established in *all* usable spectrum which would become the licensees' property to be bought, sold, leased, aggregated or subdivided as the licensee saw fit, subject to the technical (but not use) restrictions of the license. We support the Kwerel & Williams (2001) plan[25] to place all spectrum into the market, permitting existing license holders to sell, trade or keep their licenses, thereby freeing up spectrum to move to its highest valued use. We still strongly favor this solution, as it promises to free up large amounts of spectrum for licensed use, harnessing the power of the market, rather than the somewhat anemic response of regulators thus far. Of course we recognize the political difficulties involved in this solution. We also

recognize that it is the FCC's job to manage these difficulties to ensure the "public interest, convenience and necessity."

Should the FCC be exploring alternative network architectures such as mesh networks? We are of the view that further work in mesh networks is desirable. While mesh networks are a very interesting field of research there are major problems that still have to be solved prior to commercial deployment. The notion of mesh networks is not a new one; past attempts have often suffered from the same difficulties as we face now. Security is one of the major issues as well as sustaining geographic coverage. There have been a number of experiments in other countries, in particular Japan, utilizing this technology in mobile automobile-oriented networking. The results of these experiments are illuminating but still suggest caution in the belief that this technology is the solution to all our problems. As is usual there are advocates for mesh networking -- some have commercial interests they are pursuing and some are researchers with strong beliefs about their pet technology. Prior to any commitment of spectrum, both government and industry will need to devote considerable resources to funding a program of research in this area. This is not being done at present.

Should experimental work be undertaken in mesh networks, we believe it is best suited to deployment in unlicensed spectrum on a trial basis. Since the FCC has designated very large swathes of spectrum to unlicensed uses, this should be ample for experimentation with mesh networks. We certainly hope to see such experimentation; given the level of interest in mesh networking, we are in fact surprised it has taken so long. Should this technology appear to have some promise after thorough experimentation and field experience, we believe it will find a home in unlicensed spectrum. Should it require licensed spectrum, we see no reason why the market will not work. Mesh operators can either buy their own spectrum or lease capacity from existing licensees, much as MVNOs lease capacity from CMRS carriers today. There is no need to mandate sharing of licensed spectrum in order to accommodate this technology, if it proves viable.

In later work, Faulhaber (2005) again argued strongly that dispute resolution in a property rights regime would occur in courts rather than at the FCC and that this would substantially reduce costs and increase both speed and efficiency. The evidence suggests that dispute resolution, for example in interference disputes mentioned in the NOI, are long, drawn-out regulatory battles often followed by a court case. If licensees had clearly defined property rights, then interference disputes could be resolved like trespass cases within the court system.[26] We continue to believe, based on the evidence, that resolution of interference claims in court is substantially less costly, faster and more efficient[27] than resolution at the FCC.

Mandated "Openness"

The well-known paper by Wu (2007) argued that wireless carriers have blocked application providers, caused device makers to "cripple" their phones, and violated network neutrality "regulations". In fact, many of these allegations applied only to isolated examples at the time they were made, and since that time virtually all of the carriers have made it quite easy for

application providers to write apps for their networks. Carriers such as AT&T now have a "bring your own phone" plan. Are we to conclude that Tim Wu's paper caused the carriers to see the light and change their evil ways? Of course not. It was competition that did the trick. When the iPhone showed that customers really loved apps, then everyone else responded. When some customers wanted to bring their own phones, carriers responded. A competitive market imposes the discipline on firms to meet their customers' demands. Regulators and government bureaucrats can certainly impose discipline by law, but is this what customers want? If the FCC were truly customer-centric, it would let customers decide what they want. It would recognize that its job is to enable customers, not to tell customers what they ought to want.

Can customers tell the difference between open systems and managed systems? The Apple iPhone is well-known to be a managed system; techies take pride in "jail-breaking" their iPhones in order to use them on other networks and other off-standard uses. Apple has set up restrictions on what you can do with your iPhone that are more stringent than, say, what you can do with your Blackberry,[28] or even more your Android phone. Yet the iPhone remains the most popular smartphone in the market today, after three years in the market. Customers have the choice: the managed model of Apple or the more "open" model of Android It is true that applications from sources other than the Android store can be loaded on Android-based devices (Apple allows only iTunes apps to be loaded). It is no surprise that some customers like the more managed iPhone and some customers like the more "do-it-yourself" approach of Android devices. In either case, these phones represent impressive innovations and should be lauded as such. And in either case, customers choose what they want, without the help of government bureaucrats forcing them to have one or the other.

Our view of network management practices is much the same. Different carriers will adopt different network management strategies; provided customers are informed (see below) as to what their carriers are up to, they can make informed decisions about which carriers will get their business. Network management that is too restrictive, perhaps anticompetitive, will be punished by customers. Likewise, network management that is too lax, that permits outages and dropped calls because of congestion will also be punished. Again, let the customer decide what level of network management they prefer. And again, we expect different customers will make different choices. What we know for sure is that this is not a choice government bureaucrats should be making for customers.

There is no market failure here. Mandating "openness" is quite unnecessary, as the competitive market will produce what customers want. The evidence in this market is that is exactly what is happening, without counterproductive and inefficient government mandates. There is nothing broken here; there is nothing to fix. "Hands off" is the customer-centric policy in a competitive market.

Network Neutrality

On September 21, 2009, Chairman Genachowski announced in a speech at the Brookings Institution that he would be initiating a Notice of Proposed Rulemaking (NPRM) to make binding the four Network Neutrality principles the FCC adopted under Chairman Powell, plus two new ones: non-discrimination and transparency.

We find much to like in the Chairman's speech. The Chairman's rhetoric emphasized that FCC actions should be "fact-based" and not respond to "imaginary" threats. He also emphasized he wasn't advocating regulating the Internet. And yet the content of his speech belied the rhetoric. In asserting that network neutrality in the wired and wireless ecosystems was necessary to preserve innovation, there was not one shred of evidence adduced that shows innovation is being harmed. In the face of the very substantial amount of innovation occurring in all segments of the wireless industry, the allegation that innovation is under some sort of threat in wireless is demonstrably false and beyond incredible. The Chairman's assertions that this does not constitute regulation of the Internet is also beyond credible: imposing constraints on carrier pricing (zero charges on application providers), on carrier product differentiation (no expedited service), and on how carriers are permitted to manage their own networks certainly sounds like regulation. Even worse, adopting "reasonable" network management as a rule introduces great uncertainly into the market; exactly what behaviors will incur the wrath of the regulator? Don't know; we'll punish you when we see it. If ever a policy was designed to increase cost, reduce customer choice, reduce incentives to innovate and reduce incentives for carriers to invest, this would be it.[29] Where's the market failure? Where is the rigor by which the Chairman has arrived at this conclusion?

