PRINCIPLES AND GUIDELINES FOR ALLOCATING SPECTRUM FOR WIRELESS VOICE AND DATA COMMUNICATIONS SERVICES IN INDIA

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I. INTRODUCTION

Spectrum is essential for the continued growth in mobile telephony and wireless and data services in India. This report begins by providing a brief description of the current situation in India and the options for allocating additional spectrum for wireless mobile voice and data services.[1] The report next reviews the policies adopted in other countries. The next section of the report provides a framework for evaluating the available policy options. It then provides a brief analysis of spectrum pricin g options. The final section of the report comments on the various policy options available and some of the questions posed in the Telecommunications Regulatory Authority of India's Consultation Paper of earlier this year.

The situation in India is, in many ways, similar to that in other countries. India is facing rapidly growing demand for mobile telecommunications services and for the spectrum that those services must have to operate. The radio spectrum is a limited resource with competing demands for its use. For example, radio broadcasts cannot take place in the same spectrum bands as mobile telephony. Even for a single, defined use, such as mobile telephony, competition can arise over the technical standards used to provide service. Consequently, decisions about how much radio spectrum and which bands to allocate

[1] 2G is the common abbreviation for second generation mobile telephony and mainly refers to mobile digital voice services. 3G, or third generation, generally refers to mobile broadband data and voice services. Note that India bypassed 1G or analog mobile phone services.

inevitably affects all aspects of the mobile phone market, including the standards that can be used, the price and types of mobile telecommunications services available, and overall, including mobile, telecommunications penetration in India. Regulatory policy that aims to promote diffusion of advance telecommunications services at the lowest possible prices should not impose restrictions on band plan and technology that will limit operator ability to introduce services and expand the market. Releasing as much spectrum as possible, as soon as possible, and with the minimal possible constraints on band plan and technology will be the best means of achieving this goal. Cursory review of cross-country data suggests that rapid spectrum release will have significant benefits in promoting penetration growth and competitive pricing.

II. CURRENT SITUATION

India has previously allocated spectrum in each region to a number of mobile service providers. Service providers are using both CDMA and GSM based technologies. The geographic coverage of individual spectrum licenses is called a "Service Area." India has designated 23 Service Areas, consisting of 19 Telecom Circle Service Areas and 4 Metro Service Areas. Four GSM and either three or four CDMA licenses have been awarded in most Service Areas. Each GSM operator has been allocated no more than 2x10 MHz of spectrum in any single service area except in Metro areas, where some GSM operators have been allocated as much as 12.5 MHz. CDMA operators have been allocated as much as 2x5 MHz of spectrum in a few areas, but more often they are operating with only 2.5 MHz or 3.75 MHz. The GSM spectrum has been allocated in the 900 MHz and 1800 MHz bands. The CDMA spectrum has been allocated in 800 MHz bands. In addition, spectrum for corDECT services, mainly in rural and low traffic density areas, has been allocated. CorDECT uses spectrum, from 1880 – 1900 MHz. The corDECT allocation can limit availability of spectrum for CDMA or GSM in the 1900 MHz bands, in part due to out of band interference.

The Indian market for wireless services is considerably less concentrated – both in how spectrum is allocated and its ownership structure – than almost anywhere else in the world. In other countries, there are typically three, four of five operators serving any region. Hong Kong is one of the most competitive markets outside of India. Hong Kong is extremely densely populated and has a higher per capita GDP than India, yet it has only six operators. Moreover, the amount of spectrum per operator in India is among the lowest in the world. Other countries have started with a fragmented market including the United States. But, even in the United States, where there were eight bands available in each geographic area, it was most commonly the case that there would be only five or six competitors initially acquiring those licenses. Indeed, even as of the 1995 DEF block auction, over 85% of the licenses acquired in that auction were by incumbents seeking to deepen spectrum holding and/or fill in their footprints. And there has been significant and ongoing consolidation accompanying the introduction of new and more advanced service offerings. Consequently, consolidation in the India market is to be expected, and should be encouraged, to a point, as it will probably accelerate improvements in service offerings for end users and increases in overall mobile telephony penetration.

The speedy release of the additional available spectrum for mobile telephony is essential if India wishes the recent success in the wireless sector to continue unabated. The spectrum of greatest value to mobile operators that is still available is the 1800 MHz and 1900 MHz bands. At least 2x40 MHz should still be available. There should also be spectrum available at 700 MHz, 450 MHz and the Korean PCS bands (1750 – 1780 x 1840 – 1870 MHz). However, for reasons discussed further below, these options are much less desirable.

III. SPECTRUM ALLOCATION OPTIONS

Service providers using CDMA and GSM technologies will both want additional spectrum as their subscriber base grows and as they seek to expand their offerings to more customers in their existing service areas. Moreover, over time, operators will want to introduce new technologies and spectrum for doing so. In this section, I provide a brief description of the types of technologies available and their spectrum requirements. I also describe what allocations have already been made in other countries.

Wireless Voice and Data Technologies: Wireless voice and telecommunications services today primarily use two technologies GSM and CDMA. GSM is the mandated standard in Europe and has been deployed in many other regions as well. CDMA had its first commercial deployment in the US in 1995 and is now available in most of the Western Hemisphere and much of the world, including India, China, and Korea. While there are other mobile technologies in use, most notably TDMA, DECT (or corDECT), and iDEN, GSM and CDMA are by far the most widely used standards. Therefore our discussion focuses on GSM and CDMA. These technologies are used to serve the same market. Spectrum is only one input for providing very comparable services with CDMA or GSM equipment.

New technologies are being developed and deployed. The so-called 3G systems, WCDMA (also called UMTS) and CDMA2000 are only now beginning to be deployed. CDMA2000 has already seen widespread deployment in countries in which CDMA was deployed for so-called 2G networks. CDMA2000 is most accurately described as an upgrade of the previous generation of CDMA. Indeed, there are several upgrades being developed and deployed. The first upgrade, to CDMA 1X, was to allow data rates up to 153 kbps on the existing network. Old handsets continue to work on the upgraded network. Recently, 1X DO has been introduced which provides data rates in excess of 400 kbps. The CDMA upgrades increase the traffic the operator can carry with a given amount of spectrum and base stations. This potential capital expenditure savings is an additional incentive for its deployment.

Most GSM operators are planning to eventually introduce WCMDA, which is also called UMTS. This is the standard which has been largely adopted in Europe, with the possibly exception of the 450 MHz bands. It is incompatible with GSM, and requires an entire new network. GSM handsets will not work on WCDMA networks. WCDMA requires a minimum of 2x5 MHz per carrier channel for deployment, and the consensus appears that the minimum commercially viable allocation is 2x10 MHz. In other words, WCDMA is quite spectrum intensive. In contrast, CDMA2000 requires only 2x1.25MHz per carrier channel, and deployment of a single carrier channel is commercially viable way of upgrading an existing CDMA network.

In India, spectrum has been allocated for corDECT, which is essentially a wireless local loop system and not an advanced mobile voice and data technology. The corDECT spectrum allocations in India can present interference problems for CDMA around 1900 MHz. However, as corDECT is mainly intended for rural markets, it may be practical allow CDMA to share the same frequency, but with geographic separation of base stations. In what follows, I discuss alternative approaches for deploying other technologies along with corDECT.

Not only are GSM and CMDA two different technologies for providing similar wireless voice and data services, but they have somewhat different spectrum requirements. The differences in bands associated with each technology are largely driven by the availability of equipment, which in turn is driven by previous allocations in other countries.

Table 1: Bands for Broadband Voice and Data Services

450 MHz	450.4 - 457.6 MHz paired with 460.4 - 467.6 MHz or 478.8 - 486 MHz paired with 488.8 - 496 MHz or 380 – 400 MHz paired with 410 – 430 MHz
700 MHz	698 – 746 MHz paired with 746 – 794 MHz
800 MHz	824 – 849 MHz paired with 869 – 894 MHz
900 MHz	880 – 915 MHz paired with 925 – 960 MHz
1700 MHz	1750 – 1780 MHz paired with 1840 – 1870 MHz
1800 MHz	1710 – 1785 MHz paired with 1805 – 1880 MHz
1900 MHz	1850 – 1910 MHz paired with 1993 – 1990 MHz
2100 MHz	1920 – 1980 MHz paired with 2110 – 2170 MHz
DECT	1880 – 1900 MHz, 1900 – 1920 MHz and/or 1910 – 1930 MHz

Table 2a: Allocations in Other Countries

Region / Band	800 MHz	900 MHz	1800 MHz	1900 MHz	Technologies
North America	2 Bands - 50 MHz			6 Bands - 120 MHz, 3x2x15 + 3x2x5	CDMA, GSM TDMA
Canada	14 Tier 2 Areas			14 Tier 2 Areas	CDMA, GSM TDMA
Mexico	9 Regions			9 Regions	CDMA, GSM TDMA
United States	734 Cellular Market Areas			51 MTAs 493 BTAs	CDMA, GSM TDMA
Latin America					
Brazil	10 Regions/2 bands per region		2 bands, regional licensing	2 bands – 2x5 MHz each, 3 regions	CDMA, GSM
Other Latin America	2 bands			Up to 6 bands	CDMA, GSM TDMA
European Union	2 bands – 70 MHz		Up to 6 bands and 150 MHz		GSM
UK, Germany Italy		Four competitors	Nationwide licensing		
France Spain		Three competitors	Nationwide licensing		
Netherlands		Five (but previously 6) competitors	Nationwide licensing		
Asia Pacific					
China	1 CDMA	1 GSM			CDMA, GSM
Australia	4 Bands	4 Bands	15 Bands		GSM, CDMA
Taiwan	1 Band	Four GSM Competitors and 1 CDMA Competitor			
Singapore		3 GSM Competitors	3 GSM Competitors		

Table 2b: Allocations in Other Countries

Country	Bands	Technology	Geography	Size of license
Japan	800, 1500	PDC,CDMA	National	2x10 - 2x15
Korea	1800	CDMA	National	2x20 - 2x25
Russia	450, 800, 900, 1800	GSM, CDMA	Regional	varies

GSM*:* GSM has been deployed in the 800 MHz, 900 MHz, 1800 MHz and 1900 MHz bands. Equipment for GSM is readily available *only* in the latter three sets of bands. Moreover, tri-band, and even four- band, handsets and terminals, which can be used in any three, or all four, bands, are commonly available. Indeed dual-band handsets have been available for several years, initially for 900 MHz and 1800 MHz, and subsequently for 900 MHz and 1900 MHz.

CDMA: CDMA has been deployed at 450 MHz, 800 MHz and 1900 MHz. A significant variety of low-cost terminal equipment is available only at 800 MHz and 1900 MHz. CDMA2000 (1X DO) is now available in these three bands as well. Additionally, Korea has CDMA in the 1700-1800 MHz bands, but is not using the conventional DCS1800 MHz channels. Dual band handsets that work in the 800 and 1900 MHz bands are available. No other dual band handsets are now readily available for CDMA. In particular, there are no dual band CDMA handsets that work in the Korean PCS bands and any other band, such as 800 or 1900. Therefore, allocating additional 1800 MHz to supplemental spectrum holdings for operators having CDMA spectrum at 800 MHz, or 1900MHz, will not help those operators relieve congestion.

GSM versus CDMA band plans: Significantly, there is an overlap between the 1800 MHz bands and the 1900 MHz ones. CDMA can only be deployed economically in 1900 MHz and not at 1800 MHz, whereas GSM can be readily deployed with existing equipment in both. ***Therefore, a decision to use the 1800 MHz over the 1900 MHz bands is a decision to block CDMA, whereas a decision to use the 1900 MHz band does not create a technology bias.*** The European Union and a number of other countries, such as Australia, locked into the GSM standard by adopting the 1800 MHz plan. Assuming there are potential benefits from standards competition, it would be imprudent to designate the 1800 MHz for CDMA over the 1900 MHz unless other factors limit the options. Some preliminary empirical findings indicate that standards competition can have beneficial affects on both prices and diffusion rates.

Reserving the 1920-1980 MHz bands for WCDMA at the expense of cdma2000/CDMA 1X is not in the interest of promoting consumer welfare, increasing teledensity or promoting diffusion of new information technologies in India.

An additional consideration in deciding on what spectrum to allocate for wireless services is the potential impact on the availability of spectrum for so-called third generation or 3G technologies. For Europe, the ITU has designated the bands 1920 – 1980 MHz paired with 2110 – 2170 MHz for 3G. The EU policy towards 3G favors WCDMA, also called UMTS. CDMA2000 is being deployed in the 800 MHz and 1900 MHz, essentially as a seamless upgrade of the earlier generation CDMA (or IS-95A/cdmaOne) systems. **In contrast, WCDMA requires a new network to replace GSM.** Moreover, the 1900 bands currently used for CDMA and the new 3G bands allocated in Europe both use the 1930 – 1980 MHz, but in different directions (one for receive channels and the other for transmit channels). This creates a conflict in that an allocation of spectrum for WCDMA makes 2x60 MHz unavailable for CDMA and vice versa. While GSM may work in the 1900 MHz bands used for PCS including CDMA in the Americas, WCDMA has yet to be deployed in a manner consistent with that channel plan. Moreover, WCMDA is not yet a commercially successful technology.

