Response to

Consultation Paper
on
Valuation and Reserve Price of Spectrum

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1. **What method should be adopted for refarming of the 900 MHz band so that the TSPs whose licences are expiring in 2014 onwards get adequate spectrum in 900/1800 MHz band for continuity of services provided by them?**

The 900 MHz GSM band is being migrated to 3G/4G technologies in India. The band being migrated is held by two kinds of operators – those whose licenses are coming to a close, and those who still have significant time remaining on their licenses. The Supreme Court has prohibited the reservation of spectrum for refarming, and mandated all of it should be auctioned. However, a proposal was tabled to take back their spectrum for 'refarming' and allocate an equal amount of pectrum suitable for lower technologi es (i.e. 2G) at a market determined price. Let us evaluate the proposal independent of the Supreme Court directive.

The operators are unhappy with the approach on a number of counts. First, they contend that the transition to the new spectrum is costly. Refarming makes the equipment used in previously held frequencies partially unusable. Hence getting an equal number of units in lieu of the spectrum they held is not a fair deal. Second, the replacement spectrum may have lower propagation characteristics, as is the case in the current episode of refarming in India from 900 MHz to 1800 MHz. This increases the cost of the physical infrastructure.

The objections of the operators may not be entirely valid. The ostensible objective of the government in refarming is to ensure continuity of business of the incumbent by guaranteeing a certain amount of spectrum at the market determined price while at the same time migrating spectrum bands to modern technologies. However, there is no obligation upon the government to assure incumbents an equivalent spectral capacity at the time of license renewal. Indeed, even the limited measures toward continuity, while common in spectrum jurisdictions, may be regarded as unnecessary, especially when a number of spectrum bands are available in auctions. The onus of retaining enough spectrum to provide uninterrupted services to subscribers rests with the operator, not the government. The welfare of the subscriber in turn will be ensured by market competition, and the USO fund. The government's responsibility is to the continuation of the service not that of a specific operator.

Reserving a certain amount of lower generation technology spectrum for operators renewing licenses reduces the amount of spectrum that is auctioned, and thereby distorts the determination of the market price. The distortion is further accentuated by the fact that the cost of license renewals depends on the price discovered in the auctions, thereby dampening the bids of affected operators. A more suitable approach would be to take back all spectrum from those whose licenses are expiring and invite them to bid in the auction to acquire the frequencies they need. In a liberalized spectrum regime, these frequencies can be used in any manner by the winning bidders subject to limits of the power of emissions, as in the case of New Zealand and Australia. Alternatively, in a command and control regime, they can be used for the specific technologies stipulated by the government. In case the operator does not want to participate in the auction or loses in the bidding, it has the option of bidding for other spectrum bands in order to service its customers.

The second category of operators, those who have some years remaining in their license should be allowed to change use provided they pay the market determined rates for the spectrum they hold. The argument for continuity has relevance in the case of in-term licenses. Taking back spectrum from such licensees would disturb the stability of the licensing regime.

Operators often argue against refarming practices because they want to retain control over valuable spectral resources on the pretext of continuity of business. The cost of migration to the new spectrum bands is lower than the cost of setting up a new network. Hence in an auction for this particular spectrum band where new operators and incumbents participate, this cost will be factored into the bids, and will be reflected in the market price. In order to maintain their network capacity they can bid for more units of spectrum or choose another spectral band entirely, in line with their business plans.

Overall, refarming continues the old paradigm of command and control in which the government decides the technology to be used in a particular band. Moving to a truly flexible use regime would make refarming irrelevant. This is the goal regulators should strive to attain.

Q.2. In case spectrum is to be "reserved" for such TSPs, should it be restricted to licences expiring in 2014 (metros) or include licences expiring afterwards (LSAs other than metros)?

Answer: Even if spectrum is reserved for licenses expiring in 2014, it should not be reserved for the next tranche of licenses expiring in 2019. If secondary markets are established by that date, those licensees will have enough opportunities to acquire the spectrum they need. Reserving spectrum for them at this stage will dampen the activity on secondary markets and prevent spectrum value from being unlocked for five years.

However this would go against the principle of a level playing field. Hence no spectrum should be reserved for either set of licensees.

Q.3. Is any restriction required to be imposed on the eligibility for participation in the proposed auction?

Answer: Standard restrictions should be imposed to prevent irresponsible bidding.

Q.4. Should India adopt E-GSM band, in view of the diminishing interest in the CDMA services?

Answer: As per my understanding, the Supreme Court has prohibited the reservation of spectrum for refarming, and mandated all of it should be auctioned. For that reason, and in the spirit of liberalization, all 800 MHz spectrum should be auctioned and so should spectrum in the 1900 MHz (extended GSM) band. **If yes,**

a) How much spectrum in the 800 MHz band should be retained for CDMA technology?

b) What are the issues that need to be addressed in the process?

c) What process should be adopted for migration considering the various issues involved?