There has been a long debate over network neutrality in the policy community, to which both authors have contributed (see especially Farber & Katz (2007)) which we need not rehash here. While network neutrality advocates are overjoyed, some have sounded alarm bells including those most sympathetic to Internet openness. Tweney (2009) from *Wired* magazine predicts the end of unlimited Internet as a result of network neutrality regulation. His rationale mirrors the principles in this paper. He notes three problems:

- "Bandwidth is not, in fact, unlimited, especially in the wireless world. 'As long as there have been networks, people have had to engineer them to ensure that congestion doesn't occur'" (quoting Farber).
- "Enforcement of neutrality regulations is going to be difficult."
- "New regulations create an additional layer of government bureaucracy where the free market has already proven its effectiveness….Now the FCC is proposing taking a free market that works, and adding another layer of innovation-stifling regulations on top of that?"

But this is more than the government intervening with no evidence whatsoever of market failure. We believe that this prospective rulemaking is the *polar opposite of a customer-centric* policy. If network neutrality in wireless is something customers want, then in the competitive

carrier market a competitor will offer a neutral network service offering, and customers will flock to it. Other carriers will be forced to follow suit, or not. In practice, we would expect that some carriers would offer a more neutral network and others would offer a more managed network, while still others would offer customers the option of either; customers will make different choices, reflecting their different priorities and preferences. But it appears that under Chairman Genachowski's proposal customers will not be allowed to choose. They will get a one-size-fits-all government-designed business plan whether they want it or not. With all due respect, this should not be an FCC decision; this decision should be left to customers, and it is the FCC's job to ensure customers are enabled to make this decision, not to make the decision for them.

Which Business Models Promote Innovation?

The choice here is between the more "do-it-yourself" model of Google/Android and the more managed model of iPhone and Blackberry; between the more open Sprint and more managed Verizon Wireless. And the answer is crystal clear: both models promote innovation. In the device segment, iPhone was the pioneer and Google/Android a fast follower. Both are innovators but we must give the nod to the iPhone for being first and showing the way. Blackberry has had a strong position in the business market, but has moved strongly into the consumer market with its Storm and Tour models, showing impressive innovation in doing so. Its model is more traditional; not as open as Android and not as proprietary as Apple's. Sprint has been more open in accepting devices and applications that it doesn't sell, and it has shown substantial innovation by being the first to deploy WiMAX (claiming it is 4G). Verizon Wireless has been more managed, only recently accepting phones it does not sell and setting up a developer's website. It also has shown substantial innovation in early deployment of 3G and it will likely be the first to deploy LTE 4G. But the point is clear; innovation is forthcoming from a variety of business models. There is no need for the FCC to choose the better business model, nor is there a need for FCC "guidance" in favoring one business model over another. The FCC's imposition of open platform restrictions[30] in the recent 700 Mhz C-block auction is an egregious example of unnecessary meddling. But having established the C Block restrictions and committed to the "experiment" in their operation, it plainly makes no sense at all to expand those restrictions to other spectrum before the experiment even begins. If customers want more open platforms, then there will be a wireless carrier that will provide service that meets their needs and gain a competitive advantage over its rivals. There is no market failure here; if the FCC wants to mandate business models and impose costs and eliminate customer choices the FCC should not cloak it in the language of efficiency and innovation.

Transparency

We are very pleased that Chairman Genachowski featured transparency so prominently in his September 21, 2009 speech. We are entirely supportive of vigorous action to ensure transparency, preferably in concert with the FTC. We are disappointed that the Chairman

seemed to think transparency ought only to apply to carriers. We believe transparency should apply to all segments of the wireless ecosystem: applications, devices and carriers.

We have argued strongly that the FCC must take a customer-centric view of its role, by which we mean the FCC needs to support the existing competitive marketplace in all wireless segments and refrain from damaging interventions that raise costs and reduce customer choice. But in order for competitive markets to fully realize their potential to empower customers, those customers need to have the information they need to make informed purchase decisions. That information can only come from sellers: application providers, device manufacturers and core network providers. If this information is lacking, we do indeed face an information symmetry market failure. The role of information in markets was starkly presented in Akerlof's (1970) seminal paper, in which he demonstrated that a market can actually collapse in the absence of information.[31]

This type of market failure is recognized in virtually all markets, and public policy intervention to correct it is well-established. A fundamental mission of the Federal Trade Commission is to ensure that firms disclose decision-relevant information to customers in an easy-to-understand format. In Faulhaber (2009b) several examples of successful disclosure mechanisms are discussed in terms of ease of use, convenience to customers and relevant information, all of which the FTC developed (in collaboration with the FDA), including both food and prescription drug labeling. Not all of these mechanisms are good fits for other industries or situations and none of them may be the right fit for wireless, but it behooves the entire industry to avoid the pitfalls such as the dreaded End User License Agreements (EULAs) that accompany boxed software, which seem designed to baffle anyone without a J.D.

If competition is to ensure a customer-centric environment in the wireless ecosystem, transparency is an absolute necessity.[32] Overall, the wireless industry has done a reasonably creditable job at providing customers with the information they need, but there is room for improvement. Although complete precision is plainly impractical in such a rapidly evolving marketplace, customers need to know what types of applications are permitted, what types of network management practices are in place, and what range of performance they can typically expect. These are complicated technical issues which must be suitably simplified for easy presentation to customers. But surely describing a carrier's (or device's) characteristics is no more complicated than describing the benefits and risks of taking a prescription drug, and we seem to manage that task fairly well. And if the FCC is to adopt a customer-centric policy of letting the competitive market do its thing, then the FCC must ensure that these markets are fully transparent. We note that the Federal Trade Commission is the agency with the most experience in the area of transparency and disclosure, and we suggest the FCC partner with the FTC and industry to develop standards on transparency and disclosure.

Conclusion

All three segments of the wireless marketplace (applications, devices and core networks) have extraordinary track records in innovation. This extraordinary innovation has been driven by

the brutal competition that characterizes this industry. There are no classic market failures in this industry that require regulatory intervention; calls for such interventions by pundits, advocates and special interest groups (some reflected in the NOI) are attempts to harness the regulatory power of the government to impose their personal agenda on customers. Our position is crystal clear: let customers decide what they want and need. In order to implement this customer-centric policy, the FCC must undertake the following:

- Put much more spectrum at auction for licensed use. While we have made suggestions as to how much bandwidth is needed (1 Ghz) and where it might come from, it is really the FCC's job to find it and figure out how to clear the bands. It alone has the knowledge and ability to do this.
- Ensure that all segments of this industry practice good disclosure practices with their customers, as outlined in Faulhaber (2009b). We suggest the FCC partner with the FTC in this endeavor, as the FTC has far more experience (and successful experience) than does the FCC.