Therefore, prudent public policy would suggest that:

?? The 1920 – 1980 MHz bands should be made available *now* in India to alleviate spectrum scarcity and promote increased diffusion of wireless voice and data services. This spectrum could be put to immediate use for CDMA, both CDMAOne and CDMA2000, *and GSM* and subsequently re-deployed for other technologies should they become available.

?? CDMA2000 can be deployed ***now*** in the USPCS band of 1850-1910 p/w 1930-1990 MHz bands and in a completely seamless manner, which would allow the current cdmaOne/IS-95 operators to expand capacity and add service offerings, such as high speed, wireless data 1xDO service.

?? The GSM operators will need to invest in a completely new network to introduce WCDMA, as the WCDMA and GSM radio networks are incompatible. A decision reserving 1920-1980 MHz for WCDMA would leave this spectrum idle until WCDMA is deployed.

I conclude this section with a few comments:

(1) All operators should have access to spectrum on equal terms and conditions, independent of the technology they choose to deploy.

?? Indeed the TRAI need not even consider the operator's choice of technology when licensing spectrum.

?? As consumer welfare depends on price, service quality and features, and coverage, TRAI need not regulate technology, only ensure adequate competition and that spectrum is not warehoused.

(2) India has so far failed to adopt a truly technology neutral spectrum allocation policy. A truly neutral policy would provide equal opportunity for operators to acquire spectrum matching their technology. A spectrum allocation consistent with only one technology, or one for which there is no equipment available for one but not the other technology. Allocating Korean PCS bands to CDMA operators would require CDMA operators to deploy two networks, as there are no dual band handsets. Similarly, allocating GSM operators Korean PCS spectrum would not be useful.

(3) No other country uses technical efficiency criteria to determine how much spectrum individual operators should receive. Where technological considerations enter into how much spectrum is allocated, the decision is usually one of determining the minimum size for each license, and not for each licensee individually. Even where there are small bands available, such as in the German and Austrian 3G auctions, the smallest license was set at 2 x 10 MHz. No decisions were made in advance of either auction about which operators might need 10 and which might need 15 MHz of spectrum nor which would need supplemental TDD spectrum.

(4) A national frequency allocation plan should be consistent with the equipment available as much as possible. If there is no equipment available, the frequency may be idle and fail to generate benefits. Such has been the experience to date with 3G spectrum in Europe, and is increasingly the case with Tetra spectrum there. When there is limited equipment availability, deployment costs tend to be high and service availability limited.

(5) A national frequency plan that is more responsive to operator needs and developments in technology and equipment availability will result in more rapid diffusion of new services, better quality and more competitive prices.

(6) GSM, CDMA, 1XDO can all make immediate use of the 1930-1990 MHz frequencies. The 1880-1910 x 1960-1990 would not interfere with any other frequency allocations that would provide immediate value. These frequencies should be made available as soon as possible. A technology frequency allocation plan would make the 1850 – 1880 MHz x 1930 – 1960 MHz available for GSM or CDMA, but let the license holder decide. Those allocated frequencies in the 1930-1980 MHz range should then be permitted to re-farm their spectrum and deploy technologies at their discretion.

IV. INTERNATIONAL COMPARISON OF SPECTRUM ALLOCATION POLICY

A. The European Union

1. GSM/DCS1800 MHz

The European Union (EU) has a harmonized approach to spectrum allocation. The first tranche of 2G spectrum was allocated in the 900 MHz bands (880 – 915 MHz paired with 925 – 960 MHz). Since then, most EU countries have allocated an additional 2 x 75 MHz at 1710 – 1785 x 1805 – 1880 MHz. Only GSM is in use in these bands. Most European Union countries have issued only nationwide licenses. A number of companies have aggregated licenses across the EU and have developed pan-European footprints, including Vodafone and Orange/FT. In most, but not all, European countries, the minimum spectrum bandwidth allocated to any single operator is 2x10 MHz. There are operators in some countries who have been allocated more than of 2 x 35 MHz.[2]

2. Tetra/450 MHz

The EU also allocated spectrum for *Private Mobile Radio (PMR) or* "trunk radio" services. The EU/ETSI standard for trunk radio is called *Tetra.* Tetra uses spectrum allocated for Tetra is in the 450 MHz bands (at 380 – 400 MHz x 410 – 430 MHz and 450 – 470 MHz).[3] Tetra has had very limited commercial impact. Since this spectrum has not been used very intensively, and in some cases is not being used at all, many EU national regulatory agencies (NRAs) have made an effort to *re-farm* the frequency with more advanced, and presumably more profitable, technologies. Inquam is one firm whose aim has been to introduce CDMA 1X service in these bands and has obtained licenses in UK, Germany and France[4] in the EU, and elsewhere. To our knowledge, CDMA 1X has not been rolled out anywhere in the EU in this or other bands. It is also our understanding that there are no dual band handsets that use 450 MHz.

Recently in Norway, The Ministry of Transport and Communications completed a first-bid, sealed-bid auction for a 15-year license for the 450 MHz (453-457.5 - 463-467.5) frequency band in June, 2004. The license was awarded on a technology neutral basis. Network is expected to be operational by early 2005. Sweden is also planning to issue a license to provide mobile telephony in the 450 MHz band likely in late 2004. One nationwide license will be awarded on a technology neutral basis.

3. Elsewhere in Europe

Russia generally issues regional, and not national, spectrum licenses. It has awarded GSM licenses, and CDMA at 450 MHz and 800 MHz. In approximately half a dozen cities, CDMA 1X licenses have been awarded. The license allocation process appears to be somewhat decentralized. No operators are offering service that allows roaming between 450 MHz and 800 MHz. Other countries in Eastern Europe largely follow the EU. Poland has issued CDMA licenses at 450 MHz and 800 MHz and Belarus, the Czech Republic, Latvia and Romania at 450 MHz.

B. The Americas

[2] See European Radio Office "ERO Information Document on GSM Frequency Utilization within Europe," updated February 2001.
[3] See http://www.tetramou.com/Tech/index.asp
[4] Inquam no longer has the French 450 MHz license as it failed to gain approval to deploy service.

1. **North America**

   The US, Canada and Mexico have all allocated 2x25 MHz in the 800 MHz bands, and 2 x 60 MHz in the PCS 1900 bands. CDMA and GSM are deployed in the latter. The 850 MHz bands were initially only used for AMPS cellular (1G). Subsequently, CDMA and TDMA were introduced in those bands. Recently, GSM has been deployed at 850 MHz. In the US, the 800 MHz band was initially allocated, starting in the mid-1980's. These bands were allocated for what are now called Cellular Market Areas (CMAs). The US is divided into 734 CMAs. The largest CMAs cover major cities with populations around 10 million. The smallest, in terms of population, cover rural service areas with a few thousand inhabitants. The PCS licenses at 1900 MHz were awarded for 51 Major Trading Areas (MTAs) and 493 Basic Trading Areas (BTAs). The MTAs range in coverage from over 20 million for New York down to approximately 100,000 for American Samoa. The The BTAs, which are partitions of the MTAs, are just a bit larger on average than the CMAs. Canada allocated cellular and PCS spectrum for 14 Tier II service areas and Mexico for 9 regions. Also, there are now five players with near complete coverage in the US, Cingular/ATT, which has coverage in Canada and Mexico, Verizon, also having coverage in Canada and Mexico, Sprint, T-Mobile and Nextel.

   Starting in the mid-90s, operators throughout North America began replacing their AMPS equipment with digital, either TDMA or CDMA equipment.

   Other spectrum allocation provisions in North America include:

   ?? iDEN, a time division technology has been used, mainly by Nextel, for 2G voice and data services using spectrum originally allocated for trunk radio services. The spectrum has been largely in the 800 and 900 MHz band.

   ?? The US, and to a lesser extent Canada and Mexico, permits spectrum trading. Firm footprints have been filled in via spectrum trading. One notable example is Nextel that converted tens of thousands of tiny Trunk Radio licenses into a seamless nationwide 2G network.

   The US has also set aside spectrum at 700 MHz, but very little of that spectrum has been assigned, and it is all heavily encumbered.

2. **Latin America**

   Latin America, with the exception of Brazil, follows the North American model. The AMPS cellular bands have been deployed throughout Central and South America and the Caribbean. With the exception of Brazil, any additional spectrum allocation has come from the PCS (1850 – 1910 x 1930 – 1990 MHz) bands. Brazil has allocated spectrum in both the 1800 MHz and 1900 MHz bands (1800 MHz for GSM and 1900 MHz for CDMA).

   There are other bands in use in parts of Latin America. Trunk radio is has been popular in many rural and low-income communities. The Japanese Personal

Handyphone System (PHS), and Digital European Cordless Telephone (DECT) systems have apparently been tried in parts of Latin America. It is our understanding that DECT has not been successful anywhere in Latin America.

Brazil allocated the AMPS cellular bands, as in the rest of the Americas, a large fraction of the DCS1800 spectrum for GSM and a portion of the PCS bands for wireless local loop (Vesper), which has or is being converted to allow mobile services.

Uruguay allocated *triples*, rather than pairs, of blocks between 1710 and 1990 MHz. This, in theory, was intended to allow the licensee to decide between GSM/DCS 1800 and PCS 1900. Thus, for example, a license would consist of 1775-1785 MHz x 1870-1880 MHz x 1950-1960 MHz. This auction was aborted due to lack of interest. Uruguay previously allocated frequency that conforms to North American AMPS bands and a limited amount of spectrum in the PCS 1900 MHz bands. Most, but not all, Latin American countries issued nationwide licenses. Notable exceptions include Brazil, with 10 regions, and Colombia, with three regions.

C. Australia

In a sequence of auctions Australia allocated most of the spectrum from 825 MHz – 960 MHz (in both the 800 MHz and 900 MHz bands), as well as 1710 – 1880 MHz for 2G and 1900 – 1980 MHz and 2110 – 2170 MHz for 3G. The spectrum between 1900 MHz and 1920 MHz is unpaired. Although the Australian spectrum licenses do not specify any technology, **in practice, the band plan for all licenses allocated in the 1710 – 2170 was consistent only with GSM/UMTS. In other words, the band plan effectively determined the technology, and was not technology neutral.** Indeed, QUALCOMM purchased one of the 3G blocks, hoping to be able to deploy CDMA2000. Limitations of equipment availability hampered this effort. CDMA has been deployed in Australia, but only at 825 – 845 MHz x 870 – 890 MHz. Australia permits spectrum trading. Spectrum trading has permitted some consolidation and allowed successful operators to absorb spectrum that unsuccessful operators were not able to utilize. Australia allocated the original GSM licenses as nationwide licenses. However, most additional spectrum was allocated in 21 regions.

D. Taiwan

Taiwan allocated the GSM/DCS1800 MHz bands for GSM. Taiwan recently conducted a 3G auction in which there were four licenses at 1920 – 1980 x 2110 – 2170 MHz and one license at 825 MHz for CDMA 2000. This latter license is considered a 3G band by Taiwan regulators. CDMA 1X has been deployed in that band.

E. Korea and Japan

Both Korean and Japan have allocated frequencies for CDMA and 3G/WCDMA. CDMA operators in Korea are using the 1750 – 1780 x 1840 – 1870 MHz frequency spectrum.

One should not view CDMA's success as providing evidence that NRAs in other countries need not consider frequency coordination with other countries and will not have an impact on mobile operators, terminal availability, subscriber costs and penetration in their own countries. Korean CDMA was introduced at a time when, by global standards, it still represented a significant improvement over the then more dominant analog and GSM systems.[5]

Unconventional spectrum allocations will increase costs of both network and terminal equipment. In addition, the variety of terminal equipment will be limited. These factors would tend to increase prices and reduce diffusion.

In Japan, CDMA is at 800 MHz. Japan also has PHS service around 1.5 GHz. Due to significant time to market advantages, CDMA 2000 has achieved significantly greater success that has WCDMA in Japan.[6]

F. China

China has allocated spectrum for both GSM in the conventional DCS1800 MHz bands and CDMA in the conventional 800 MHz bands. Both GSM and CDMA operators have achieved significant penetration. As in India, licenses are regional. Only China has achieved more rapid growth of mobile penetration than has India.

G. Africa

Africa has very low per capita GDP. There is insufficient demand for service for the entire 2G and 3G spectrum to be allocated. Africa has largely followed Europe, in that most service is GSM. GSM is much more common in Africa. CDMA is available in a number of central African cities.

H. Other Countries

Other countries have allocated spectrum differently. For example, Hong Kong has one CDMA license and several GSM licenses. Singapore has three GSM operators who each one 3G licenses in the EU 3G bands and one CDMA operator who turned back its license. In Israel, spectrum has been allocated spectrum for CDMA, TDMA and GSM.