Q.5. Should roll out obligations for new/existing/renewal/quashed licenses be different? Please give justification in support of your answer.

Answer: There should be no difference.

Q.6. Is there a need to prescribe additional roll-out obligations for a TSP who acquires spectrum in the auction even if it has already fulfilled the prescribed roll-out obligations earlier?

Q.7. What should be the framework for conversion of existing spectrum holdings into liberalised spectrum?

Answer: Liberalized spectrum is spectrum

- allocated through an auction
- usable with any technology for any service
- sharable with other license holders
- tradable and leasable on secondary markets.

The way to move from a situation where spectrum is

- administratively priced
- technology and service specific
- non-sharable
- non-tradable but leasable (in roaming agreements)

is to move to a system where primary issues of spectrum, unencumbered by technology and service restrictions, are conducted via auction, secondary markets for sharing, trading and leasing are encouraged, and all license holders with significant time left on their licenses have an option to move to liberalized spectrum by paying the market determined price.

Q.8. Is it right time to permit spectrum trading in India? If yes, what should be the legal, regulatory and technical framework required for trading?

Answer: Yes. Trading viable if sufficient numbers of market participants exist and the amount of tradable spectrum is balanced to the demand. Trading can be via mutually agreements between the parties or via exchanges. A uniform spectrum usage charge homogenizes the taxes faced by the buyer and the seller and promotes transactions.

The most critical element is allowing sellers who are unable to make use of spectrum to sell it even within their rollout period. Ostensibly they will have all paid a market determined fees for the spectrum they hold. Hence they should be allowed to sell, but only after paying a tax to the government meant to discourage speculative activity in the acquisition of spectrum. The tax should not be so high as to make such transactions infeasible.

Q.9. Would it be appropriate to use prices obtained in the auction of 3G spectrum as the basis for the valuation in 2013? In case the prices obtained in the auction of 3G spectrum are to be used as the basis, what qualifications would be necessary?

Answer: No. The benchmarking of the value of 1800 MHz spectrum to the price discovered in the auction for 2100 MHz spectrum is problematic for a number of reasons. As shown in the TRAI recommendation (TRAI 2012), at present, 3G devices in the 1800 MHz band are far fewer in number than in the 2100 MHz band. Further, voice services will continue to dominate for the next several years and it is plausible that the 1800 MHz band will continue to be used mainly with voice services in the foreseeable future. Finally, while the new blocks available for auction are contiguous, the 1800 MHz band presently held by operators, (for which they will be charged based on the auction prices), suffers from fragmented assignment, compared to that of 2100 MHz band. Their assignment is in chunks of 200 KHz discontinuous spectrum, whereas the assignments in the case of the 2100 MHz band are in chunks of 5 MHz. A fragmented band with a nascent 3G eco-system cannot be treated at par with a harmonized band which has been used for 3G services for a number of years.

On the other hand it is also inappropriate to conclude from present data that the 1800 MHz band will not develop an eco-system matching the 2100 MHz band. On account of the uncertainty, the 1800 MHz spectrum should be auctioned for 10 years only instead of 20 years, and the reserve price for the 1800 MHz auction computed on the assumption that GSM technology will continue to be deployed on it.

The value of spectrum that operators are going to deploy mainly with 2G technology (1800 MHz) differs from 3G prices in two important respects: a. scale: pan-India 3G prices as discovered in 2010 (suitably adjusted for inflation etc.) are 35-40% higher than the value of pan-India 2G spectrum. b. The distribution of 2G values across LSAs is different from the distribution of 3G prices. 2G values are far more uniform across LSAs while 3G values are sharply skewed toward metros and some category A LSAs where 3G demand is expected to be strong. The basis for these statements is a paper co-authored with Prof Rajat Kathuria and accepted for publication by the Journal for Telecommunications Policy, entitled: Divergence between 2G and 3G values in India and Implications for Auction Policy'. Extracts are appended with this response (Appendix 1).

Q.10. Should the value of spectrum for individual LSA be derived in a top-down manner starting with pan-India valuation or should valuation of spectrum for each LSA be done individually?

Answer: No. LSA's differ in several aspects including per capita income, population density, and topography. Given the heterogeneity of LSAs and the many dimensions of this heterogeneity, it would not be appropriate to use a top down approach as the main method of valuation. Valuation should principally rely on a bottom-up approach and may , in addition, carry out some top down estimates, like the one mentioned above. However the worth of such top-down estimates would not be the determination of value as much as the identification of the LSA specific multiples that would bring the top down value close to the bottom up estimates, and what these multiples would indicate about the proclivity of different LSAs for telecom services, in contrast or alignment with the standard socio-economic indicators.

Q.11. Is indexation of 2001 prices of 1800 MHz spectrum an appropriate method for valuing spectrum in 2013? If yes, what is the indexation factor that should be used?