We conclude by stating that innovation will best thrive with a customer-centric FCC policy of ensuring that competitive markets continue to flourish, spectrum is made available and transparency is assured. Regulatory interventions into markets without rigorous justification can only raise costs, reduce customer choice, reduce incentives for investment and reduce incentives for innovation. In the absence of market failure, we see no reason for the FCC to now adopt a "bull in the china shop" strategy of dictating firms' business models and practices in a fully functional competitive market. It ain't broke; don't try to fix it.

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-- Endnotes --

[1] Most prominent is Tim Wu (2007) who noted a number of problems with openness (and lack thereof) in the wireless industry. In the event, many of his examples of non-openness were either isolated examples at the time (absence of WiFi on certain phones) or have long since been eliminated by innovation and customer demand (lack of open application development).

[2] The economics literature on well-meaning regulations causing substantial harm is extensive. We note particularly Carlton and Perloff (2005) and Noll (1989).

[3] In earlier work (2003), the authors suggested the use of "non-interfering easements" as a means of encouraging more efficient use of spectrum. In later work, Faulhaber (2005, 2008) raised doubts about how "non-interfering" such uses would be in practice.

[4] For a synopsis of mobile communications worldwide, see Faulhaber (2010), among many others.

[5] Generally, each device vendor or carrier screens applications to verify that they will work as claimed on their system. The Android app store allegedly accepts applications without screening, in the interest of openness. Of course, independent app stores cannot verify their products work on particular devices or carrier networks. This topic is discussed further under Business Models.

[6] A quick scan of AT&T Wireless' website shows 33 models for sale (not including refurbished phones and non-phone devices). A scan of Verizon Wireless' website shows 40 phones, 10 smartphones and 8 Blackberry devices; websites visited Sept 18, 2009.

[7] AT&T Laboratories is a leader in wireless innovation as well as the standard-setting process in the US. It is a successor to Bell Telephone Laboratories, of which both authors are alumni.

[8] System spectral efficiency differs from link spectral efficiency, in that it takes into account real-world factors that affect the capacity that can be obtained in real-world applications. See Wikipedia (2009a).

[9] Apologies to Mac and Linux customers; some applications are developed for both platforms, but the dominance of the Windows OS makes it the must-have platform of choice for many developers.

[10] By way of example, some wireless network systems can detect when the "noise floor" (the amount of ambient radio noise affecting transmission quality between device and cell tower) raises or lowers, and ask devices to adjust their power level of sending and receiving to make maximum use of spectrum as the noise floor fluctuates.

[11] The complexity/simplicity dichotomy has an interesting and instructive economic analogy. Suppose two firms are to transact business. In the first instance, suppose the transaction is simple; for example, buying copier paper. There are well-established standards for copier paper, the purchasing firm can simply specify the standard and check the standard is met upon delivery. In the second instance, suppose the transaction is more complex; for example, the purchasing firm wishes the supplier to provide research and development for a common project. There is no standard, and execution of the transaction depends upon the supplier operating in good faith and in close cooperation with the staff of the purchasing firm. Simple contracts are no long possible and some form of long-term relationship usually characterizes such transactions, with elements of trust and common purpose that are not present in the purchase of copier paper. As in the case of the Internet/PC ecosystem (simple interfaces) vs. the wireless ecosystem (complex interfaces), the difference in collaborative innovation is marked.

[12] Using patents as a measure of innovation has its pitfalls: increasingly, patents are applied for as defensive measures by innovative companies, and so-called "submarine" patents are a favorite tool by which persons can

threaten firms that offer innovative products with patent infringement suits. Despite its faults, it is likely the best direct measure of innovative activity available.

[13] Regional/national carriers typically do marketing and pricing at a regional/national level, although competition at the local level in the form of promotions is quite active.

[14] See Wikipedia (2009b) for a definition of HHI and its use in competition analysis.

[15] Simple concentration measures such as HHI are in no way dispositive of the state of competition, as discussed in Katz (2009). Indeed, in antitrust analysis at the Department of Justice and the Federal Trade Commission, HHI is simply an initial screening measure to determine if further analysis is warranted. No antitrust finding ever rests upon the HHI index of an industry.

[16] We are mindful that international comparisons can be misused and are at best indicative. We believe the Bank of America/Merrill Lynch work is as reliable and unbiased as any available.

[17] Static efficiency is sometimes referred to as Marshallian, after Alfred Marshall, a founder of modern economic analysis. Dynamic efficiency is referred to as Schumpeterian, after Joseph Schumpeter, a pioneer in identifying the role of innovation in economic growth.

[18] A personal anecdote illustrates the point: the TV show "La Femme Nikita" debuted in 1999 and was the most popular cable show for several years. The heroine worked for an antiterrorist organization which was kitted out with very high-tech gear: holographic projectors, fancy computers and servers,…and cell phones. Viewing the show a decade later, one is impressed that everything still looks very high tech…except the cell phones. The show's producers used Motorola StarTac phones, the hottest phone of 1999; today the StarTac phone seems like the mobile equivalent of a steam locomotive: quaintly old-fashioned. The cell phone is the one technology whose rapid advance is obvious even to a TV viewer.

[19] This is not the only study to show that spectrum is underutilized; several studies are mentioned in Faulhaber (2005) fn 5. The conclusion in that work was not to force sharing on licensees but rather to establish property rights in spectrum so current licensees that are underutilizing their spectrum would have incentives, through sale or sharing, to capitalize on their asset.

[20] See for example, Eric Peterson (2009), Executive Director of the Rural Cellular Association.

[21] This is not to say that spectrum *in general* is not underutilized. The authors have argued strongly (Faulhaber and Farber (2003)) that spectrum is generally woefully underutilized and have advocated market measures to improve utilization. But certain bands are quite heavily utilized, such as the CMRS bands and the 2.4Ghz WiFi bands.

[22] The FCC does not set a schedule for conducting auctions, and often years go by before spectrum becomes available. Carriers are forced to buy spectrum for future use of uncertain duration, as they have no idea when more spectrum will become available. In this uncertain regime, where the FCC creates an artificial scarcity of uncertain duration, carriers must maintain a buffer of licensed spectrum in order to ensure future capacity demands can be met.