V. POLICY GOALS AND EVALUATION CRITERIA

Any analysis of spectrum allocation policies requires a definition of the policy goals. According to the Department of Telecommunications, the Government of India has: "recognize[d] that provision of world class telecommunications infrastructure and information is the key to rapid economic and social development of the country" and

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[5] CDMA was launched in Korea in 2000. At that time, CDMA was only firmly established in North America.

[6] Information about Japanese mobile network subscription by firm and technology can be found at http://www.tca.or.jp/eng/database/daisu/index.html.

announced a National Telecom Policy defining certain important objectives, including availability of telephone on demand and provision of world class services at reasonable prices. Additionally, the Telecommunications Regulatory Authority of India web site lists "competition and efficiency" first among its policy goals.

A. Economic Efficiency

In order to translate the above goals into quantifiable measures, I focus on two specific quantifiable objectives: economic surplus and total telecommunications penetration. Economic surplus is measured as the sum of consumer and producer surplus. Consumer surplus is the difference between total value derived and the amount paid. However, as there may be different prices for different packages, this surplus may need to be summed across service offerings and price plans. Producer surplus is measured as the difference between revenues and variable costs.

Total telecommunications penetration includes both wireline and mobile phones. Historically, teledensity has been measured by dividing the number of fixed access lines by the population. However, for many, wireless service is available more widely, more affordable to consumers and less costly to provide. Of course, due to the fact that it is easier to disconnect a wireless account, especially with the prevalence of pre-pay service, it is appropriate to include in a measure of teledensity only those mobile accounts for which there were activity within 90 days of the measurement.

The two goals, economic efficiency and teledensity, can conflict at times. Absent direct government support of universal service programs, economic theory suggests that a competitive market will efficiently maximize both teledensity and economic surplus. Government programs may want to boost teledensity beyond what may be possible absent subsidy.

B. Engineering versus Economic Efficiency

The economic notion of efficiency differs significantly from notions of efficiency that engineers usually apply, or that TRAI has considered in its recent Consultative Report, to compare different technologies and spectrum allocation band plans. Technical evaluations of alternative technologies typically tend to focus on the data throughput that can be achieved with a given amount of spectrum from a single cell, or, with a given density of cell-sites over a specified area.[7]

The advantage of a cellular network is that it can re-use the same spectrum. Barring interference from nearby cells, capacity of a network can be increased by reusing spectrum more often. This can be accomplished by shrinking the average cell size radius in a given

[7] The standard measure of engineering efficiency is Erlangs per MHz per square km. This is discussed in more detail in the Appendix.

area at least until the cell radius is reduced to the level at which interference between adjacent cells becomes a constraint. Very roughly speaking, doubling the number of cells in an area will double the capacity, other things equal. This is a very rough approximation, as power and interference management will affect the available capacity, or erlangs, per cell as the cells shrink. The result of the process of optimizing cellular architecture is that a great deal of traffic can be served with very little spectrum. However, there is a cost of doing so – high network costs due to the need for many cells to compensate for spectrum limitations. More spectrum can reduce the need for splitting cells and investing in additional equipment. **Therefore, there is an economic tradeoff between spectrum and capital equipment expenditures.**

Data networks differ from voice networks in that latency, or the tolerance for delay, can be quite a bit higher. Indeed, on any voice network, there are "gaps" that will allow transmission of some data because data does not usually need the real-time, open channel of a voice communications. Therefore, at low data traffic levels there is essentially no tradeoff between voice and data capacity. This is not true at higher traffic levels for data, and capacity planning for a wireless data network or a hybrid voice and data network is quite a bit different than it is for a voice only one.

CDMA is spectrally more efficient than GSM and other time division technologies. What this means is that a larger number of logical voice channels can be carried over a given amount of spectrum using CDMA technology than using GSM. This does not necessarily mean that a CDMA network will have more capacity or will be more cost effective. Indeed a dense GSM network (one with small cells having 3 or 4 sectors per cell) with a large capital investment, will provide more total Erlangs of capacity over a geographic area, than will a sparse CDMA network with much less capital investment. Note that an option for shrinking or splitting cells is to divide the cells into sectors. So, for example, 120° sectors would result in three times the capacity as a network with 360° sectors assuming the same frequency can be re-used in adjacent cells and sectors.

Because of trade-offs, the question of what technology is more efficient often depends on what is more cost effective at a given level of usage. Clearly spectrum is a scarce resource that has a value. Therefore, inefficient technology that requires lots of spectrum but little capital may be less *cost effective* than a more efficient technology for which the electronic equipment is more expensive. Moreover, what is most cost-effective at one traffic level may be much less so at another.

For many different reasons GSM equipment has been less expensive than CMDA equipment. More specifically, the cost of provisioning the network for a given number of GSM base stations may be less than it is for the *same number* of CDMA base stations. If and when this is the case, GSM will be more cost effective than is CDMA. And this is more likely to be the case for low traffic densities. For high levels of traffic, the reverse is likely to be true. Moreover, a CDMA network designed for both high traffic and large spectrum allocations may have great cost advantages over GSM networks. Thus, the optimal spectrum allocation, i.e., the one that is most cost effective or achieves lowest total costs for a given level of traffic, may be one in which the GSM operators have large cells and not much spectrum and the CDMA ones smaller cells, very highly loaded and lots of spectrum. In addition, GSM may be more cost-effective for some operators because of their contracts with vendors whereas for other operators CDMA will be more cost effective. Detailed knowledge of information that is typically highly proprietary, including specific provisions of the contracts between operators and equipment vendors, is needed to *know* the optimal approach for dividing spectrum between operators and technologies. Precise cost information is essential to make such determinations. The most spectrum efficient technology can be prohibitively expensive or at least much more expensive and raise service costs and end user tariffs.

The cost and variety of terminal equipment can vary with both technology and band. GSM terminals and CDMA terminals do not offer identical features. Moreover, unconventional band plans can limit terminal/handset can limit terminal availability and costs, as I have discussed above. The impact of terminal cost on consumer and produce surplus is readily measured and can be compared with other directly measurable benefits. However, the value of service and terminal diversity is harder to assess. Consumers do not place uniform values on variety. Measuring the value of increased variety requires good market data. Such data is usually difficult to acquire, especially in advance of deployment.

To summarize, many dimensions of market demands are needed to optimize cellular systems and spectrum allocations. For example, to answer the question of the cost effectiveness of GSM versus CDMA, knowledge of eventual usage patterns and, consequently, cell density is needed. The bottom line of these trade-offs is that it may not be possible to know all of he variables needed to optimally allocate and assign spectrum to specific technologies. As explained below, mechanisms to allow the market participants with the relevant information to make the choices of technology and spectrum assignments are possible, practical and preferable.

VI. BASIC ECONOMIC PRINCIPLES OF SPECTRUM ALLOCATION

A. When to Allocate Additional Spectrum

This section discusses the economic principles that can be applied to determine when additional spectrum should be allocated for provision of mobile services. Absent need for "common areas" or spectrum reserved for future use, conventional economic theory would suggest that ***all*** potentially valuable radio spectrum be released essentially with no delay. In the event that not all radio spectrum can be productively used in the near term, there may be no more economic justification for governmental warehousing of spectrum than there is for private sector warehousing.

A few factors suggest that the government should not release all currently unused spectrum for public use. First, spectrum can be valuable when made available for common or unlicensed, use. One example of such spectrum is that now used for WIFI to provide short distance wireless broadband connections. However, many other spectrum commons provide some benefits, such as for Citizens Band Radio, Ham Radio, and unlicensed bands used for cordless phones, baby monitors and garage door openers.

A second reason why the government might want to hold back spectrum is that there can be non-commercial experimental benefits from some spectrum being maintained for such purposes.

Third, if the only buyers, or the most likely winners of spectrum rights for a particular band, are speculators seeking to "flip" spectrum, then there is no real social welfare loss from the government retaining rights until technology develops that would utilize the spectrum more effectively.

Fourth, spectrum rights can be an important source of non-tax revenues for the government. If taxes would be needed to supplement for lost spectrum revenues, then social welfare would be improved if the government were to try to time spectrum sales to increase revenue proceeds.

Given these considerations, a prudent approach, which can be based on economic principles, is for the government to set a reserve price and to allocate spectrum for which a potential licensee is at least willing to match the reserve price. For 2G spectrum, and for other reasons we explain in further detail below, public policy considerations suggest that most, if not all, the available spectrum be released fairly soon. TRAI or WPC can set an annual administrative fee per MHz and per POP to reduce the incentives for warehousing of spectrum. The fee should not be so large as to block deployment of valuable new services. Spectrum that would be allocated as a commons area should only be subject to user fees, possibly assessed on equipment, to reduce congestion, but not license fees.[8]

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[8] Administered incentive prices would be similar to these types of fees. Efficient prices require detailed knowledge of marginal valuations and costs.

National Regulatory Agencies typically assume that they should rely mainly on engineering analyses to assess the optimal use of spectrum. Such dependence on engineering will tend to result in misallocations for a number of reasons, especially when market forces can assist. No engineering study can possibly reach a definitive conclusion absent proprietary and confidential information about equipment costs, which also tends to change over time. Engineering studies can describe how to use spectrum, but not how spectrum should be used as they cannot predict consumer demand. Competitive pressures can often be relied on to achieve efficient allocations without any intervention, and to also create pressures for firms to adjust spectrum in response to changes in market conditions. Ironically, reliance on engineering studies often increases the risk of misallocations as compared to reliance on market forces. Moreover, dependence on engineering analysis often implicitly overly emphasizes technical efficiency without properly factoring in costs. The most spectrally efficient solution can be prohibitively expensive, and often better technical solutions, even if not prohibitively costly, add so much to cost as to significantly retard diffusion.

Most successful spectrum policy can be attributed to a licensing approach which provides firms opportunity to acquire spectrum rights that allows flexibility to introduction of innovative technologies and service offerings. Indeed, the success of GSM in Europe probably arises as much from the spectrum being released for private sector use in a timely fashion. A contributing factor in North America's lower mobile penetration is the delay in allocating PCS spectrum, which occurred approximately five years later than in Europe. The rapid growth of mobile penetration in India is likely in large part attributable to making what had been initially designated as wireless local loop spectrum available for CDMA mobile services. Not only did this decision make available more spectrum but it also increased competitive pressure on incumbent GSM operators.

For these reasons, making as much spectrum available as quickly and with as few restrictions as possible will best promote public policy interests. This is true in large part because relatively little spectrum is available for commercial development, most being reserved for government and other public uses. Although there can be a solid economic rationale for reserving spectrum for future use, there is some empirical evidence that delays in allocating 2G spectrum have had a significantly adverse impact on penetration. Therefore, awarding more spectrum with fewer restrictions should promote more rapid growth and penetration. Given the potential adverse impacts from delaying spectrum allocations, erring on the side of allocating too much spectrum rather than too little, and with fewer restrictions on standards rather than more would be the prudent decision.

This line of reasoning suggests that it is difficult for a regulatory agency to determine when additional spectrum is really needed to allow operators to expand their subscriber base or what technology and service offerings will prove most popular. At one level, once an operator has one or a few carrier channels it can continue to subdivide cells to expand capacity, at least until a minimum cell-site radius/maximum density is reached. However, this ignores the potential impact on costs.

What should govern the tradeoff between spectrum and capital equipment expenditures is economics. In particular, if one knows the true opportunity cost of the spectrum, and the cost of the equipment, then the choice of how much spectrum is needed to efficiently serve a given level of traffic becomes a relatively straightforward optimization exercise. It is much more difficult, if not impossible, to perform such an optimization analysis when the spectrum prices are not competitive market prices. On the other hand, if operators incur a charge for spectrum, or can sell it, then they have incentives to economize, and minimize total costs.

B. How to Allocate Spectrum

In most countries, regulatory agencies manage spectrum allocation. The regulatory agency reviews applications for licenses based on legislatively determined public policy criteria. Traditionally, regulatory agencies have decided how to allocate spectrum among competing proposals based on subjective evaluations. This type of evaluation process is commonly called a beauty contest. For decades, economists have argued that market mechanisms should be used to efficiently allocate spectrum.[9]

Over the past decade, auctions and other market mechanisms have been introduced for a limited set of spectrum rights. The first spectrum auctions were conducted during the early-1990's in New Zealand and the U.S. The idea behind the use of market mechanisms and auctions is that prices should be used to ration the spectrum supply among competing users and uses. If the value of a slice of spectrum is higher for one party in one application than it is for others currently using that spectrum in different ways, then the entity with the high value use can compete by bidding up the price. In this manner, competitive forces will achieve and maintain an efficient allocation of spectrum rights, even or especially in cases where the regulator cannot know all of the relevant information needed to make the efficient allocation decision.

Ideally, an initial allocation, whether by an auction, other market mechanism, or regulatory review, would result in an efficient outcome and maximization of total surplus. Allocations which result in inefficient assignments – such as giving GSM operators spectrum for which only CDMA equipment is available and vice versa or not making adequate provisions to limit need for guard bands by assigning operators contiguous spectrum – will reduce both economic efficiency and social welfare.

It would not be in the public interest for any country to offer spectrum for which custom-made equipment would be required because costs would likely be prohibitive.