Answer: No. The technologies and market conditions are too different to allow any sensible indexation. The exercise would be highly sensitive to assumptions made.

Q.12. Should the value of spectrum in the areas where spectrum was not sold in the latest auctions of November 2012 and March 2013 be estimated by correlating the sale prices achieved in similar LSAs with known relevant variables? Can multiple regression analysis be used for this purpose?

Answer: This method can be used but some concerns will need to be addressed:

1. Low number of observations available
    a. Can the observations related to the 800 MHz auction be merged with the observations for 1800 MHz given the difference in the spectral efficiencies of the two bands, the different eco-systems and demand?
    b. Sometimes having a very low number of observations can lead to a very high goodness of fit at the cost of the significance of the regression coefficients.
2. Correlation between independent variables may increase the goodness of fit but make the regression coefficients insignificant

Q.13. Should the value of spectrum be assessed on the basis of producer surplus on account of additional spectrum? Please support your response with justification. If you are in favour of this method, please furnish the calculation and relevant data along with results.

Answer: The producer surplus method is a 'discrete' version of the production function method which treats spectrum and BTSs as 'continuous' variable in order to calculate the cost saving on BTSs due to incremental spectrum.

Both the producer surplus and the production function method need to take into account the fact that the cost savings at the margin will not carry through to the entire block of spectrum held. To elaborate, if an additional 1 MHz of spectrum at an initial holding of 6.2 MHz translates into a cost saving equivalent to 1000 BTSs, it does not mean that every MHz of spectrum in the 6.2 MHz block will yield similar cost savings. In fact, in an architecture where the first 3 MHz are reserved for administrative purposes, one needs a minimum 3 MHz of spectrum to start operations. The way to address this issue is elaborated in Q14.

Q.14. Should the value of spectrum in the 1800 MHz band be derived by estimating a production function on the assumption that spectrum and BTS are substitutable resources? Please support your response with justification. If you are in favour of this method, please furnish the calculation and relevant data along with results.

Answer: The production function method computes the opportunity cost of spectrum by estimating the number of BTSs saved by virtue of possessing an additional MHz of spectrum 'at the margin.' This method is called the production function method as the opportunity cost estimation relies upon a 'production function,' that yields the number of subscribers/minutes that can be serviced by any combination of spectrum and BTSs.

The merit of the production function approach is that it is able to evaluate the opportunity cost of spectrum without relying on too many parameters other than the production data. However this approach is less reliable in markets which are very heterogeneous as the estimation of the production parameters may lose statistical validity or the degree of variation explained by the equation estimating the production parameters (the R^2) may become low. Such markets include most Category B and Category C LSAs in India which comprise a few urban agglomerations in the midst of far-flung villages with varying population density.

The challenge of computing the value of spectrum using the production function methodology (even in relatively homogeneous markets) is that a spectrum block is not a homogeneous unit. It consists of two different types of spectrums – the first 3 MHz used for 'administrative purposes', and the rest, with the initial 3 MHz spectrum having 1/3.75 of the capacity, on a per MHz basis, as compared to each incremental unit. Estimating the production function with raw data on spectrum would be inappropriate on account of this heterogeneity. In order to homogenize the data on spectrum we need to convert every block of spectrum into its corresponding quantity of effective spectrum, defined as spectrum beyond 3 MHz. If we fail to do this, given the variation in the holding of spectrum in different data points, we are likely to get a misleading estimate of the per MHz value of the spectrum block of 4.4 MHz. For instance, the presence of a number of data points with holdings of 8 MHz of spectrum, (each of which has 5 MHz of spectrum beyond 3 MHz), would give an overestimate of the per MHz value of 4.4 MHz of spectrum[1].

We convert actual holdings of spectrum into units of effective spectrum as follows: a holding of x MHz consists of 3 MHz with capacity equal to (1/3.75) of the capacity of effective spectrum, and (x-3) MHz of effective spectrum. Hence the total number of units of effective spectrum is given by the following equation

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[1] The estimates where the heterogeneity of spectrum holdings is not taken into account is given later and bears out our intuition.

Number of units of effective spectrum = (3/3.75 + x – 3) MHz = (x – 2.2) MHz

The regressions are carried out with these re-calibrated spectrum holdings.

Please see Appendix 2 for details on the production function method.

Q.15. Apart from the approaches discussed in the foregoing section, is there any alternate approach for valuation of spectrum that you would suggest? Please support your answer with detailed data and methodology.

Answer: The Cash Flow Method determines the price per MHz of a block of spectrum in by determining the Net Present Value (NPV) over the license period of 20 years of the cash flow that an operator would command by virtue of holding a certain block (4.4 MHz/6.2 MHz) of spectrum. The cash flow accruing from the possession of a given block of spectrum is equal to the revenue earned from subscribers less the costs: the sum of the cost of the physical network[2], spectrum charges, the license fees, and administrative, marketing and operating costs, i.e.