[23] Many pundits and commentators champion unlicensed spectrum as a means of ensuring our wireless communication needs. Certainly the FCC has moved much more spectrum into unlicensed than licensed in the past few years. Faulhaber (2009a) addressed unlicensed vs. licensed as a means to meet our wireless broadband needs and concludes, based on the evidence, that unlicensed spectrum is a "regulatory cul-de-sac." I need not repeat the arguments here. The short version is that the FCC has allocated two U-NII bands (unlicensed)

specifically for wireless broadband, with a total bandwidth of approximately 555 Mhz and to date, almost none of it is being used to provide wireless broadband. None.

[24] This estimate was derived by Jackson & Robyn (2007); the range of bandwidth available depends upon the stringency of interference rules, with more stringent rules associated with lower capacity. It is important to note that this is an average over all metro areas in the US; in some areas, there may be no available white space under strict interference rules.

[25] Their proposal is often referred to as the "Big Bang Auction".

[26] The assumption in Faulhaber (2005) is that interference problems would be handled under trespass laws, not nuisance laws. The example used in this paper of lengthy and litigious regulatory procedures was the 800 Mhz Nextel dispute. Apparently, the FCC handled this case on an expedited basis and yet it took almost two years to resolve.

[27] We recognize that this assertion depends upon technical restrictions of a spectrum license that are both clear and measurable so that a lay judge and jury can determine whether or not a property right has been transgressed.

[28] For example, the iPhone is only available on AT&T Wireless while Blackberry phones are available from numerous carriers.

[29] Sidak (2006) discusses the costs imposed by mandating network neutrality, including increased transaction costs, administrative costs and opportunity costs.

[30] In the recent 700 Mhz auction, the FCC required the winner of the C block spectrum to permit customers to use any device and any application on service offered using that spectrum (PC Magazine (2007)).

[31] In the Akerlof example, the market collapses because each seller (of a low-quality auto, or "lemon") has an incentive to misrepresent the quality of his or her automobile, and customers cannot distinguish the good from the bad. Any method, private or public, that results in a *credible* signal of quality from the seller corrects the market failure, restores the market, and is preferred by customers and sellers of high-quality autos (but not the sellers of "lemons").

[32] Faulhaber (2009a, 2009b) makes this point in the context of the broadband industry (both wired and wireless); it is equally valid here.

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"The Governing Regime of Spectrum," in *Reforming Spectrum Policy*, Vodafone Policy Paper Series #5, Sept, 2006, 13-28.

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"Deregulation and Innovation in Telecommunications," in G. Libecap, ed., *Advances in the Study of Entrepreneurship, Innovation, and Economic Growth* Vol. 2, New York: JAI Press, 1988.

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Telecommunications in Turmoil: Technology and Public Policy, Ballinger Publishing, 1987.

Services in Transition: The Impact of Information Technology on the Service Sector, editor (with E. Noam and R. Tasley). Ballinger, Inc., 1986.

Telecommunications Access and Public Policy, editor (with A. Baughcum), Ablex, Inc., 1984.

TALKS AND SEMINARS

"Mobile Communications: Economic and Social Impact," presented at Wireless Technologies: Enabling Innovation and Growth, Georgetown University Center for Business and Public Policy, Washington, D.C., April 17, 2009.

"China: A World Player," presented at Wharton China Week, Wharton School, Unversity of Pennsylvania, Philadelphia, PA, March 24, 2009.

"Mobile Opportunities for China," presented at Wharton China Business Forum, Wharton School, University of Pennsylvania, Philadelphia, PA., February 21, 2009.

"Broadband – More Is Better?" presented at Congressional Chief of Staff Briefing, George Mason University Mercatus Center, Philadelphia, PA., February 20, 2009.

"Solving the Interoperability Problem: Are We on the Same Channel?" presented at Wharton Information Security Best Practices, Wharton School, University of Pennsylvania, Philadelphia, PA., January 30, 2009.

"Deploying Cognitive Radio," presented at Korean Information Society Development Institute, Seoul, Korea, November 14, 2008.

"Economic and Social Impact of Mobile Telephony," presented at Broadcasting and Telecoms Meet the Digital Convergence, Korean Information Society Development Institute, Seoul, Korea, November 13, 2008,

"Network Neutrality: Dealing with the NetHeads," presented at Nominum Global Customer Conference, New York City, NY., October 16, 2008.

"Are We On the Same Channel?" presented at Public Safety Communications Summit, Institute for Defense and Government Advancement, Washington, D.C., April 29, 2008.

"Whatever Happened to the Spectrum Debate?" presented at Spectrum Policy: From the Foundations to the Future, Georgetown University Center for Business and Public Policy, Washington, D.C., April 25, 2008.

"Internet Video Policy," presented at Internet Video Policy Symposium, Washington, D.C., March 18, 2008.

"Broadband Deployment and Policy," presented at the Congressional Briefing, George Mason University Mercatus Center, Alexandria, VA., August 21, 2007.

"Telecommunications Regulatory Reform: Then and Now," presented at the 34th Annual PURC Conference, *A Century of Utility Regulation: Looking Forwad to the Next Hundred Years*, University of Florida, Gainsville, FL, February 16, 2007.

Panelist, Plenary Session on Network Neutrality and commenter onBenkler, Y., *Wealth of Networks*, at Telecommunications Policy Research Conference, George Mason University, Alexandria, VA., September, 2006.

"Solving the Interoperability Problem: Are We on the Same Channel?" presented at The Crisis in Public Safety Communications, George Mason School of Law, December 8, 2006.

Panelist, "Open Source in the International Marketplace," Roundtable discussion sponsored by the University of Pennsylvania Law School *Journal of International Economic Law*, March 31, 2006

"Life and Death on the Radio: Thoughts on Public Safety," presented at Penn Law Ad Hoc Seminar, December 6, 2005.

"The Question of Spectrum: Technology, Management and Regime Change," presented at the Wharton Colloquium on Media and Communications Law, October 28, 2005. Also presented at New Directions in Regulation Seminar, John F. Kennedy School of Government, Harvard University, October 20, 2005. Also presented at the USC Law Center Conference on Wireless Broadband: Is the US Lagging?, Washington, DC, October 27, 2005.

"File Sharing, Copyright, Digital Rights Management, and the Optimal Production of Music," presented at Penn Law's Ad Hoc Summer Seminar, July 19, 2005, Wharton's Applied Economics Workshop, August 10, 2005, Kennedy School's New Directions in Regulation Seminar, October 20, 2005, and Wharton's Colloquium on Media Law, October 28, 2005.

Keynote Speaker and Panel Moderator, Conference on Spectrum Policy in Guatemala and Latin America, Francisco Marroquín University,Guatemala City, Guatemala,June 9-10, 2005

"The Question of Spectrum: Issues for the US Congress," MIT briefing of Congressional Staff, March 30, 2005.