Nor would it be in the public interest for bands to be partitioned so small as to require guard bands that take up a high percentage of usable spectrum. Allowing operators to determine their own needs, and to determine the spectrum they can get access to subject to a few restrictions, such as caps, would greatly reduce the likelihood of such inefficiencies occurring. Moreover, as long as concession rights are transferable and transaction costs are not too high, spectrum manager concessions can approximate efficient allocation and

[9] See Ronald Coase, "The Federal Communications Commission," *Journal of Law and Economics*, Volume II (1960): 1-40, or Evan Kwerel and Alex Felker, "Using Auctions to Select FCC Licensees," Office of Plans and Policy Working Paper No. 16 (1986).

assignment of spectrum rights, no matter how they are assigned in the first place. This argues too in favor of spectrum trading.[10] Indeed, initial allocations can, for a variety of reasons, be inefficient. Spectrum trading should be encouraged if only to correct for inefficiencies caused by the initial allocations. The benefits of so doing can be very large especially when initial spectrum holdings are highly fragmented and requiring a relatively high percentage of spectrum being needed for guard bands.

Spectrum trading does require some continued regulatory oversight. For instance, absent oversight, one party may be able to secure market power by acquiring control of all spectrum that can be used for a service. TRAI or any NRA will want to implement appropriate monitoring procedures prior to allowing spectrum trading. For simple swaps to reduce guard bands, a simple registration process will likely suffice. For more complex transactions, such as acquisitions or virtual network operator or marketing agreements, greater vigilance is appropriate.

C. How Much Spectrum to Allocate and How to Divide Spectrum Rights Among Competing Operators

The basic economic principle that should be applied in determining the amount of spectrum to allocate and how to allocate it among competing operators and services is maximization of the (possibly weighted) sum of consumer and producer surplus. Consumer surplus depends on prices operators charge and services offered, which, in turn, depends on the amount of spectrum each has. Each operator will receive producer surplus equal to the difference between revenues and variable costs. Producer surplus also depends on prices each can charge.

Additional spectrum should be allocated as long as the incremental total surplus derived exceeds opportunity costs. The opportunity cost of licensing a spectrum block is the value that may be derived from re-allocations that could not otherwise occur or from common or shared use of the frequency. This approach suggests setting a reserve price for spectrum, which can vary by frequency block and region, equal to its opportunity cost. No entity should be able to acquire a license that is unwilling to at least match its opportunity cost. I am not aware of any quantitative analysis of the opportunity cost of 2G spectrum reserved for unlicensed, shared or future use.

For determining how to divide spectrum among competing operators, the same principles would imply that spectrum should be allocated based on its marginal value to the different operators assuming that all operators are allocated spectrum.[11] These marginal values depend on not only how much value each operator can provide consumers and the costs of doing so, but on the amount of spectrum they have and how much their rivals have. The marginal value of a spectrum to an operator is not just a function of its cost structure only.

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[10] See Statement of 37 Concerned Economists, FCC (2001).

[11] It can turn out to be the case that marginal values of one operator is higher than that of another, yet, the total value of former is so low, that it should not be allocated any spectrum. For example, equating marginal values of spectrum between allocation for 1G and 2G technologies would suggest that a lot more spectrum should be allocated to analog (1G). However, this is clearly not the case, as analog technology is so inefficient that no amount of additional spectrum could reasonably offset its technical disadvantages.

The marginal value may depend on how much spectrum the operator has. Hence a competitor with less spectrum than its rivals may have a higher marginal value for incremental spectrum. On the other hand, a firm may *choose* to purchase less spectrum than its rivals in an auction or in secondary markets if it has lower marginal values than its rivals. Marginal values can depend on how much spectrum rivals have too.

There are several implications of the above analysis for decisions India will need to make soon about spectrum allocations. First, firms that derive low marginal values should not be allocated spectrum when it is scarce. Second, the amount allocated to any one firm will depend on its marginal value, which, in turn depends on its ability to use spectrum profitably and efficiently. A firm that can serve more customers and generate higher revenues will have a higher marginal value for spectrum, others things equal, than a rival with a less effective technology and business plan. Economic efficiency and public policy considerations both suggest that less efficient firms should receive less spectrum, other things equal. Indeed, if a technology is inefficient, e.g., AMPS and perhaps in some situations GSM, then it should not receive any spectrum. In North America, the amount of spectrum being used for AMPS is gradually diminishing. This is occurring without any government mandate. Rather, operators provide economic incentives for their subscribers to shift to digital service. This process seems to be winding down now.

The above assumes no installed base of old terminal equipment and no switching costs. This analysis will apply directly to long run allocation decisions. In the short run, maintaining an old, and inefficient, network can be optimal, although both private and public incentives will exist to encourage migration. Government intervention might be unnecessary, and may be ill-advised, for managing such migration and re-farming.

Further, over time, the marginal value of additional spectrum changes. With subscriber growth, what may have been adequate at one point, implying low marginal value, may be inadequate at a subsequent point in time. What this means in practice is that the marginal value of spectrum shifts up over time. As it does, the optimal amount of spectrum for any use or user will change.

The above analysis is limited in that it is not based on any empirical analysis of the determinants of marginal values. In general, a firm with higher marginal values should be allocated more spectrum. However, a more efficient technology may have higher marginal values for all allocations, or only for initial allocations. One way of imputing marginal values is to assess relative savings of capital expenditure for a given amount of incremental spectrum.

D. Re-farming, relocation, and re-allocation of spectrum

When spectrum has been cleared for new applications, such as the clearing of microwave for PCS in the US, or the shutting down of analog cellular service in Europe, the decision to do so was essentially a political one and ultimately decided by a governmental ministry or regulatory agency. Often this requires agreement from other agencies, such as defense ministries. At times, this decision involves some amount of political compromises or supplemental governmental treasury allotments. There have been a few exceptions. At times, a government may substitute an auction for annual first-come, first-served licensing on a fee basis. This is now occurring in the 2.3 GHz and 3.5 GHz bands in Canada. At other times, a government may provide the new licensee with secondary status, and permit those getting the new licenses to work out any arrangement they can with incumbents. The secondary and primary status may be flipped after some period time. This was the case with the US PCS auctions. After that auction, the incumbent point-to-point microwave operators were required to relocate within a specific period of time. Incumbent microwave permit holders were provided a definite time line for re-locating. During the early part of the transition window, the incumbent microwave operators were provided primary status. What this means is that new PCS licensees were not to be permitted to interfere with existing microwave operations without gaining consent. FCC regulations allowed PCS license holders to negotiate compensations to induce the microwave operators for re-locating and/or shutting down. After this period ended, the microwave holders were provided another window in which they could continue operations with secondary status. What this means is that they could continue to operate as long they did not interfere with PCS operations.[12]

In other instances, in the US and elsewhere, incumbents have been grand-fathered and new licensees have been able to negotiate with the incumbents. This has been the case with MMDS frequency in the US and Mexico, and SMR (trunk radio) frequency in the US. In many cases, as in Europe with 1G, operators in the old spectrum have been shut down. Generally, a pricing mechanism provides good incentives for firms to reallocate only when it is cost effective for it to do so.[13]

This is not an uncommon approach when there are auctions of frequency bands in which there is some limited use of spectrum The US adopted this approach for trunk radio, MMDS and PCS bands. Mexico adopted this approach for its MMDS licenses.

A related issue is determining policy for re-allocating spectrum once a license expires. In the US and elsewhere, many licenses have finite terms, e.g., 20 years, but with an "expectation of renewal." What this means is that the license is effectively for an indefinite term. An alternative is to allow re-auction of the spectrum. The economics literature suggests that incumbents will have a strong incentive to outbid potential entrants, and so a policy of re-auction expiring licenses may in practice differ little from a policy of granting renewals to firms continuing to make efficient use of spectrum.[14] Further, a policy that allows spectrum trading and re-farming will tend to result in efficient re-assignment of spectrum *without any regulatory intervention or re-allocation of spectrum rights.*

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[12] See www.fcc.gov/wtb/auctions

[13] See "The FCC Spectrum Auctions: An Early Assessment," *Journal of Economics and Management Strategy,* 6:3, 431-495, 1997, and Kwerell and Felker *op.cit.*

[14] See Vickers (1986) "The Evolution of Market Structure When There is a Sequence of Innovations, *Journal of Industrial Economics,* 35(1) 1-12.

E. Mergers, Acquisitions, Concentration and Economies of Scale or Density

Previous studies of the economies of scale for wireless voice networks have shown there to be some economies of density or scale.[15] These studies have provided estimates of the market concentration that may be efficient or stable – that is where economies of scale level off. This number will depend on density of the addressable population over the area covered. However, few would argue that most areas would be able to support more than four or five firms, and certainly not more than six.

These economies of scale, or density, can limit the number of viable competitors and also suggest that a relatively permissive policy toward mergers and acquisition is advisable – especially in markets starting with seven or eight operators each having tiny slices of spectrum. There would be two types of concentration limits that would be appropriate. One, as discussed above, is a limit on the fraction of spectrum in the relevant market that any one firm could have. We suggested that this could be 30%. The other is the limit on the share of subscribers in the market that the new firm could have. We would suggest that a relatively permissive level for this share provide would be appropriate provided that there is adequate competition from firms that are just entering or can enter the market.

VII. SPECTRUM PRICING OPTIONS

This section provides analysis of specific spectrum pricing options as well as a brief review of international experience.

A. Spectrum pricing principles

Until the mid-1990s, spectrum prices, assuming any, were set by NRAs. Since then, spectrum prices have been set increasingly by auctions for initial allocations. In addition, many NRAs allow secondary trading, which can set a market price. Virtually all secondary markets for spectrum operate through bilateral negotiation. Such negotiations leave large ranges of uncertainty, and are not transparent.

Most countries impose some sort of administrative fees. These fees can be based on the perceived value of the spectrum, which depends in large part on the availability of equipment in the band, the population and demography of the license area and the bandwidth. There have been several studies of auction price determination within a band, but not across bands. The reason for the lack of across band studies is that each band's value depends so much on the equipment that can be used. For instance, television and PCS services use roughly adjacent, and possibly the same, spectrum. The value of 5 or 10 MHz of spectrum for television will be much different than it is for PCS. Generally, lower frequency spectrum is more valuable than higher frequency spectrum. However, the availability and nature of the complementary equipment can matter a great deal. Other factors can affect prices, such as financial and other market conditions. For instance, the

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[15] See David Reed "Putting It All Together: The Cost Structure of Personal Communications Services," November 1992, FCC Office of Plans and Policy Working Paper No. 28.

prices of LMDS spectrum relative to 3G spectrum was very low in most countries, such as Italy and the UK, but quite high in Switzerland. The Swiss conducted their LMDS auction when the market view for that business was probably at its all time high. And the Swiss 3G auction was essentially uncontested – 4 bidders competing for 4 virtually identical licenses.[16] The English and Italians conducted their LMDS auctions after the telecom market turned back down.

Spectrum pricing can affect investment incentives and incentives to offer new services. Basic economic principles suggest that fees based on subscribers, percentage of revenues, or traffic will provide disincentives for investment as compared to lump-sum fees or fees based on spectrum used. The reason is that if fees are sensitive to subscribers or revenues, then an operator who invests in increasing subscription or revenues will lose a portion of the increase to higher spectrum fees. However, when spectrum fees are independent of subscription or revenues, this is not the case and subsequently, there are larger incentives to invest in the new services.

B. Reserve prices and market prices

Administratively determined prices can be based a number of different criteria. Commonly, two measures are used to set reserve prices – the prices of similar licenses in other countries and a cash flow analysis of the license value. Administrative prices are sometimes imposed as a substitute mechanism for market prices. Any price mechanism is a mechanism for rationing scarce supplies among competing demanders. When markets do not exist or are not practical due to regulation, administrative prices can serve as a proxy for market prices. As is discussed in more detail below, Administered Incentive Pricing (AIP), should be set in proportion to estimated marginal values. AIP should NOT be technology dependent, in that if two or more technologies can use the same spectrum for the same, *or even different*, services, the firms using the different technologies should face the same prices for spectrum. Offering firms different AIP prices based on technologies creates a distortion favoring the technology with the lower price.

Detailed information about the criteria used for setting reserve prices for 3G licenses is limited to a few countries, including the UK, Latvian, Singapore, and Italian 3G auctions. These reserve prices were more than starting prices in what was expected to be competitive auctions. Indeed, except for the UK, the auctions were not very competitive – three bidders for four licenses in Singapore, two bidders for three licenses in Latvia and six bidders for five licenses in Italy. The reserve prices represented a floor on what the government ministries considered a fair price.

In the case of Singapore, the reserve prices were based, in part, on a cash flow analysis. In the UK, the Radiocommunications Agency supposedly set reserve prices in part based on preliminary estimates of spectrum values, which were quite far off.[17] This was also true for the Brazilian auctions of cellular frequencies a few years prior. In Italy and Latvia there was some consideration to what similar spectrum licenses sold for in other countries. In

[16] www.bakom.ch
[17] Starting prices were approximately 100 million GBP, and final prices exceeded 4 billion GBP.

comparing spectrum values across countries it is important to compensate for differences in addressable population, potential penetration and revenues.