Cash Flow = Revenue – (Network Cost + Spectrum Charge + License Fees + Administration, Marketing, & Personnel Cost)

The value of spectrum is computed from the cash flow by factoring in an allowed return on investment (15-20%) on the investment in spectrum. This method is perhaps the most reliable, though not the most elegant, way of arriving at the value of a spectrum block. It relies on a large amount of operational data which is gathered by the TRAI in the normal course.

See Appendix 1 for details on this method.

Q.16. Should the premium to be paid for the 900 MHz and liberalised 800 MHZ spectrum be based on the additional CAPEX and OPEX that would be incurred on a shift from these bands to the 1800 MHz band?

Answer: Yes. In addition the superior eco-systems accompanying these bands must be taken into account. One approach could be to do a cash flow valuation for 2100 MHz based on the experience of operators with 3G and then factor the lower capex and opex required for 900 MHz.

Q.17. Should the valuation of spectrum and fixing of reserve price in the current exercise be restricted to the unsold LSAs in the 1800 MHz band, or should it apply to all LSAs?

Q.18.

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[2] At a first glance it would seem natural to start directly with the average profits earned by firms holding 6.2MHz or even 4.4 MHz. However these profits are not available at a circle level. We therefore have to calculate these profits using data available, or through estimation.

a) Should annual spectrum usage charges be a percentage of AGR or is there a need to adopt some other method for levying spectrum usage charges? If another method is suggested, all details may be furnished.

Answer: A flat usage charge is recommended.

b) In case annual spectrum usage charges are levied as a percentage of AGR, should annual spectrum charges escalate with the amount of spectrum holding, as at present, or should a fixed percentage of AGR be applicable?

Answer: A flat usage charge is recommended as an escalating charge acts as a chilling factor in transactions on the secondary market, where buyers and sellers may have different applicable charges. The usage charge should be low – 1 or 2 % but there may be a need to make it revenue neutral for the government.

c) If your response favours a flat percentage of AGR, what should that percentage be?

Answer: 1 or 2 %

Q.19. What should be the ratio adopted between the reserve price for the auction and the valuation of the spectrum?

Answer: 50% is fair since it controls for the possibility of having overestimated the market value of spectrum. The auction should be designed to be competitive and transparent so that the market value emerges from the bidding process rather than being determined by the reserve price.

Appendix 1: The Divergence between 2G and 3G Prices

The benchmarking of the value of 1800 MHz spectrum to the price discovered in the auction for 2100 MHz spectrum is problematic for a number of reasons. As shown in the TRAI recommendation (TRAI 2012), at present, 3G devices in the 1800 MHz band are far fewer in number than in the 2100 MHz band. Further, voice services will continue to dominate for the next several years and it is plausible that the 1800 MHz band will continue to be used mainly with voice services in the foreseeable future. Finally, while the new blocks available for auction are contiguous, the 1800 MHz band presently held by operators, (for which they will be charged based on the auction prices), suffers from fragmented assignment, compared to that of 2100 MHz band. Their assignment is in chunks of 200 KHz discontinuous spectrum, whereas the assignments in the case of the 2100 MHz band are in chunks of 5 MHz. A fragmented band with a nascent 3G eco-system cannot be treated at par with a harmonized band which has been used for 3G services for a number of years.

On the other hand it is also inappropriate to conclude from present data that the 1800 MHz band will not develop an eco-system matching the 2100 MHz band. Hence, this paper takes the view that, on account of the uncertainty, the 1800 MHz spectrum should be auctioned for 10 years only instead of 20 years, and the reserve price for the 1800 MHz auction computed on the assumption that GSM technology will continue to be deployed on it.

In 2010-11, at a time when the liberalization of spectrum had not been proposed, industry stakeholders had been invited to comment on the relative values of 1800 MHz 2G spectrum and 2100 MHz 3G spectrum. The comments broadly fell into two categories (TRAI 2011): one category of stakeholders held the view that 2100 MHz 3G spectrum was more valuable than 1800 MHz 2G spectrum as it allowed a larger traffic capacity and service and application offerings. The other category of stakeholders argued that 1800 MHz 2G spectrum was more valuable on account of the better developed eco-system, dominance of voice demand in the years ahead, and higher propagation characteristics.

Given the divergent views, a direct estimation of the value of 1800 MHz 2G spectrum is required. This paper addresses the task through an incremental cash flow model[3], and compares the estimates arrived upon with the

[3] Other methods to estimate the value could be used. One such method is the 'opportunity cost' method which has been used in the Administered Incentive Pricing (AIP) schemes in the United Kingdom (Cave et al 2007).

2100 MHz auction determined prices. Henceforth the term 1800 MHz spectrum is assumed to mean 1800 GSM spectrum and the term 2100 MHz is used to mean 2100 MHz 3G spectrum.