"The Question of Spectrum: Technology, Management and Regime Change," presented at Penn Law Ad Hoc Seminar, December 14, 2004. Also presented at the Silicon Flatirons conference "The Digital Broadband Migration: Rewriting The Telecom Act," University of Colorado Boulder Law School, Feb 12-13, 2005. Also presented at Michigan State University conference on the "Economics, Technology, and Policy of Unlicensed Spectrum," East Lansing, MI, May 15-16, 2005**.**

"Spectrum Management: Understanding the Issues," presented at IWCE Conference on Spectrum issues, Las Vegas, NV, March 25, 2004.

"Researchable Issues in Spectrum Management," presented at FCC-Academic Workshop on Setting the Research Agenda, Federal Communications Commission, Washington, DC, December 5, 2003.

"Wireless Telecoms in Asia," panel moderator at Wharton Asia Conference, November 15, 2003.

"Telecoms in Trouble: Can Policy Help?" presented at PrincetonSymposium on Helping Troubled Industries, October 18, 2003.

"The Chief Economist: Necessary and Sufficient Conditions to be Effective," presented at The Chief Economists Speak Out, McDonough School of Business, Georgetown University, October 17, 2003.

"Spectrum Management: Property Rights, Markets, And The Commons," with David Farber, presented at International Symposium on Advanced Radio Technologies, Boulder, CO and University of Colorado Law School Moot Court, Boulder, CO, March, 2002. Also presented at Stanford Law School Conference, "Spectrum Policy: Property Rights or Commons?" and Moot Court, March, 2003.

"Access ≠ Access_1 + Access_2,", presented at *Rethinking Access*, Third Quello Center Communications Policy & Law Symposium, March, 2002, Washington, DC

"Economics at the FCC," plenary address at the Telecommunications Policy Research Conference, October, 2001.

"Network Effects and Antitrust: FCC Analysis of the AOL-Time Warner Merger," presented at Georgetown University, March 13, 2001, American Enterprise Institute, April 25, 2001; London Business School, May 14, 2001; Wharton Applied Economics Workshop, July, 2001; Duke University School of Law, October, 2001, University of Pennsylvania Law School, October, 2001.

"Policy-Induced Competition: the Telecommunications Experiments," presented at Wharton Applied Economics Workshop, September, 2001.

"Broadband Deployment: Is Policy in the Way?" invited paper presented at AEI-Brookings Regulatory Center Conference on Broadband Deployment, October, 2001.

"Cross-Platform Competition in Telecommunications," Aspen Institute Telecommunications Workshop, Aspen, CO, August, 2001.

"FCC Analysis of the AOL-Time Warner Merger," Wharton Applied Economics Workshop, December, 2000.

"Information, Disinformation and Lobbying," presented at Institut d'Analisi Economica, Barcelona, Spain (October, 1999), Wharton Applied Economics Workshop, February, 2000.

" Lobbying, Voting, and the Political Economy of Price Regulation"; presented at INSEAD Business and Economics Seminar, Fontainebleau, France on April 24, 1997, and Séminaire Roy, CERAS-ENPC, Paris, France on April 28, 1997; Cornell Economics Dept. Econometrics Seminar, September 8, 1997; Telecommunications Policy Research Conference, Alexandria, VA, September 28, 1997; Stanford Economics Department's Economics & Political Science Seminar (November 25, 1997); the Applied Economics Seminar at Wharton (October 15, 1997); Political Science Dept, UC Berkeley, Public Policy Seminar (May 4, 1998), Tsinghua University (Beijing) (April, 1999)., Institut d'Analisi Economica, Barcelona, Spain (October, 1999).

"The Market Structure of Broadband Telecommunications: Is Regulation Necessary? ", (joint work with Christiaan Hogendorn), presented at the symposium "Bridging Digital Technologies And Regulatory Paradigms," UC Berkeley, June 27-28, 1997; Telecommunications Policy Research Conference, Alexandria, VA, September 29, 1997; Wharton Public Policy & Management Brown Bag Seminar (October 16, 1997); Wharton Marketing Department's Electronic Commerce Seminar (December 3, 1997) Tsinghua University (Beijing) (April, 1999).

"Voting on Prices: The Political Economy of Regulation," presented at the Wharton School PP&M Brown Bag Seminar, Nov., 1995; Department of Economics, Universidad Carlos III, Madrid, Spain, April, 1996; the Public Utility Workshop sponsored by Rutgers Center for Regulated Industries; the University of Warwick (UK) Industrial Organization Workshop; the Business & Public Policy Seminar at the Haas School, UC Berkeley; the Telecommunications Policy Research Conference; and INSEAD's Business and Economics Seminar, Fontainebleau, France

"The Networked Future: Market Outcomes and Policy Options," presented at Aula Fundesco, Universidad Carlos III, Madrid, Spain, April, 1996.

"Banking Markets: Productivity, Risk, and Customer Satisfaction," presented at (i) Wharton Financial Institutions Seminar, April, 1995; (ii) Institut d'analisi Economica, Universitat Autonoma de Barcelona, July, 1995, and Wharton Applied Economics Workshop, January, 1996.

"Pricing the Net: Economists' Contributions," presented at Stanford University Conference on Data Network Pricing, March, 1995.

"The Information Superhighway: Public Policy Issues," presented at Wharton School PP&M Brown Bag Seminar, November, 1994.

"Bank Efficiency: A Profitability Modeling Approach," presented at Wharton School Financial Institutions Center Seminar, October, 1993.

"Profitability and Bank Size: An Empirical Analysis," presented at Wharton School PP&M Brown Bag Seminar, November, 1992.

"Pricing Internet: The Efficient Subsidy," presented at "Information Infrastructure for the 1990s" Symposium, Harvard University, November, 1990.

"Unbalanced Growth Redux: Sectoral Productivity and Capital Markets," (with F. Allen and C. MacKinlay) presented at AEA Winter Meeting, New York, NY, December 1988.

"Quality Control in the Service Firm and Consumer Learning," presented at the Symposium on Quality in Services, Karlstad, Sweden, August 1988.

"Telecommunications and the Scope of the Market in Services," presented at the Conference on Services and World Economic Growth, Kiel, Germany, June 1988, and the Conference on Innovation in Europe 1992, Spoleto, Italy, July 1988.

"Payment Risk, Network Risk and the Role of the Fed," (with A. Santomero and A. Phillips), presented at the Richmond Federal Reserve Bank's Payment System Symposium, Williamsburg, VA, May, 1988.

"The Changing Role of R&D in Telecommunications," presented at VISIO '88, Helsinki, Finland, March, 1988.