France was apparently influenced by the 3G spectrum prices in the UK when it set the fee for a 3G license. The French regulators did not anticipate the fall in the demand and set a price so high that only two firms expressed interest in getting one of the four licenses. This left two of the French 3G licenses unallocated.

In general, the reserve prices or the license fees will depend on the population of the area of coverage and the bandwidth. It has generally been the case that the fees, reserve prices or upfront deposits have been proportional to bandwidth. It is commonly the case that these fees are also proportional to population. No regulatory agency that we are aware of fails to account for differences in potential spectrum value in setting reserve prices or license fees. The spectrum prices generally will not affect end user costs, provided the spectrum prices are not a share of revenues nor related to subscription or usage. The only affect that spectrum prices will have on end-user costs is to the extent that high spectrum costs cause operators to economize on spectrum and substitute capital. In that case, spectrum prices can affect end user costs. In the US, operators paid significantly different amounts for their licenses. In many cases, the operators did not have to pay at all - for the 800 MHz licenses that the FCC assigned by means of lotteries or beauty contests. In other cases, the operators paid market prices in auctions or in secondary transactions. If anything, the firms that paid the most on average for the spectrum, Sprint and T-Mobile, have the *lowest* prices. It would be difficult, however, to find a relation.

The public policy rationale for reserve prices can be based on a number of criteria. First, spectrum may have a current value in government hands or may have future value that may not provide great ex ante benefits to any one firm. For instance, if there are two technologies, each unproven and each with equal probability of success and the most likely scenario is for one, but not both, systems to *work*¸ then the private sector may undervalue the spectrum. In this case, the government may prefer to only release the spectrum once some entity is willing to pay its fair market value ex post, i.e., after the uncertainty is resolved. At times, license revenues will be a factor in setting reserve prices as reserve prices can have a significant effect on long run revenues, especially when the spectrum is allocated for new and unproven technology.

C. Administrative prices or user fees vs. market prices and auctions

Administrative prices can be set so as to recover costs or as a substitute for market prices. Setting a positive price on spectrum can encourage its efficient utilization. The ideal price would be that which would prevail in at equilibrium in a perfect competitive market. At such equilibrium price equals the marginal value of spectrum to each operator utilizing positive amounts of spectrum. Marginal value is measured as the value of the additional capacity the spectrum provides. An alternative measure of marginal value is the savings of other inputs that is afforded when an operator acquires additional spectrum. This has been called the “least-cost alternative” approach to AIP.

Auctions for initial allocations, absent market imperfections, are likely to result in prices that more closely approximate the competitive ideal than will the results of engineering and market studies based on historic information. However, auctions are not always without significant transaction costs. Design and administration of an auction, especially one subject to the scrutiny typical in NRA rule-making processes, can require significant upfront costs, and at times the costs will exceed the value of the spectrum. For lower value spectrum, AIP or another means of administratively determining market proxies can result in more efficient outcomes than imperfect markets.

Auctions present risks as well. One risk is that auctions need not be equitable, especially when the bidders start with different amounts of spectrum being granted by means of an administrative process. While spectrum costs are fixed costs, and need not affect marginal costs, firms who have to pay for spectrum competing against firms who don't may acquire less spectrum, raising relative costs of capacity as well as face capital budgeting constraints for financing investments and innovations not faced by competitors. These considerations can ultimately affect marginal costs. To the extent possibly, a NRA should try to provide all firms with similar opportunities prior to the start of any auction. Auctions can be biased or present other risks. For instance, multi-attribute tenders often result in inefficient price service offerings, such as very low air time charges accompanying intolerable blocking probabilities. Sequential auctions often result in misallocations, as the strong bidders can guess wrong and wait too long to submit serious offers.

Auctions can have design flaws that result in post-auction license revocation or litigation. Two of the six "winners" in the German 3G auction announced their intention to abandon their licenses, despite having paid €8 billion each. One winner in an early US PCS auction, of nearly $6 billion of licenses, sued the Federal Communications Commission for fraudulent conveyance in an effort to reduce their obligation. It took almost a decade of litigation to resolve this. When only a very limited amount of spectrum is made available for auction, prices can be unrealistically high and winners can suffer a winner's curse or have plans to renegotiate. Well-designed and managed auctions will tend to mitigate these risks.

Note, the competitive ideal does not translate to equal prices for all spectrum. Spectrum should be priced in proportion to its value. Better spectrum should be priced higher. This suggests that GSM, CDMA and WCDMA spectrum should all be priced more or less the same, as the spectrum is essentially the same and even overlaps.

D. Spectrum pricing practice

Until the early 1990's, market approaches for pricing spectrum were practically unknown. Since then, countries have been turning with increasing frequency to auctions for initial allocations and liberalizing spectrum trading provisions. The following table provides a sampling of how 3G spectrum has been allocated in different countries.

In addition, many countries impose various types of administrative or user fees, range from small sums for filing fees to a significant percentage of revenues - as is the case in Hong

Kong and India.[18] Such fees tend reduce incentives to invest or expand service. The reason is that the operator only retains a fraction of the incremental revenues. Lump-sum fees for licenses provide stronger investment incentives than do royalties on taxes as a percentage of revenues.

Table 3: 3G Allocations

Country	No. of Licences Awarded	Method of Allocation	Population Total	Population Per License	Revenue (USD) Total	Revenue (USD) Per Pop.	Per Capita GDP (USD)
Switzerland	4	Auction	7.1 m	1.8 m	$120m	$17	36.7k
Netherlands	5	Auction	15.6 m	3.1 m	$2.4b	$154	24.7k
Germany	6	Auction	80 m	13 m	$46b	$575	26.3k
UK	5	Auction	58.5 m	11.7 m	$34b	$581	23.9k
South Korea	2	Hybrid	46.8 m	23.4 m	$2.2b	$47	8.7k
Austria	6	Auction*	8.1 m	1.4 m	$1.2b	$148	25.8k
Italy	5	Auction*	57.6 m	11.5 m	$11b	$174	19.1k
Spain	4	Beauty contest	39.4 m	9.9 m	$500m	$13	14.3k
Finland	4	Beauty contest	5.2 m	1.3 m	$2.2m	$43	24.3k
Portugal	4	Beauty contest	10 m	2.5 m	$342m	$137	10.8k
France	4	Beauty contest	58.5 m	14.6 m	$19.2b	$328	24.0k
Singapore	4	Auction	3.9 m	1 m	$176m	$45	26.5k

The above table is only meant to illustrate that spectrum is priced by means of different mechanisms in different countries. The table also shows is that the market prices are not necessarily higher than administratively determined, i.e., beauty contest, prices. Moreover, pricing can assume different forms, such as a concession fee, which is a percentage of revenue (Hong Kong adopted this approach), a one-time fee, installment payments or an annual per MHz spectrum usage fee.

VIII. POLICY IMPLICATIONS FOR SUPPLEMENTAL SPECTRUM ALLOCATIONS

The above has implications for a number of issues now facing Indian regulators that are discussed in the following section.

A. Release more spectrum sooner.

Economic principles and the limited empirical analysis currently available both support release of more spectrum sooner. Parceling out spectrum in small amounts only after there is a strong case that the additional spectrum is needed is likely to impair penetration growth.

[18] Canada requires spectrum license holders to devote a percentage of revenues to research and development.

Standard property rights models, based on pioneering work by Coase, argue that social welfare is enhanced by defining property rights and assigning them. The argument is that as long as property rights are defined and tradable, and transactions costs are sufficiently low, the resource will be acquired by the party placing the highest economic value on it. The empirical evidence to date, though limited, does tend to support a liberal approach to releasing spectrum.[19] Holding back 50 MHz or 100 MHz for use only when need has been firmly established may actually retard growth. Data is available that can shed light on this issue. It appears that Indian mobile telephone operators may hit a spectrum or capacity wall. When this type of situation occurs, prices tend to spike. It is an empirical question as to how much risk there is of this occurring in India.

B. Spectrum in the 800 MHz, 900 MHz, 1800 MHz and 1900 MHz bands can be of immediate value.

Spectrum in the GSM, AMPS, DCS1800 and PCS1900 MHz bands all have potentially high and immediate economic value. At least in the metropolitan areas, it would seem economically inefficient to reserve any of this spectrum for future use, even the 1920 – 1980 MHz bands. Even if that spectrum might be needed subsequently for WCDMA, an economically efficient approach to managing this spectrum might be to issue shorter duration licenses, which may be at risk of being re-assigned. The re-assignment, if any, should be based on economic criteria, i.e., willingness to pay of a new operator reaching some threshold. Economic theory would tend to favor an open auction for the renewal of the license, or that the threshold for reassignment will be set preferably according to some market-based process, or at least administratively determined prices that attempt to approximate market prices.[20]

C. Spectrum rights should be tradable.

Allowing spectrum rights to be tradable is necessary if regulatory authorities want to ensure spectrum will be allocated in an efficient fashion. Regulatory authorities, in a command and control mode of allocating spectrum rights, may fail to find an optimal allocation ex ante. Even if the spectrum is assigned efficiently ex ante, changes in market conditions can make initial allocations inefficient and then lock them in, thus creating the need for reallocations. The fragmented way in which spectrum has previously been allocated and the inability of operators to swap slices so as to permit reduction of spectrum has resulted in the need for guard bands that would otherwise be necessary and in inefficient utilization of spectrum.

Allowing spectrum rights to be tradable means operators can sell excess spectrum or buy additional spectrum. This helps establish a price for spectrum that represents its opportunity

[19] One study on the costs of delay of the analog cellular (1G) allocations in the United States measured the costs of delay in the tens of billions of dollars per year. See Evan Kwerel and John Williams, "Changing Channels: Voluntary Reallocation of UHF Television Spectrum," November 1992, FCC Office of Plans and Policy Working Paper No. 27.

[20] Estimating what market prices might be in an imperfectly competitive market in which supply is subject to stochastic capacity can be difficult due to the potential for unstable price dynamics in such markets. See Kreps and Scheinkman (1983) Bell Journal of Economics for a discussion of such markets.

cost, which, in turn, provides a powerful economic incentive to use spectrum efficiently. A firm with excess spectrum, or one who can fairly easily manage with less spectrum may find it worthwhile selling parts of its spectrum holdings. Similarly, firms who need more spectrum will economize on their purchases. Spectrum trading and re-farming would encourage firms to move toward bands that are less congested, in that the less congested bands will be less expensive.

D. For purposes of spectrum management, efficiency should be evaluated based on economic and not solely on engineering criteria.

Efficiency is best measured by economic values created in terms of the weighted sum of consumer surplus and producer surplus. In Appendix A, I explain how consumer and producer surplus are measured. A higher weight on consumer surplus than on producer surplus can account for the fact that telecommunications penetration is an important policy objective.

Standards decisions should not be based on engineering measures which may favor technologically ideal solutions, imposing a single solution but which may have significant adverse affects on value created and on consumer demands. Variables such as handset/terminal features and data throughput may matter more or less to different consumers.

Competition allows firms to tailor their offerings to consumer needs and preferences, and for a wider variety of service offerings than would be available with a single regulatory mandate about what service should be offered and with which technology. Decisions about band plans, standards, and amount of spectrum needed for economical provision of service is better left to private parties seeking to trade off benefits of additional spectrum costs, with costs of additional capital equipment and the value created from expanding capacity.

E. A spectrally efficient technology need not be the most cost effective.

The most efficient technology need not be the least costly or cost effective at all traffic levels. Indeed, while CDMA may be more efficient in that a single base station can serve more traffic with a given amount of spectrum, many other factors need to be considered in identifying the optimal solution for any particular situation. For instance, CDMA may be a very poor choice of technology, as compared to GSM, for low traffic density and a very good choice where traffic density is high.

The optimal network configuration, number of cell-sites, spacing, etc., depends on a number of variables. At one extreme, with low traffic levels, the spacing between cell-sites needs to be sufficiently dense to ensure coverage. For higher traffic levels, the spacing between cells needs to be reduced so as to allow greater re-use of the frequency. Cellular technology allows the same frequency to be re-used many times. In CDMA, each cell uses the same frequency bands. In GSM and other technologies, the same frequency bands will be re-used in essentially every other sector or cell.

The number of cells required to serve an area will therefore tend to be an increasing function of the traffic. For most traffic levels, CDMA can serve more traffic per cell than can GSM. This does not necessarily mean that CDMA always has a cost advantage, only that fewer CDMA cells may be needed for some traffic levels than would be the case for GSM. A number of variables affect a network's configuration. There are limits, due to potential interference, for how close cells can be spaced. It is our understanding that GSM cells can be spaced more closely together than can CDMA cells. The ability to place GSM cells more closely together would offset some of its efficiency disadvantages relative to CDMA. It is also our understanding that the power levels of the signals can affect the spectrum and cell site capacity. High bandwidth services require higher power levels in the signals. These higher power levels mean that the spacing, both in terms of distance and in terms of frequency, needs to be greater.