1. Estimated Value of 1800 MHz Spectrum

The price per MHz of a block of contracted spectrum is computed for every LSA by determining the Net Present Value (NPV) over the license period of 20 years of the cash flow that a mature operator in March 2010 would command by virtue of holding the corresponding block of spectrum. A 20 year license period is chosen even though a recommendation to reduce the duration of spectrum holding to 10 years is made, in order to compare with the price of 2100 MHz spectrum revealed in the 2010 auction. The sample calculation for Maharashtra is shown below.

1.1. Contracted Spectrum

The cash flow accruing from the possession of a given block of spectrum is equal to the revenue earned from subscribers less the costs: the sum of the spectrum charges, the license fees, the cost of the physical network[4], and administrative, marketing and personnel costs, i.e.

Cash Flow = Revenue – (License Fees + Spectrum Charge + Network Cost + Administration, Marketing, & Personnel Cost) (2)

The details of the method using the Maharashtra circle are now presented as an illustration.

Sample Set of Operators: In our analysis in order to estimate the value of spectrum held by a mature operator, data from GSM operators who have acquired spectrum in a circle on or before 2006 is taken. In Maharashtra, we take Airtel, Vodafone and Idea into consideration for our calculation. In the exposition all totals at a circle level should be taken to mean totals with respect to the sample set of operators unless otherwise mentioned.

For revenue, it is not possible to use actual data to arrive at the revenue figure for a representative firm because the Adjusted Gross Revenue (AGR) data at a circle level aggregates wireless and wireline access services. In our model, revenue is equal to the product of the number of wireless subscribers and the Average Revenue per User (ARPU) per annum[5].

Assuming that operators at 6.2 MHz can command a subscriber base proportional to the amount of spectrum they hold, the fair share of subscribers is equal to the proportion of spectrum held (6.2 MHz divided by the total

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[4] At a first glance it would seem natural to start directly with the average profits earned by firms holding 6.2MHz or even 4.4 MHz. However these profits are not available at a circle level. We therefore have to calculate these profits using data available, or through estimation.

[5] This only looks at the mobile revenues.

spectrum assigned to the sample operators in that circle) multiplied by the total number of subscribers of the sample operators in that circle[6]. We take the number of subscribers and the spectrum allocated in the year 2010 as the base for calculation of the fair share.

In Maharashtra the total subscriber base is 21.2 million, and the total spectrum held is 26 MHz. Thus the fair share of subscribers of a representative operator with 6.2 MHz is 5.06 million. The ARPU is Rs. 161. Hence the annual revenue is Rs. 976.7 crores.

Physical Network: The cost of the physical network is equal to the cost of the BTSs and associated towers and the cost of the core network, which includes transmission and switching. The cost of the BTSs is equal to the number of BTSs multiplied by the cost per BTS, including the rental and electricity costs associated with the physical infrastructure, while factoring the incidence of tower sharing observed in the market.

Our aim is to estimate the average number of BTSs held by an operator with 6.2 MHz. If at least two operators in a circle with 6.2 MHz or below are not present, we take the BTS-spectrum ratio of the sample operators as a whole and fix the BTSs for our representative operator in a proportional fashion. If we do have two or more operators with 6.2 MHz or below we take their BTS-spectrum ratio alone in our calculations. From the data at an all India level there appears to be no correlation between the BTS-spectrum ratio and the quantity of spectrum held so a simple pro-ration where necessary appears to be justifiable. In Maharashtra the average number of BTSs obtained from such a calculation is 5256.

The cost of the BTS provided by TRAI is presented in Table 6.

(table 6 here)

The cost of the core network, as provided by industry sources, is around Rs. 500 per subscriber[7]. Amortizing this over 20 years at 11%, we get an annual cost of Rs. 53 per subscriber. Multiplying this by the number of subscribers we get the annual cost of the core network.

The total cost of the physical network in Maharashtra is thus Rs. 376.03 crores.

License Fees, Spectrum Charges: We compute spectrum charges and license fees according to the figures given in

6 We remove the public sector operators from the total spectrum held, as well as from the total subscribers serviced since their operations may not always reflect pure commercial considerations.

7 The results are not very sensitive to changes in this rate. Doubling the cost reduces the pan India value by 10%, halving it increases the pan-India value by 6%. This is because the cost is amortized over twenty years.

Tables 4 and 5 respectively.

The license fee is computed from the license fee percentage and the corresponding revenues; the spectrum charge is calculated from the spectrum charge percentage and the corresponding revenues; and these are deducted from the total revenue. The total levy, i.e., license fees and spectrum charges, in Maharashtra in Year 1 comes to 12%, i.e., 9% for license fees and 3% for spectrum charges. Applied on revenue of Rs. 976.7 crores, the absolute levy equals Rs. 126.9 crores.