"Rational Rationing," presented at University of Pennsylvania Transactions Cost Workshop, November, 1987, and the Federal Trade Commission, Washington, DC, April, 1988.

"Financial Services: Markets in Transition," presented at Conference on the Service Economy, Spoleto, Italy, July, 1987, and the Hungarian Academy of Sciences World Economics Institute, July, 1987.

"The American Experience with Service Sector Deregulation," presented at the Hungarian Academy of Science World Economics Institute, July, 1987.

"Optimism Invites Deception," (with F. Allen) presented at Stanford University and the University of California, Berkeley, workshops, and American Economic Association Meetings (contributed paper), New Orleans, December, 1986.

"Reputation, 'Fly-by-Night' Firms, and the Market for Product Reviews," (with D. A. Yao) presented at University of Pennsylvania Transactions Cost Workshop, April, 1985, European Association for Research in Industrial Economics, Berlin, August, 1986.

"The Market for Product Reviews: Who Pays?" (with D. A. Yao) presented at American Economic Association meetings (contributed paper), New Orleans, December, 1986.

"Communications, Information and Economic Growth," presented at the Conference on Technological Development: Causes and Consequences, United States and West Germany, Bonn, November, 1984.

"Pricing In the Twilight of Regulation," presented at the Twelfth Annual Telecommunications Policy Research Conference, Airlie, Virginia, April, 1984.

"Cross-Subsidy Control: In General, and in Telecommunications," presented at American Economic Association meetings, New York, December 1982.

"Public Policy, Corporate Strategy, and Telecommunications Restructure," presented at Association for Public Policy Analysis and Management Conference, Minneapolis, MN, October 1982.

"A Public Enterprise Pricing Primer," presented at International Institute of Management Regulation Conference, Berlin, July, 1981.

"Separate Subsidiaries, Cross-Subsidy Control, and the Restructure of Telecommunications" Panel presentation at Telecommunications Policy Research Conference, Annapolis, May, 1981.

"Subsidy-Free Prices and Anonymous Equity," presented at (a) U.C. Berkeley Ind. Org. Seminar, March, 1981, (b) U.C. San Diego Theory Seminar, March, 1981, (c) Princeton University Econometric Seminar, April, 1981, (d) NYU Theory Seminar, November 1980, and (e) American Economic Association meetings, Denver, September, 1980.

"Cross-Subsidy in Increasing Returns Industries," presented at Federal Trade Commission, September, 1980.

"Market Structure and Competitive Outcomes in Telecommunications," presented at WEA Conference, June 1980 and Telecommunications Policy Research Conference, Annapolis, May, 1980.

"Regulation and Market Structure in Telecommunications" (with J.H. Rohlfs), presented at Conference on Economics of Telecommunications: Current Research on Demand, Pricing, and Regulation, Northwestern University, January 1980; and Conference on Utility Regulation and Management for the 1980's, University of Florida, January, 1980 .

"Telecommunications: A Structural View," Princeton University. Industrial Organization Workshop, May, 1979.

"A Perspective on Telecommunications Industry Restructure" in Proceedings of the 1979 Rate Symposium on Problems of Regulated Industries.

"Peak Load Pricing and Regulatory Accountability," presented at Rutgers University Conference on Public Utility Regulation and Performance, October 1978 .

"Cross-Subsidy and Public Enterprise Pricing," presented at Telecommunications Policy Research Conference, May, 1978.

"Pareto Efficiency, Increasing Returns, and Partial Information," presented at the University of California Berkeley Industrial Organization Seminar and at Stanford University Industrial Organization Seminar, October 1977, and WEA Conference, June 1978.

"Optimal Two-Part Tariffs with Self Selection," presented at Telecommunication Policy Research Conference, April 1977, and WEA Conference, June, 1976, and Bell Laboratories Economic Discussion Paper #74, January, 1977 (with J.C. Panzar).

"Competitive Entry and Natural Monopoly," presented at Telecommunications Policy Research Conference, April, 1976.

"Optimality and Equilibrium with Increasing Returns to Scale," presented at NSF-NBER Seminar on Decentralization. Princeton University, April 1975, and Telecommunications Policy Research Conference, April, 1975.

"Some Tentative Thoughts on Cross-Subsidization," presented at White House Conference on Telecommunications, Washington, November, 1972.

"The Pricing of Warrants," presented at Princeton University Industrial Organization Seminar and Cornell University Operations Research Department, November, 1971.

"The Design of Priority Reservation System," presented at IEEE Conference, Philadelphia, January, 1968 and International Teletraffic Congress, New York, June, 1967.

PREVIOUS TEACHING EXPERIENCE

Visiting Professor, Princeton University Woodrow Wilson School, 1993, Regulatory Economics

Visiting Professor, Tsinghua University, Beijing, China, spring 1999, Technology for Managers (International MBA program).

Research Associate Professor, New York University, 1979-1983, Industry Regulation (Graduate).

Visiting Instructor, Princeton University, 1976-77, Welfare Economics and General Equilibrium (Graduate).

RESEARCH GRANTS

Institut d'Analisi Economica, Barcelona, Spain, fall, 1999. Information, Disinformation and Lobbying.

Annenberg School summer 1996. The Networked Future: Market Outcomes and Public Policy Options .

Wharton Financial Institutions Center, Summer 1994. Empirical Analysis of the Impact of Customer Satisfaction on Bank Profitability.

Wharton Financial Institutions Center, Summer 1993. Empirical Analysis of Theoretical Model of Bank Efficiencies.

PROFESSIONAL ACTIVITIES:

National Research Council Committee on the Transborder Flow of Scientific Data, 1995-96.

Editor Board member, *Journal of Industrial Economics*.

Associate Editor, *Information and Economic Policy*

Referee for *American Economic Review, Econometrica, Journal of Industrial Economics, The RAND Journal of Economics, Information and Economic Policy, Journal of Regulatory Economics*, and *Journal of Political Economy*.

Reviewer of National Science Foundation Grant Proposals.

Member of Advisory Board, Columbia University Information and Telecommunications Institute (CITI).

Chairman of Organizing Committee, 1988 Telecommunications Policy Research Conference.

Governor's Task Force on Economic Development: Service Sector Task Force, 1987.

Served on original Organizing Committee for Telecommunications Policy Research Conference, 1973-1974.

Served on Organizing Committee for Workshop on Local Access, held in St. Louis, MO, September, 1982.