F. Band plans should be technology neutral.

The choice of a band plan can be a choice of technology. In particular, allocating frequency in 2 x 5 MHz pairs, from 1710 – 1785 MHz x 1805 – 1880 MHz is a decision in favor of GSM over CDMA. This is unnecessary, and probably unwise. Reserving 1920 – 1980 MHz for WCMDA is similarly unnecessary and possibly unwise. Indeed, WCDMA has, in the four years since the first licenses were awarded in Europe, not yet become established as a commercially successful technology. The fact that spectrum has been allocated for WCDMA does not mean it will succeed. Regulatory fiat to determine standards always runs the risk of choosing a standard that does not work, and delaying the allocation of that spectrum for productive uses. Further, the 1930 – 1980 MHz portion of this band can be used now to relieve spectrum constraints facing rapidly growing CDMA operators.

G. Limitations of spectrum release for future needs and for common use can best be achieved by setting reserve prices.

Not all previous spectrum auctions have generated high prices. Some spectrum auctions have even failed to result in prices that meet opportunity costs of the spectrum remaining in government control. One example is the "wireless communications services" band at 2.3 GHz. In 1997, the U.S. FCC auctioned 30 MHz covering the entire United States for a little less than $14 million.[21] The forecasted value was in excess of $1 billion. To prevent warehousing, and to ensure the government gets a fair price, a floor or reserve price for each band can be set. The floor should not be uniform across bands. Those bands for which equipment is available and which can be used to provide more valuable services, either now or in the foreseeable future should have higher reserve prices.

H. Spectrum caps should be uniform across all technologies used to provide the same set of services

Spectrum caps are generally designed to ensure competition in the market for the services provided using the spectrum. In some countries, such as the United States, spectrum caps were generally abandoned in favor of more traditional methods for limiting market power.

[21] See the WCS auction results at www.fcc.gov/wtb/auctions.

A traditional means of limiting market power would be to assess the impact on market power, on a case-by-case basis, all spectrum acquisitions, whether through secondary transactions, mergers and acquisitions or through direct purchases from the regulatory agency.[22]

When and where spectrum caps are applied to limit market power, several factors should be considered in setting caps those caps.

1. Caps are used to limit concentration of spectrum holdings and not to ensure every firm has the same access to spectrum and technology. Caps on spectrum holdings are one means of limiting market concentration in the market for the services offered using spectrum. One firm may choose a more spectrum efficient technology, and incur higher equipment costs, a second may choose a less efficient technology for which equipment is less costly, and a third may strive to achieve larger market share using both more efficient technology and perhaps additional spectrum. When spectrum holdings are not overly concentrated, market shares should not be either.

2. Some consolidation, that is mergers, is likely. Very few other countries have more then five operators competing, and where there are, consolidation is the rule rather than the exception. Spectrum caps should be permissive up to the limits of desired concentration, so as to facilitate efficiency enhancing mergers. Spectrum caps should be applied in the same manner to mergers as they are to individual firm license acquisitions. Indeed in India, where there may be up to eight operators in a region, some consolidation is to be expected, and is likely desirable.

   It is unusual for a government agency to be so biased toward promoting competition, as appears to be the case in India, at the potential expense of costs and efficiency. Permitting mergers and acquisitions so long as the concentration of spectrum holdings, given the available relevant spectrum, is limited is likely to benefit consumers. The TRAI may want to limit mergers until all relevant spectrum is released, as a firm merging or acquiring a rival in a region so as to acquire more spectrum now still has the possibility of getting spectrum from the government. International standards suggest that any spectrum cap should be set at no less than 30% of the total spectrum available for 2G and 3G services, including both CDMA and GSM. Until WCDMA is widely deployed, the *relevant* market may be the spectrum available for CDMA and GSM, and not the WCDMA spectrum. Mergers among firms operating in different regions are to be expected. There are several reasons for this. On the demand or revenue side, a firm with a larger footprint may be able to offer roaming across a larger area, or on better terms and conditions, than a firm with a smaller footprint. On the cost side, equipment and handset cost and availability can depend on firm size. An operator serving a limited area may not have access to the same equipment or at the same cost as one serving a much larger area. Typically, larger operators are the first to gain access to new handsets, which

[22] Below I discuss spectrum pricing principles. These principles are largely the same whether or not spectrum caps are imposed.

can drive market share. Moreover, there are many fixed costs of operating a network. The more subscribers a firm has, the lower its average fixed costs.

3. Spectrum caps should not be used to limit spectrum available to an operator because the operator might not need the spectrum. An assessment of whether more spectrum or more capital equipment is a more cost effective means of adding to capacity is essentially an economic and financial decision. This is a type of decision that a regulatory authority would have difficulty making without knowing each firm's true cost of capital and tolerance for risk.

4. Spectrum caps can be too restrictive. Spectrum caps should not be so low, even to limit market concentration, so as to result in significantly increased service costs. Setting spectrum caps very low can have a significantly adverse affect on costs.

I. Allow secondary licensing.

To the extent spectrum is being under-utilized, secondary licensing, which grandfathers the rights to those who have the primary licenses, can increase utilization. The FCC adopted this approach for 2G licenses in 1994 with relatively little difficulties. The FCC is now considering introducing a temperature *index* to measure the potential for interference. This type of an approach could free up additional spectrum, such as that adjacent to corDECT, without harming in any way any existing operations. Care should be taken in defining license conditions so as to limit potential for disputes about interference.

J. Spectrum should be allocated in proportion to its marginal value.

In comparing spectrum to be allocated to two operators with different technologies, the decision should be based on the marginal or incremental values of spectrum. If one can create more value per MHz than the other, then it should receive incremental spectrum. Indeed, if one technology is so inefficient that for it the marginal value of spectrum is always less than it is for the other, only the more efficient technology should be allocated any spectrum. AA government regulatory agency has no need to decide on which technology is more worthy of more spectrum, as it can set a price for spectrum and let market forces determine the optimal allocation. However, social welfare, penetration and economic efficiency are all reduced if inefficient operators are rewarded with more spectrum for choosing for inefficient technologies.

K. Spectrum pricing should reflect marginal values. Equivalently, a mechanism for pricing spectrum that approximates pricing in a perfectly competitive market will achieve this result.

Market mechanisms, absent market power and informational asymmetries, tend to result in prices that approximate marginal values. Well-designed auctions for initial allocations and secondary markets assuming secondary trading is possible will tend to result in efficient prices. Regulatory agencies can try to set user fees to approximate market prices and marginal values. However, such efforts are usually both contentious and subject to significant measurement error. Even lotteries for awarding spectrum need not be terribly inefficient if secondary markets are fairly efficient.[23]

Two approaches have been used to set fees for new spectrum licenses. One is to compare the value of the license with what similar licenses have been sold for elsewhere. This method requires there having been auctions or other market transactions for similar licenses in similar types of locations. This may not be practical for India. The other is to develop a cash flow model of the value of the license. This approach can be quite sensitive to assumptions about discount rates, take up rates and terminal values. A third approach to valuing spectrum, which should under competitive conditions result in similar valuations, is to calculate the capex savings of additional spectrum. In an appendix I discuss these approaches in more detail.

L. Spectrum allocation should allow Indian operators to take advantage of equipment availability.

Spectrum allocations should maximize the benefits of equipment availability. Lack of equipment availability can make any spectrum policy ineffective or worse, destructive. Worst of all is locking into a band plan that depends on a standard that may never prove out. There are many such cases, even in very recent experience. Failures include CT2 (in Europe), WCS (in the US), and LMDS and WLL (in both North America and Europe).

For this reason, TRAI and WPC should not delegate CDMA to unusual bands, such as the Korean PCS ones. Doing so will have little impact on congestion in the bands currently used for CDMA. Nor should CDMA be blocked from using any of the spectrum in 1920 – 1980 MHz in the hope that WCDMA may eventually prove to be a valuable technology.

IX. CONCLUSION

India has achieved remarkable growth in wireless communications over the past few years. Key to this growth has been the ability of Indian operators to operate efficiently to achieve the low costs necessary to allow them to offer low price services. However, growth can be limited by spectrum constraints, as well as constraints on technology. If spectrum capacity constraints become effective or spectrum allocations do not permit operators to deploy cost-effective equipment and offer handsets which are widely available and cost-effective, then service offerings will be constrained, prices will rise and growth will slow, if not stop. Experience in other countries, as is indicated by diffusion data, suggests that spectrum constraints have limited development of the wireless communications sector.

To avoid hitting a spectrum wall, it would be prudent to consider allowing use of frequency in the 1900 MHz bands for mobile voice and data services, such as CDMA, as soon as possible. While this can admittedly interfere with subsequent deployment of WCDMA, release of such spectrum will bring benefits sooner. This entire 1900 MHz band need not be allocated now, or, better yet those receiving allocations can be allowed to subsequently swap out older technology in favor of newer technology of their choice.

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[23] The US used lotteries for assigning some AMPS cellular licenses

APPENDIX
Total Surplus, Marginal Valuations and Efficient Allocations of Spectrum

This Appendix describes how to derive total surplus resulting from different spectrum management policy options as well as how to derive optimal spectrum allocations under each option.

A. Measuring total surplus from a spectrum allocation

I have stated above that spectrum should be allocated to maximize economic surplus. Economic surplus can be measured based on supply and demand curves, assuming these are observable. Economic surplus is measured as the sum of consumer and producer surplus.

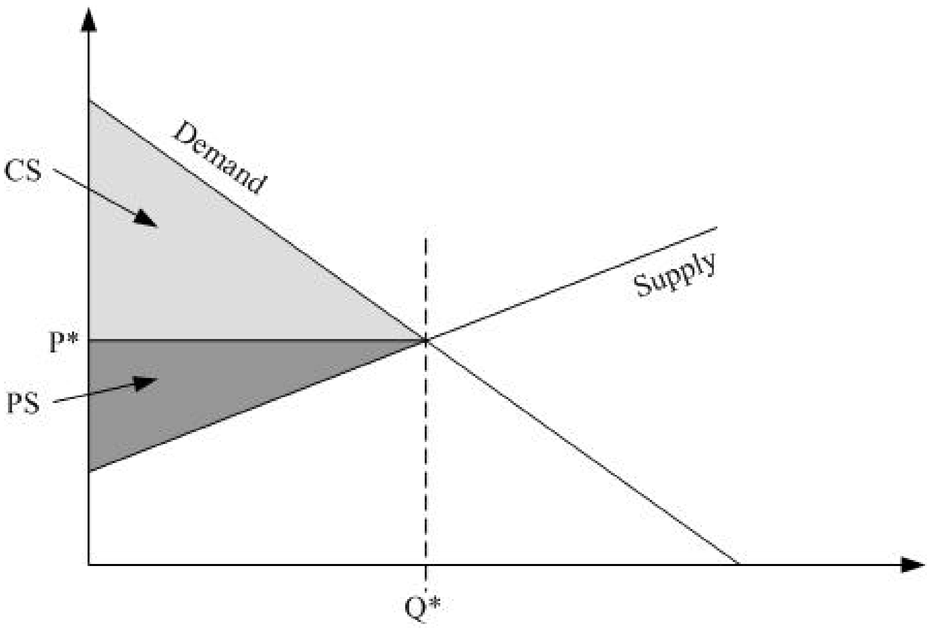

Figure A-1

Economic surplus is defined as the sum of consumer and producer surplus. Figure A-1 above illustrates how consumer surplus (CS) and producer surplus (PS) are measures in a perfectly competitive market. With the price P* and quantity sold Q*, the area CS represent the difference between total value derived and amount paid. The area PS is the different between revenues and variable costs. Although the Indian telecommunications industry is not perfectly competitive, surplus is measured using the same principles. Consumer surplus is still the difference between total value derived and amount paid. However as there may be different prices for different packages offered, this surplus may need to be summed across service offerings and price plans.

We would measure total telecommunications penetration by including both wireless and mobile phones. Historically, teledensity has been measured by dividing the number of access lines by the population. However, for many, wireless service is more affordable and also less costly to provide. Of course, due to the fact that it is easier to disconnect a wireless account, especially with the prevalence of pre-pay service, we would suggest including in a measure of teledensity only those mobile accounts for which there were activity within 90 days of the measurement. The two goals, economic efficiency and teledensity, can, at times conflict. Absent direct government support of universal service programs, economic theory suggests that a competitive market will maximize both teledensity and economic surplus. However, government programs may want to boost teledensity beyond what may be possible absent subsidy.

B. Measuring marginal values of spectrum and determining the optimal allocation of spectrum across operators and technologies.

Measurement of the marginal value of spectrum is not a straightforward exercise in that the value of spectrum is only derived from the value of the services provided using that spectrum. In the case of 2G spectrum, this means wireless voice and data.

The value of the services depends in part on the amount of spectrum each firm has. For instance, the marginal value of the first 10 MHz of spectrum to the first firm in a geographic market is not the same as the first 10 MHz to the second firm to enter the market or the 10th firm. Indeed, past some n, the value of 10 MHz to the nth is likely to be zero.