Administration, marketing and operating costs: The total administration, marketing and operating costs of operators as a percentage of AGR as presented in the accounting separation statements submitted by operators to TRAI as per statutory disclosure vary from 22% to 30%. The percentage is lower for operators with higher number of subscribers reflecting economies of scale. We take the percentage as 28% for small operators, those with 6.2 MHz, and 22% for larger operators. As an operator holding 6.2 MHz, our representative firm in Maharashtra incurs a cost of 28% of AGR amounting to Rs. 273.47 crores. Deducting the cost of the network, the license fees, spectrum charges, and general, marketing, and personnel costs from the AGR gives us the cash flow accruing from holding a 6.2 MHz block of spectrum in Year 1. In Maharashtra this comes to Rs. 200.22 crores. The NPV over 20 years at 11%, the weighted average cost of capital suggested by TRAI in its May 2010 recommendation (TRAI 2010a) gives the value of 6.2 MHz. This is Rs. 1594.39 crores.

The price charged to the operator must allow a reasonable rate of return on their investment, i.e. on the price they pay for the spectrum. We fix the rate of return at 20%[8]. The value of spectrum less the NPV of the annual return, i.e. 20% of the price, over 20 years gives the price for 6.2 MHz for 20 years, i.e.

Price = Value - NPV over 20 years of (Price*20%)   (3)

The above equation allows us to compute the price of the spectrum. In Maharashtra this comes to Rs. 807.73 crores for 6.2 MHz for 20 years. The price per MHz for 20 years is thus Rs. 130.28 crores. This price represents the weighted average of the price of 900 MHz and 1800 MHz spectrums where the weights are the proportions of 900 MHz and 1800 MHz spectrums being used in the circle in question, and where the price of 900 MHz spectrum is 2 times the price of 1800 MHz spectrum as per the TRAI recommendation (TRAI 2012).

% of 900 MHz*(price of 1800MHz*2) + (% of 1800 MHz)*price of 1800 MHz = Weighted average of price of 900 MHz and 1800 MHz   (4)

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[8] Given the long period over which profit is discounted changing the rate of return makes little difference to the results.

From this equation, knowing the % of 900 MHz and 1800 MHz, and the weighted average of the price of 900 MHz and 1800 MHz (derived above), we extract the price of contracted spectrum in the 1800 MHz range. This comes to Rs. 82.53 crores. The price for durations smaller than 20 years can be computed by simple pro-ration. See Table 8 for the sample calculation for contracted spectrum for Maharashtra.

The price of contracted spectrum in a Category C circle is derived indirectly as reliable data for Category C circles is not available. The price is set equal to the price of 3G spectrum in that circle multiplied by the ratio of the price of contracted 2G spectrum to the price of 3G spectrum in Category B circles as a whole (0.94). Our method results in the following prices for contracted spectrum at an all India level (see Table 7).

(table 7 here)

2. The Values of 1800 MHz and 2100 MHz Spectrums

In 2010, the government auctioned spectrum blocks of 2 × 5 MHz each to 4-5 operators in each LSA for the provisioning of 3G services. It was not possible to specify a uniform spectrum usage charge for 3G spectrum alone due to the near-impossibility of segregating 2G and 3G revenue. Therefore operators were to pay at 3%, or their current spectrum usage charge (computed on the basis of their 2G spectrum holding), whichever was higher. The annual spectrum charges for operators holding both 2G and 3G spectrum are given in column 3 of Table 4.

The value of 3G spectrum revealed in the auction is given in Table 11.

(table 11 here)

There appears to be significant differences in the values of 2G and 3G spectrums. These can be divided into scale differences and differences in the distribution of value across circles. The value of contracted 2G spectrum at a pan-India level is 38.7 % of the value of 3G spectrum while that of incremental 2G spectrum at a pan-India level is 70% of the value of 3G spectrum. Thus 2G spectrum spectrum appears to have lower value than 3G spectrum. However in a few category B circles like UP (East) contracted and incremental spectrums are more valuable than 3G spectrum.

Abstracting away from scale effects, the distribution of the value of 1800 MHz spectrum across circles appears to differ systematically from the distribution of the value of 2100 MHz spectrum. The correlation coefficient of the values of contracted 1800 MHz spectrum and 2100 MHz spectrum is 0.63 while the correlation coefficient of incremental 1800 MHz spectrum and 2100 MHz spectrum is 0.51. Scaling up the value of contracted and incremental spectrum so that they become equal to the value of 2100 MHz spectrum on a pan-India basis, it is seen that 2100 MHz spectrum is far more valuable in metros, equally valuable in Category A circles and less valuable in Category B and Category C circles. The conclusions for Category C circles must be presented with the caveat that the estimated values have been indirectly derived.