DAVID J. FARBER

EXPERIENCE

Distinguished Career Professor of Computer Science and Public Policy at Carnegie Mellon University (2002-present)

The Alfred Fitler Moore Professor of Telecommunication Systems, Moore School, and Professor of Public Policy, Wharton School University of Pennsylvania (1988 – 2003-retired)

Chief Technologist, Federal Communications Commission (1999-2000)

Director of the Distributed Systems Laboratory, University of Pennsylvania (1988 - present)

Director of the Center for Networking Technology and Applications, University of Delaware (1987 - 1988)

Professor of Electrical Engineering and Professor of Computer Science, University of Delaware (1977 - 1988)

Associate Professor of Information and Computer Sciences and of Electrical Engineering (with Tenure), University of California at Irvine (1970 - 1977)

Founder and Vice President of Research and Planning for Caine, Farber and Gordon Inc. (1970 -)

Principal Member of the Technical Staff, Xerox Data Systems (1969 - 1970)

Member of the Technical Staff, the RAND Corporation (1967 - 1969)

Supervisor; Systems Programming Department, Bell Telephone Laboratories (1965 - 1966)

Member of the Technical Staff, Programming Research Department, Bell Telephone Laboratories (1962 - 1965)

Member of the Technical Staff, Electronic Switching Engineering Systems Department, Bell Telephone Laboratories (1956 - 1962)

EDUCATION

Stevens Institute of Technology Doctor of Sciences (honorary) 1999

University of Pennsylvania MA (honorary), 1988

Stevens Institute of Technology BSEE, 1956

Stevens Institute of Technology, MS in Math, 1962

Bell Telephone Laboratories Communication Development Program, 1963 (Equivalent to MS in EE)

RECENT HONORARY APPOINTMENTS and AWARDS

Fellow of the IEEE

Fellow of the ACM

Appointed as a Commissioner to the Mayor's Telecommunications Policy Advisory Committee of Philadelphia

Trustee of the Stevens Institute of Technology

Trustee of the Electronic Frontier Foundation

Elected Trustee of the Internet Society (two full terms)

Recipient of the SIGCOMM Award for Lifetime Contributions to the field

Recipient of the John Scott Award for Contributions to Humanity for work in Networking

Visiting Professor of the Glocom Institute of Japan, International University of Japan

Advisory Board at the National Institute of Informatics of Japan

Distinguished Lecturer Hawaii International Comference on System Science 2003)

PATENTS AWARDED

Patent No. 6,072,780, 6,266,328, 6,480,474 initially filed August 26, 1996, "Telephone call-back system controlled by online data network in real time," D. Farber *et al.*

Patent No. 5,329,623 awarded July 12, 1994, "Apparatus for Providing Cryptographic Support in a Network," Jonathan M. Smith, C. Brendan S. Traw, and David J. Farber.

Patent No. 5,353,419 awarded October 4, 1994, "An Active Instruction Decoding Processor-Memory Interface," J. Touch and D. Farber.

Patent No. 6,185,678 awarded February 6, 2001, "Secure and Reliable Bootstrap Architecture," William A. Arbaugh, David J. Farber, Angelos D. Keromytis, and Jonathan M. Smith.

SELECTED PUBLICATIONS (* indicates student co-author(s))

Books

The Office of the Future: Communication and Computers, R.P. Uhlig, D.J. Farber and J.H. Bair, North Holland Press, 1979.

National Reports

The Markle Foundation Task Force report on National Security in the Information Age

Realizing the Information Future, National Research Council

Toward a National Research Network, National Research Council

Transport Protocols for Department of Defense Data Networks, National Research Council

Report on the Evolution of a National Supercomputer Access Network - Sciencenet, National Science Foundation

Journal Articles

SNOBOL, A String Manipulation Language, Co-authored with R.E. Griswold and I.P. Polonsky, Journal of the ACM, 1964.

SNOBOL 3, Co-authored with R.E. Griswold and I.P. Polonsky, Bell System Technical Journal, 1966.

APAREL - A Parse Request Language, Co-authored with R. Balzer, Communications of the ACM, 1969.

Software Considerations in Distributed Architectures, D.J. Farber, IEEE Computer Magazine, vol. 7, pp.31-35, 1974.

A Parallel Mechanism for Detecting Curves in Pictures, P.M. Merlin * and D.J. Farber, IEEE Transactions on Computers, vol.24, pp.96-98, 1975.

Recoverability of Communication Protocols - Implications of a Theoretical Study, P.M. Merlin * and D.J. Farber, IEEE Transactions on Communications, vol.24, pp. 1036-1043, 1976

The Overseer, a Powerful Communications Attribute for Debugging and Security in Thin-Wire Connected Control Structures, David J. Farber, J. B. Pickens,* ICCC 1976: 441-451

On the Design of Local Network Interfaces, Paul V. Mockapetris*, Michael Lyle*, David J. Farber, IFIP Congress 1977: 427-430

The Convergence of Computing and Telecommunications Systems, D.J. Farber and P. Baran, Science, Special issue on Electronics, vol. 195, pp.1166-1170, 1977. Invited Article. (Also published in #5 of the AAAS Science Compendia, 1978.)

SODS/OS: Distributed Operating System for the IBM Series/1, W. David Sincoskie*, David J. Farber Operating Systems Review 14(3): 46-54 (1980

The National Research Network, D.Jennings, L. Landweber, I. Fuchs, R. Adrion, D. Farber, Science Feb 28, 1986. Invited article.

NOAH NET, An Experimental Flood Local Area Network, David J. Farber, Guru M. Parulkar,* ICCC 1986: 265-269

Design and Implementation of a Trusted Mail Agent, Marshall T. Rose, David J. Farber, Stephen T. Walker, ICCC 1986: 103-107

The World of Computer Networking in the 1990's, International Congress of Radio Sciences, Israel 1987

Performance models for Noahnet, Guru M. Parulkar*, Adarshpal S. Sethi, David J. Farber, SIGCOMM 1988: 262-273

An analysis of Memnet - an experiment in high-speed shared-memory local networking, Gary S. Delp*, Adarshpal S. Sethi, David J. Farber, SIGCOMM 1988: 165-174

A Taxonomy-Based Comparison of Several Distributed Shared Memory Systems, Ming-Chit Tam*, Jonathan M. Smith, David J. Farber, Operating Systems Review 24(3): 40-67 (1990)

Traffic Characteristics of a Distributed Memory System, Jonathan M. Smith, David J. Farber, Computer Networks and ISDN Systems 22(2): 143-154 (1991)

Memory as a Network Abstraction, Gary Delp*, David Farber, Ronald Minnich*, Jonathan M. Smith, and Ming-Chit Tam*, IEEE Network, Vol. 5(4), pp. 34-41 (July, 1991).