Many have argued that in many markets the critical value of n ranges between 2 and 5 or 6. More generally, the value of an incremental few MHz of spectrum to one firm, when there are N firms in the market, each having possibly different amounts of spectrum, will depend on the prices and market shares each will gain.

As competition for wireless services is limited to a few operators in any one area, the standard competitive paradigm, in which all firms are price takers and can sell all they want at the market price, is inappropriate. Moreover, customer acquisition costs and churn are not standard parts of any of the existing economic theories of oligopolistic competition. A reasonably complete model of competition among wireless operators would need to take account of subscriber inertia, churn, and customer acquisition costs. Economic theory presents two extreme models, a price competition model, known as the Edgeworth-Bertrand model, and a quantity competition model (or of competition in capacity), known as the Cournot model. Spectrum holdings affect the cost of capacity. In a capacity/Cournot model of competition, a firm with more spectrum would have lower total costs for providing any level of capacity. Note, this does NOT mean that marginal capacity costs are always lower. For instance, once a network provides complete coverage, the cost of converting cells from 360° sectors to 180° or 120° is relatively low. And, it can be the case that an inefficient technology has lower marginal costs over a range of capacity, as the cost of the incremental radio capacity is low, than does a technologically more efficient technology. This suggests that the marginal cost of capacity of GSM can in some places be less and others higher than CDMA even if CDMA is everywhere more efficient. (Mathematically, marginal cost is the derivative of the total cost function.)

(If two firms are competitive price takers, and there are decreasing returns to scale, so that marginal costs are an increasing function of capacity, then the low cost firm will, at equilibrium, construct more capacity. If there are increasing returns to scale, then the low cost firm's expansion will make it increasingly difficult for higher cost rivals to remain competitive. In oligopolistic industries, costs and capacity or quantity need not be correlated.)

The marginal value of CDMA will be higher than GSM when both have no spectrum, independent of market structure, as the amount of spectrum needed to serve a given number of subscribers will be less for CDMA than for GSM. Similarly, if both a GSM and a CDMA network operator are at capacity given each has only built for coverage, then the marginal value of spectrum for the CDMA operator should be higher. This logic suggests that at an optimal allocation, CDMA operators should be allocated more spectrum, invest in more capital and network equipment and serve more subscribers than to GSM operators.

1. Measuring marginal values of spectrum

Economic principles, as we have already discussed, suggests that the main criteria to use for allocating spectrum is marginal value. Measures of marginal value should include incremental consumer surplus as well as producer surplus or profits. Consumer surplus can receive higher weights the more heavily policy wants to favor consumer welfare and penetration goals. Unfortunately, measurement of marginal value of spectrum is not a straightforward exercise.

The value of spectrum is only derived from the value of the services provided using that spectrum. In the case of 2G spectrum, this means wireless voice and data. The value of these services to consumers depends a great deal upon the prices the firms charge for services, which, in turn, depend upon the amount of spectrum each firm has. Moreover, the producer surplus also depends on the amount of spectrum each firm has. This means, for instance, that the marginal value of the first 10 MHz of spectrum to the first firm in a geographic market is not the same as the first 10 MHz to the second firm to enter the market or the 10th firm. Indeed, past some n, the value of 10 MHz to the nth is likely to be zero. Many have argued that in many markets the critical value of n ranges between 2 and 5 or 6.

More generally, the combined value to consumers and producers of an incremental few MHz of spectrum being allocated to any one firm, when there are N firms in the market, each having possibly different amounts of spectrum, will depend on the prices and market shares each will gain. To assess these values then requires some assessment of the prices, market shares and penetration in different scenarios. If this were a perfectly competitive industry, this would not be such a difficult exercise. However, competition for wireless services is limited to a few operators in any one area. Therefore, the standard competitive paradigm, in which all firms are price takers and can sell all they want at the market price, is inappropriate. Moreover, customer acquisition costs and churn are not standard parts of any of the existing economic theories of oligopolistic competition. A reasonably complete model of competition among wireless operators would need to take account of subscriber inertia, churn, and customer acquisition costs. Economic theory presents two extreme models, a price competition model, known as the Edgeworth-Bertrand model, and a quantity competition model (or of competition in capacity), known as the Cournot model.

Rather than try to solve a complete model of the India wireless sector, we focus on alternative approach to measuring value. This alternative has roots both in economic theory, as dual to a direct approach of modeling the competitive market, and also roots in traditional financial and account measures of value. In particular, we develop a measure of spectrum value that is based on the capital expenditure savings provided by the incremental spectrum.

This value will not be one definite amount, but will depend on the amount of capacity (as measured by traffic) being provided. This is because spectrum holdings affect the cost of capacity. With a large target capacity, the marginal value of spectrum can be quite a bit higher than it is when a firm is seeking to provide a lower level of capacity.

There are alternative means of development capacity cost models. As subscriber or traffic density determines network capacity requirements, the cost will depend, in part, on demand or traffic assumptions. Given at least one carrier channel, any network built to cover a region will have a minimum amount of capacity. For example, if with minimal amounts of radio and electronic equipment, a cell can provide X erlangs of capacity or serve Y subscribers, and coverage requires N cells, then the smallest feasible network will essentially provide a capacity of NX erlangs and be able to serve NY subscribers. Note, there will be some incremental call processing costs for each additional subscriber. Therefore, costs as a function of capacity may have parts that are close to flat with periodic jumps.

The above assumes that the capacity per cell is uniform. In most networks, some areas require more capacity per square km than others, and so this is not how costs will necessarily vary in practice across a network.

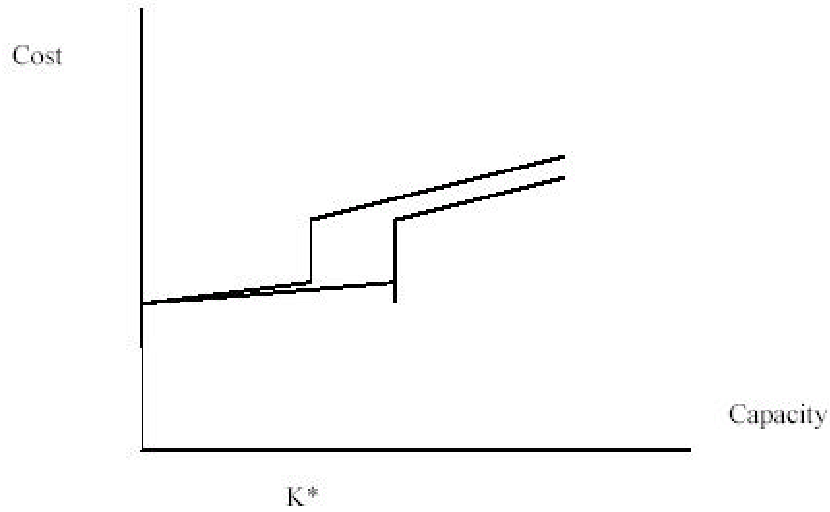

Figure A-2

After the traffic reaches some critical level, K* in the above figure, each cell would need to be split into sectors, and/or additional radio channels used in order to further increase network capacity. After some point, the spectrum would "run out" and the cells would need to be "split". What this means is that cells would be needed to be placed closer together than is necessary to ensure coverage. In practice, this splitting of cells can be accomplished in one of two ways: (1) During the planning stages, the cell-site radius can be planned to match a target capacity. In this case, cost will be a continuous function of capacity. (2) After the network has been constructed, new cells can be added. In this case, cell-site density is unlikely to ever exactly match capacity targets, and the cost function will have further jump discontinuities, as is the case above. Figure A-2, also shows that more spectrum will tend to cause the cost curves to shirt down and to the right. The vertical distance between the two curves represents the incremental value of additional spectrum at any particular capacity level.

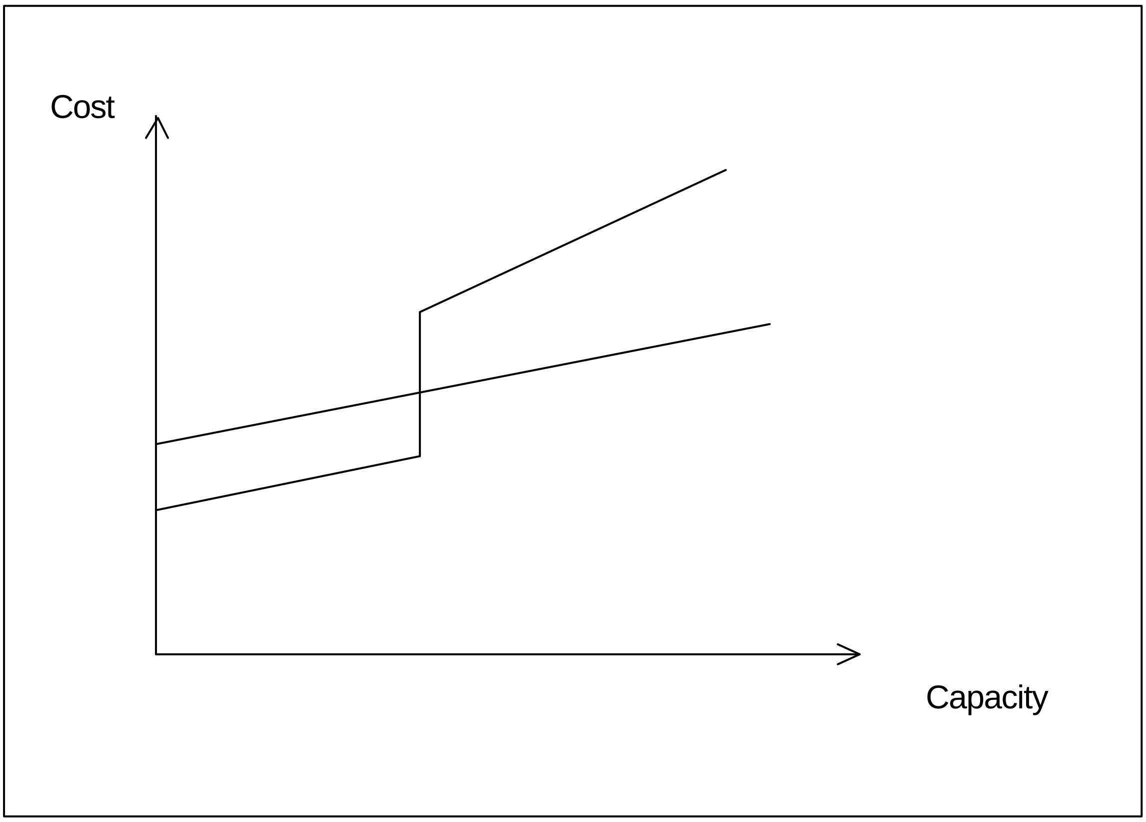

Figure A-3

Figure A-3 compares two technologies. As is shown, one technology is more cost effective at low levels of capacity or traffic and the other for higher levels. This may be the case for GSM and CDMA. An increase in the amount of spectrum available to one would shift the corresponding cost curve down and provide a measure of the value of the spectrum to that network at each capacity level.

This approach to measuring spectrum value has some immediate implications. This approach suggests that the marginal value of CDMA will be higher than GSM when both have no spectrum, independent of market structure, as the amount of spectrum needed to serve a given number of subscribers will be less for CDMA than for GSM. Similarly, if both a GSM and a CDMA network operator are at capacity given each has only built for coverage, then the marginal value of spectrum for the CDMA operator should be higher. This logic suggests that at an optimal allocation, CDMA operators should be allocated more spectrum, invest in more capital and network equipment and serve more subscribers than to GSM operators.

2. How to optimally allocate spectrum among competing operators

This section elaborates on Section V above, more fully describing the optimal conditions for determining how to divide a specific block of spectrum, for example, among wireless operators competing for subscribers. We describe the economic criteria that should be applied, assuming the goal is maximizing social surplus.

The following brief economic analysis of how to optimally allocate frequency between different applications and operators. In particular, we consider the specific problem of allocating frequency between a small set of operators, each possibly having a different technology. We assume a single fixed region, although the analysis extends quite directly to a case in which there are multiple regions and the different operators may be allocated different amounts of spectrum in each.

Each operator will place a value on spectrum depending on how much they have and how much their rivals have. Moreover, the fact that the spectrum may have an alternative use, means that it may not be welfare maximizing to allocate it all to those seeking it for a particular application. In the following figures, we let Ps per MHz denote this opportunity cost of spectrum.

Figure A-4 illustrates how a fixed amount of spectrum should be optimally allocated between two carriers.