The divergence of 2G and 3G prices can be seen as indicating the inclusiveness of 2G voice services that are being taken up across the length and breadth of the country. While rural tele-density is still only 34%, a large proportion of rural households possess at least one mobile phone. On the other hand, the uptake of 3G connections is expected to be low and skewed toward urban areas.

At present, most of the data used in India is delivered wirelessly. TRAI (TRAI 2010b) states that there were about 1.8 million data card subscribers at the end of September 2010, whose advertised speed was up to 3.1 Mbps. There were also 274.05 million wireless data subscribers who were able to use the Internet (at limited speeds) from their mobile device. More than 75% of these connections are in the top 30 cities. In contrast, rural areas alone constitute 31% of the total number of mobile phone subscriptions in the country.

The divergence in our estimates and the price of 2100 MHz spectrum discovered in the auction makes the flaw in the TRAI recommendation apparent. A new approach to the design of the auction is outlined below.

3. Conclusion

The design of the 1800 MHz auction needs to be cognizant of the nascent stage of the 3G eco-system in 1800 MHz, the differences in the valuations of new entrants and incumbents, the implications of the choice of the reserve price on the auctions of the other spectrum blocks, and the scheme adopted for the refarming of spectrum. The concern remains that the 1800 MHz auction has ramifications far beyond the narrow sphere of the bidding for the spectrum that is put on the block. For instance, the final price is to be used to charge incumbents for the spectrum they hold. This makes the considerations of bidders complicated. Under the circumstances the final price may not reflect the true value of 1800 MHz spectrum and thus may not be a suitable measure of the charge to be levied on incumbents. The discussion of this conceptually involved issue is an open problem that lies outside the scope of this paper.

Table 6: Cost of BTS in Rs.

Amortization period in years	20.00
Capital expense per BTS	6,00,000.00
Rate of interest	0.10
Amortized capex	64,068.89
Electricity and rental per year	6,00,000.00
Total cost per year	6,64,068.89

Source: TRAI 2011

Table 7: Price of contracted spectrum 1800 MHz
Rs. Crore per MHz 2010 (20 year license)

Service Area	**Price of contracted spectrum**	
Metro	% of 900 MHz spectrum	Price of 1800 Mhz spectrum
Delhi	57.1	109.81
Mumbai	54.8	74.71
Kolkata	49.3	37.25
Category A		0.00
Maharashtra	57.9	82.53
Gujarat	63.1	107.41
Andhra Pradesh	57.9	110.12
Karnataka	57.9	98.14
Tamil Nadu	56.6	136.26
Category B		0.00
Kerala	60.78	55.03
Punjab	71.56	53.64
Haryana	66.67	9.46
Uttar Pradesh (West)	60.78	43.40
Uttar Pradesh (East)	57.41	116.45
Rajasthan	60.19	79.77
Madhya Pradesh	55.86	66.24
West Bengal, Andaman & Nicobar	57.39	32.31
Category C		
Himachal Pradesh	58.49	6.97
Bihar	57.41	38.07
Orissa	66.67	18.15
Assam	66.67	7.76
North East	78.57	7.91
Jammu & Kashmir	100.00	5.67

Source: Authors' estimates

Table 11: **Price of 3G Spectrum per MHz (Rs. crores per Mhz)**

Service Area	Price of 2100 MHz Spectrum
Delhi	663.386
Mumbai	649.414
Kolkata	108.852
Chennai	
Andhra Pradesh	274.628
Gujarat	215.212
Karnataka	315.982
Maharashtra	251.564
Tamil Nadu	292.988
Haryana	44.516
Kerala	62.496
MP	51.672
Punjab	64.402
West Bengal & A&N	24.726
Rajasthan	64.206
UP W	102.808
UP E	72.914

Assam	8.296
HP	7.446
Orissa	19.396
NE	8.46
J&K	6.06
Bihar	40.692

Source: TRAI 2012

Appendix 2: Estimating the Value of Spectrum Using the Production Function Method

In the production function method the value of spectrum is determined by the value of the physical infrastructure that 1 MHz of spectrum can substitute at the margin. This is akin to the Administered Incentive Pricing (AIP) schemes in the United Kingdom (Cave et al 2007). In order to compute this value we need to determine the relation between the quantity of spectrum and physical infrastructure used and the level of output of services, i.e. the production function of mobile services.