An Overview of the AURORA Gigabit Testbed, David D. Clark, David L. Tennenhouse, David J. Farber, Jonathan M. Smith, Bruce S. Davie, W. David Sincoskie, Inder S. Gopal, Bharath K. Kadaba, INFOCOM 1992: 569-581 1991

The AURORA Gigabit Testbed, David D. Clark, Bruce S. Davie, David J. Farber, Inder S. Gopal, Bharath K. Kadaba, W. David Sincoskie, Jonathan M. Smith, David L. Tennenhouse, 1992 Computer Networks and ISDN Systems 25(6): 599-621 (1993)

An Experiment in Latency Reduction, Joseph D. Touch*, David J. Farber, INFOCOM 1994: 175-181

Gigabit Telerobotics: Applying Advanced Information Infrastructure, Ruzena Bajcsy, David J. Farber, Richard P. Paul, and Jonathan M. Smith, in 1994 International Symposium On Robotics and Manufacturing, Maui, HI (August 1994).

A new congestion control framework for large bandwidth-delay product networks, Hyogon Kim*, David J. Farber HPN 1995: 294-304

State Caching in the EROS Kernel. Jonathan S. Shapiro*, David J. Farber, Jonathan M. Smith, POS 1996: 88-100 1995

The Measured Performance of a Fast Local IPC, Jonathan S. Shapiro, David J. Farber, and Jonathan M. Smith, in Proceedings of the 5th International Workshop on Object Orientation in Operating Systems, Seattle, WA (November 1996)

Communications Technology and its Impact by 2010, David J. Farber (Invited) CACM 40(2): 135-138 (1997)

Security for Virtual Private Intranets. William A. Arbaugh*, James R. Davin*, David J. Farber, IEEE Computer 31(9): 48-55 (1998)

EROS: A Fast Capability System, Jonathan S. Shapiro*, Jonathan M. Smith, David J. Farber SOSP 1999: 170-185

Predicting the unpredictable: Future directions in internetworking and their implications, David J. Farber IEEE Communications Magazine, no. 7, Jul 2002

Balancing Security and Liberty, David J. Farber (Invited) IEEE Internet Computing 5(6): 96 (2001)

Fame, but No Riches, For Cybersecurity -- It's time for government and industry to put their money where their mouths are, David J. Farber (invited) IEEE Spectrum, Jan. 2003

Conference And Other Papers

Farber, D.J., “A Survey of Computer Networks,” Datamation 18, 4 (April 1972), 36-39.

Farber, D.J. and F.R. Heinrich, “The Structure of a Distributed Computer System -- The Distributed File System,” Proc. International Conference on Computer Communications, (Oct. 1972), 364-370.

Farber, D.J., M.D. Hopwood, and L.A. Rowe, “Fail-Soft Behavior of the Distributed Computer System,” Technical Report #24, Department of Information and Computer Science, University of California, Irvine, California, (November 1972).

Farber, D.J. and K. Larson, “The Structure of a Distributed Computer System -- The Communications System,” Proc. Symposium on Computer-Communications Networks and Teletraffic, Microwave Research Institute of Polytechnic Institute of Brooklyn (April 1972).

Loomis, D.C., Ring Communication Protocols, UC Irvine Distributed Computer Project, Memo 46-A (May 1972).

Farber, D.J., J. Feldman, F.R. Heinrich, M.D. Hopwood, K.C. Larson, D.C. Loomis, and L.A. Rowe. “The Distributed Computing System,” Proc. Seventh Annual IEEE Computer Society International Conference, (Feb. 1973), pp. 31-34.

Rowe, L.A., M.D. Hopwood, and D.J. Farber, “Software Methods for Achieving Fail-Soft Behavior in the Distributed Computing System,” 1973 IEEE Symposium on Computer Software Reliability, (April 30, May 1-2, 1973), pp. 7-11.

Mockatetris, P., Lyle, M. and Farber, D., “On the Design of Local Network Interfaces,” IFIPS 1977

Sincoskie, W. and Farber, D., “The Series/1 Distributed Operating System,” Local Networks Conference 1981

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"The Gigabit Network -- does it fill a much needed gap?" presented as a Keynote and published in the proceedings of the International Workshop on Advanced Communications and Applications for High Speed Networks March 16 – 19, 1992 in Munich Germany

Many additional conference and symposium papers.

ACADEMIC RESEARCH MANAGEMENT

Principal Investigator, Information and Society Project of Annenberg School, University of Pennsylvania on Electronic Commerce

Co-Principal Investigator and conceptualized, - TeleMentoring: A Novel Approach to Undergraduate Computer Science Education, National Science Foundation 1992-1995

Principal Investigator, Aurora Project - A Gigabit Networking Testbed - effort in collaboration with Bellcore Incorporated, IBM Research Laboratories and MIT's Laboratory for Computer Science, National Science Foundation and Darpa (1989-present)

Principal Investigator, Very High Speed Switching Studies - Project DAWN - Bellcore and the Bell Regional Companies (1988- present) (effort in collaboration with Bellcore Incorporated and MIT's Laboratory for Computer Science)

Principal Investigator, Networking studies, AT&T Bell Labs 1990-1992

Principal Investigator, Project Mirage Darpa (1990-1991) studies in the formulation of high latency networking problems and models

Principal Investigator (Joint with Robert Kahn - CNRI), Study in Very High Speed Networking, National Science Foundation (1988 - 1989)

Director, Distributed Systems Laboratory, University of Pennsylvania (1988 -)

Director, Center for Networking Technology and Applications, University of Delaware

Principal Investigator, Bitnet Modernization, National Science Foundation (1986-1988)

Principal Investigator, Memnet, Northrop Corp. (1986 - 1988)

Co-Director, Educational Technologies Laboratory, University of Delaware (1985 - 1988)

Principal Investigator; Internet Mail Relays, ARPA IPTO (1983- 1984)

Principal Investigator; CSNET Phonenet and CSNET Relay, National Science Foundation (1981-1985)

Principal Investigator; Computer Message Services, U.S. Army DARCOM (1979-1984)

Principal Investigator; Overseeing of Distributed Processing Systems, National Science Foundation (1977-1980)

Principal Investigator; Research in Distributed Processing and Office Systems, General Business Systems Division of IBM (1977- 1980)

Principal Investigator; Local Network Architecture, Advanced Research Projects Agency, Department of Defense (1976-1978)

Principal Investigator; Audio Conferencing, The Institute for the Future (1974-1977)

Principal Investigator; Network Security and Secure Protocols, Advanced Research Projects Agency, Department of Defense (1974- 1977)

Principal Investigator; Distributed Computer Project, National Science Foundation (1971 - 1975)