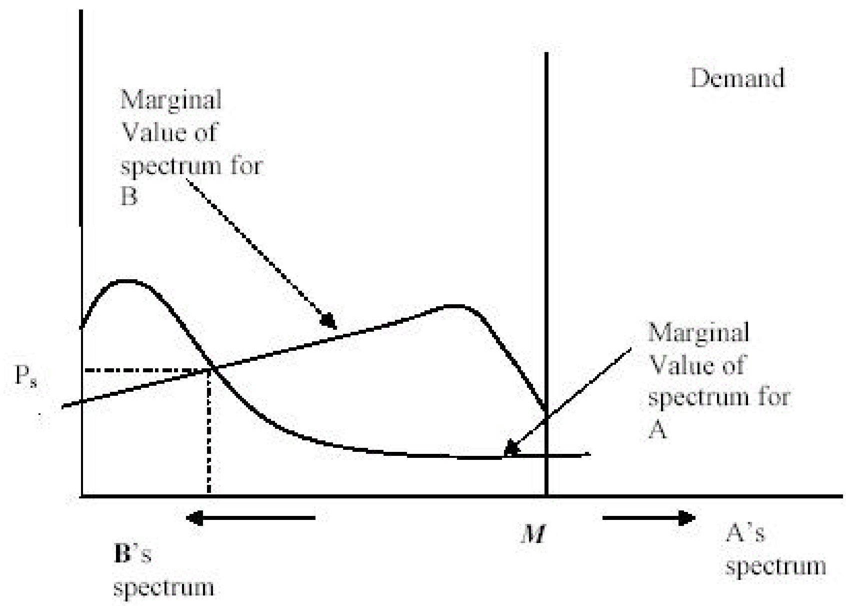

Figure A-4

In Figure A-4, I assume there are M Mhz of spectrum to be divided among two firms, A and B. I have drawn marginal value curves, measuring B's amount of spectrum and marginal value starting from the point labeled M. If one were to solve the following:

Max {Va(Ma, Mb) + Vb(Ma, Mb) : Ma + Mb ¡= M}, where Vj(Mj) is j's value from Mj MHz, the solution would require that the A's marginal value of incremental spectrum, ?Va/?Ma, equal B's marginal value, ?Vb/?Mb.

Note, if either A or B could purchase spectrum at a price Ps, they would each wish to purchase spectrum up to the point at which marginal value just equals price. Less spectrum, assuming diminishing marginal returns, means marginal values exceed price, in which case, profit would increase by purchasing additional spectrum. Conversely, if a firm purchasing more spectrum would find that the incremental value of the last few MHz would be less than the price. Profit maximization requires Ps = ?Va/?Ma = ?Vb/?Ma. But, this is the same condition that holds at an optimal allocation. Therefore, a market solution is likely to result in an optimal division of spectrum among the operators, even without regulatory intervention.

Figure A-3 illustrates how the above analysis generalizes to more firms by showing the optimal allocation of spectrum among three firms. Additional firms can be readily incorporated into the model.

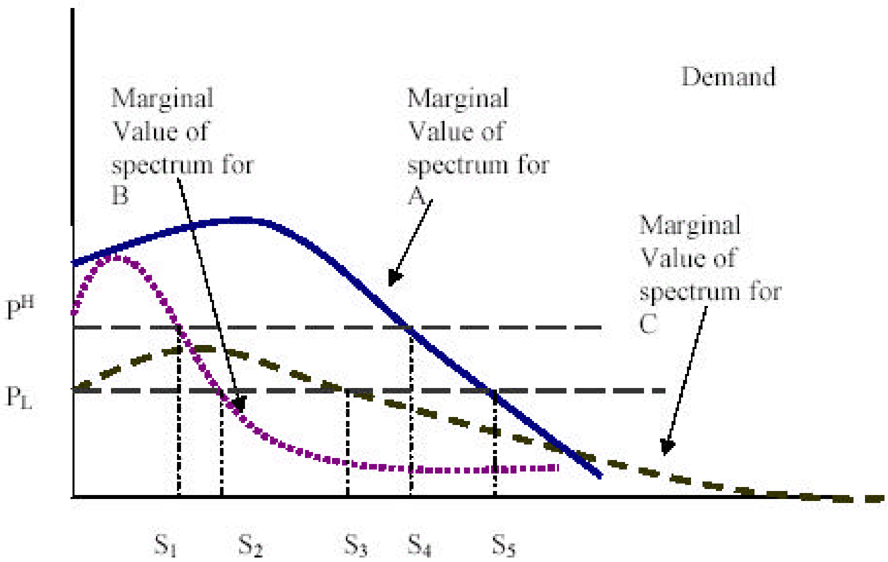

Figure A-5

Figure A-5 depicts the optimal spectrum allocation with three firms and two spectrum prices (or marginal values). When the spectrum is very scarce, so that its opportunity cost, or price, is high, PH, firm A should get S4 MHz, and firm B should receive S1 MHz. Firm C's marginal value of spectrum, even at its maximum, is too low to justify providing it any incremental spectrum. When the spectrum is relatively abundant, so it has a low price or opportunity cost, PL, then A should receive S5 MHz, B should Ss MHz, and S3 MHz. Such an allocation would equate marginal values across the three operators. In Figure A-4, we show the optimal division of spectrum across four firms.

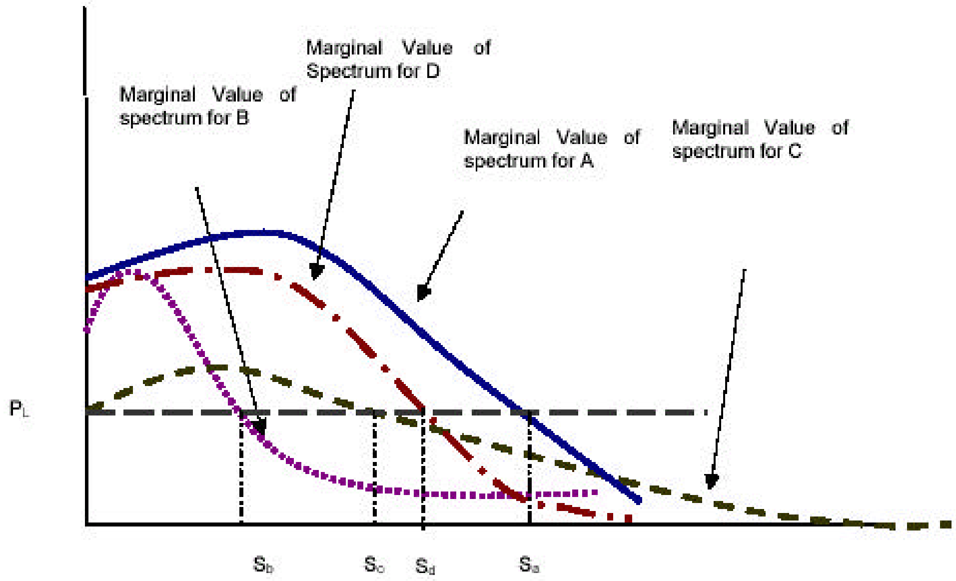

Figure A-6

There are several implications of the above analysis for decisions India will need to make soon about spectrum allocations. First, firms that derive low marginal values should not be allocated spectrum when it is scarce. Second, the amount allocated to any one firm will depend on its marginal value, which, in turn depends on its ability to use spectrum profitably and efficiently. A firm that can serve more customers and generate higher revenues will have a higher marginal value for spectrum, others things equal, than a rival with a less effective technology and business plan. Economic efficiency and public policy considerations both suggest that less efficient firms should receive less spectrum.

Further, over time, the marginal value of additional spectrum changes. With subscriber growth, what may have been adequate at one point, implying low marginal value, may be inadequate at a subsequent point in time. What this means in practice is that the marginal value of spectrum shifts up over time. As it does, the optimal amount of spectrum will increase. The above analysis is limited in that we have not yet characterized the shape of the marginal value curves. In general, a firm with higher marginal values should be allocated more spectrum. However, a more efficient technology may have higher marginal values for all allocations, or only for initial allocations. One way of imputing marginal values is assess relative savings of capital expenditure for a given amount of incremental spectrum.

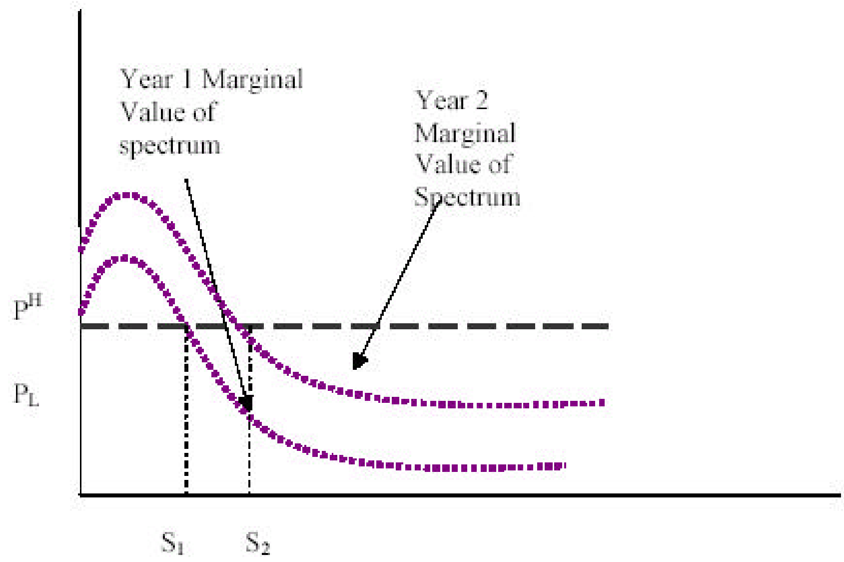

Figure A-7

In Figure A-7, the optimal amount of spectrum for this operator increases from S1 in year 1 to S2 in year 2. This is the result of the increase in the marginal value of spectrum from year 1 to year 2.

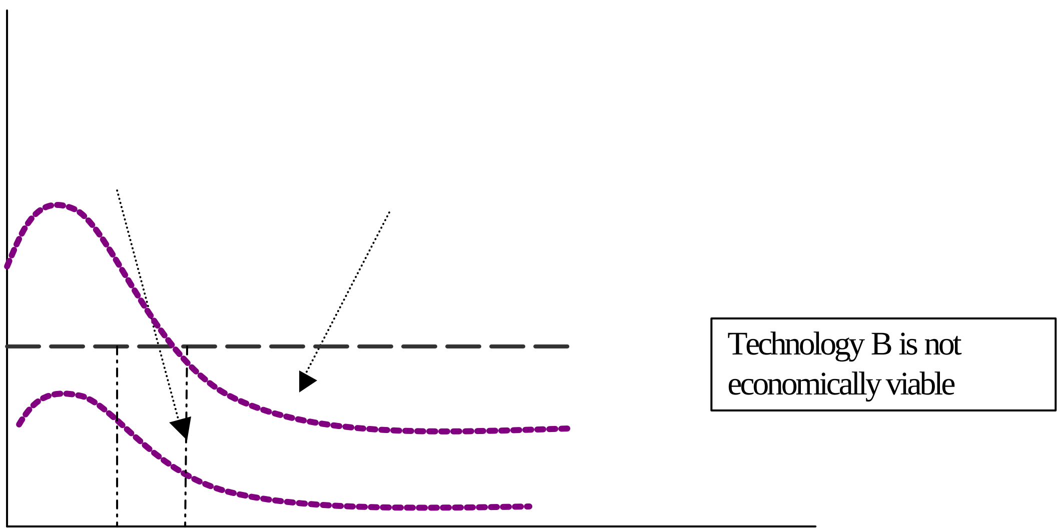

Figure A-8

In Figure A-8, one technology dominates the other. The dominated technology should not receive any spectrum. Over time, new technologies can emerge and force others out of the market.

These are static diagrams. If technology A has an installed base, or wider availability of complementary products, such as handsets, it might not be optimal to shut it down the day technology A appears in the market. However, over time, technology A should see its customer base defect to B, unless the cost of the complementary products (e.g., handsets) is high.

Application of the above analysis to determine optimal spectrum allocation requires detailed information about technology and costs. In what follows, I provide a very brief description of the main cost determinants for wireless voice and data networks, and explain the main differences between GSM and CDMA.

There are three main capital expenditure requirements for both types of networks, central switches, often called mobile switching centers or offices (MSCs), base stations and associated electronics, which are the sites for the antennas and receivers and transmitters, and the backhaul facilities to link the different nodes of the network. The main factors determining the required number of base stations are traffic, coverage, technology and some engineering decisions about how the frequency is re-used.

For low traffic levels, coverage is a constraint on the number of base stations, as a subscriber can only communicate with a base station if the two are not too far apart. In this dimension, CDMA may not have significant advantages over GSM. However, for moderate to high traffic levels, it becomes necessary to re-use spectrum more intensively. What this means is that the required number of base stations will increase only after the traffic in a given area is sufficiently high. Up to that point, there is little incremental base station or back haul cost of increasing capacity. The same is not true of switching costs, which tends to be proportional to traffic levels.

As CDMA tends to provide better capacity for a given amount of frequency, a smaller number of CDMA base stations can serve any given number of subscribers. Therefore, absent cost differences in equipment or handsets, CDMA should provide a given amount of service at a lower cost than does GSM. There are possibly relevant cost and traffic configurations that would give GSM a cost advantage over CDMA, but this would tend to require fairly low traffic levels and lower GSM network costs.