The production functi on approach relies on specification of a functional form. The Cobb-Douglas function is widely used to estimate the statistical relationship between inputs and output. The production function is specified as follows:

$$X = Ay^{b} z^{g} \text{ .... (5)}$$

where the dependent variable X refers to mobile subscriber base, which is a proxy for minutes of use (MoU). The two factor inputs considered as the independent variables are: (i) allocated amount of spectrum that provides the required channel capacity for traffic (y) and (ii) deployed infrastructure such as Base Transceiver Stations BTS (z) which provide connectivity to mobile handsets. The beta (ß) and gamma (?) values reflect the percentage change in subscriber base for a unit percentage increase in spectrum and BTS respectively and are the parameters to be estimated, besides A, which captures the magnitude of technical change. The major strengths of the Cobb-Douglas production function are its ease of use and its seemingly good empirical fit across many data sets.[9]

Our specification assumes that the two inputs i.e., spectrum and BTS can be substituted for each other over a certain range of output to service subscribers. The assumption of profit maximization implies that service providers will use an optimal mix of BTS and spectrum and that this optimal mix is determined by input prices. A higher charge for spectrum will induce service providers to substitute the less expensive BTS for spectrum to service the same subscriber base. The converse is also true.

A standard procedure to estimate the production function is to linearize it by taking logs on both sides. Thus (1) can be expressed as:

$$\ln X = \ln A + b \ln y + g \ln z \text{ ....} \qquad (6)$$

ß and ? measure the responsiveness of output to changes in levels of spectrum and BTSs respectively keeping the other input constant and are estimated using data for subscribers, BTSs and amount of spectrum held by mature operators across the different categories of circles (the data that we use is described subsequently). For example, if ß = 1.15, a 1% increase in spectrum would lead to approximately a 1.15% increase in the number of subscribers while maintaining the same number of BTSs. The estimated parameters of the production function are eventually used to derive the value of the 2G spectrum relying on the substitutability between BTSs and spectrum. If the service provider

[9] Eric Miller, An Assessment of CES and Cobb-Douglas Production Functions, Congressional Budget Office June 2008

were to give up 1 unit of spectrum, he would need additional BTSs to be able to serve the same subscriber base. Since the price of BTSs is known, the value of the 2G spectrum can be derived as an opportunity cost i.e. the savings in cost in terms of BTSs conserved by deploying an additional unit of spectrum.

The mathematics for the calculation makes use of the principle that at the optimum a service provider will allocate expenditure between the two inputs in such a manner that they yield the same marginal productivity per rupee spent[10]. The condition for optimality accordingly is given by

$$\frac{MP_y}{P_Y} = \frac{MP_z}{P_Z} \text{ .... (7)}$$

where MP_y is the marginal productivity of spectrum and MP_z is the marginal productivity of BTSs. Deriving the marginal productivities from the functional form of the production function,

$$MP_y = \frac{bAy^B z^r}{y} \text{ .... (8)}$$

$$MP_z = \frac{gAy^b z^r}{z} \text{ .... (9)}$$

the value of spectrum, denoted by P_y, is derived as follows:

$$P_y = \frac{bz}{gy} P_z \text{ .... (10)}$$

In Equation 10, P_z is the known price of a BTS, z is the number of BTSs deployed by the representative service provider holding 6.2 MHz and therefore known, y is the amount of spectrum held (6.2 MHz) and ß and ? are estimated coefficients of the production function. The only unknown therefore is the price of spectrum which is calculated based on a combination of actual data and estimated coefficients of the production function.

A panel data set consisting of 5 Category A circles for different GSM operators over the period 2007-10 has been used in the model. As in the case of the cash flow method, we do not include the public sector operators in the sample because of their high spectrum allocation and unique operating constraints. We believe that this increases the reliability of the estimates in every circle. Finally, only mature operators i.e., those who have been in the market for at least 4-5 years are considered. Newer entrants are likely to focus on customer acquisition and network coverage making their BTS-spectrum trade off very different from that of established operators.

Before carrying out the regression it is important to recall a technical attribute of spectrum which asserts that the load carrying capacity of every MHz beyond 3MHz is about **3.75 times** the load carrying capacity of each MHz up to 3MHz. In order to homogenize the data on spectrum we need to convert

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[10] This is, in fact, the solution to the firms' maximization problem in the face of a budget constraint. See for example Hal Varian, Microeconomic Analysis.

every block of spectrum into its corresponding quantity of effective spectrum, defined as spectrum beyond 3 MHz. If we fail to do this, given the variation in the holding of spectrum in different data points, we are likely to get a misleading estimate of the per MHz value of the spectrum block of 4.4 MHz. For instance, the presence of a number of data points with holdings of 8 MHz of spectrum, (each of which has 5 MHz of spectrum beyond 3 MHz), would give an overestimate of the per MHz value of 4.4 MHz of spectrum[11].

We convert actual holdings of spectrum into units of effective spectrum as follows: a holding of x MHz consists of 3 MHz with capacity equal to (1/3.75) of the capacity of effective spectrum, and (x-3) MHz of effective spectrum. Hence the total number of units of effective spectrum is given by the following equation

Number of units of effective spectrum = (3/3.75 + x – 3) MHz = (x – 2.2) MHz

The regressions are carried out with these re-calibrated spectrum holdings.

[11] The estimates where the heterogeneity of spectrum holdings is not taken into account is given later and bears out our intuition.