The value of 1800MHz spectrum in India: a submission to the TRAI

A report for Vodafone

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20 August 2013

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1 Summary

The Telecom Regulatory Authority of India (TRAI) has issued a Consultation Paper titled "Valuation and Reserve Price of Spectrum"[1] (the Consultation Paper) which focuses on valuation of spectrum in the 800MHz, 900MHz and 1800MHz bands. At Vodafone's request Plum has evaluated the various approaches to spectrum valuation proposed in the TRAI's paper. We have replicated and expanded upon two of the approaches – econometric analysis and producer surplus modelling. We find that, although both approaches have shortcomings, they produce consistently lower values per MHz for Delhi, Mumbai and Karnataka.

Plum Consulting has advised regulators and operators on spectrum valuation, pricing and setting reserve prices in Australia, Canada, Hong Kong, India, Ireland, Qatar, Singapore, Portugal, Taiwan and the UK. Many of our studies have been published. The project team was led by Phillipa Marks, a Partner at Plum. Phillipa Marks is an economist who is an expert in the application of market mechanisms to the management of radio spectrum. She advised the New Zealand government on creating the first ever national market in spectrum in 1989, and since then has developed the approach to spectrum pricing now applied in the UK, and advised regulators in many countries on auctions, pricing and trading issues (e.g. Australia, Canada, Hong Kong, Ireland, Singapore, the UK). She is a member of the Ofcom Spectrum Advisory Board and Comreg's Electronic Communications Expert Advisory Panel.

1.1 Scope of this study

Vodafone asked Plum to address Questions 9-13 in the TRAI's consultation which concern different approaches to the valuation of 1800MHz spectrum. Our work involved:

- Assessing the relative pros and cons of the five approaches proposed by the TRAI. This is given in Section 2.
- Reviewing the econometrics undertaken by TRAI. This involved seeking to replicate the TRAI's econometrics and range of outcomes and testing the robustness of the results to the use of different functional forms or independent variables in the modelling. The results of this work are given in Section 3.
- Estimating the value of additional 1800MHz spectrum using the 'producer surplus' approach. This involved building a spreadsheet model that estimates the change in network costs for a typical large operator when the quantity of 1800MHz spectrum available is changed and estimating values based on market, technology and spectrum supply scenarios for the duration of a 20 year license. The results of this work are given in Section 4.

As far as possible we have used data published by the TRAI and other Indian authorities as inputs to our modelling. However, relevant data did not exist in many cases and we have used a mix of other published sources (e.g. for subscriber forecasts), data supplied by Vodafone and our sector knowledge.

Starting with whether a top down or bottom-up valuation approach should be used, we are firmly of the view that a bottom-up approach is superior. Evidence provided by the TRAI (para 3.32 of the Consultation Paper) and the correlation and econometric analysis given in Section 3 of this report

[1] Consultation Paper on Valuation and Reserve price of Spectrum, TRAI consultation paper No. 06/2013, 23 July 2013

show that there are multiple drivers of spectrum value in each LSA and their relative importance cannot be known without statistical analysis of historic data.

The TRAI proposes three benchmarking approaches to spectrum valuation (the use of 3G auction prices, the use of 2001 1800 MHz prices, econometric analysis) and two bottom-up approaches (the producer surplus approach and the production function approach). These are discussed below and we conclude that econometric analysis and the producer surplus approach are the two most promising valuation methods. We therefore use these methods to estimate spectrum value.

1.2 Benchmark against 3G auction prices

This involves using prices obtained in the auction of 3G spectrum in 2010 as the basis for valuation in 2013. We believe this approach does not provide a good “like for like” comparison with the mobile market and general economic situation today.

1.3 Benchmark against 2001 1800 MHz prices

This involves indexing prices obtained in the 2001 1800MHz auction. We agree with the TRAI that this approach does not provide a good “like for like” comparison with the mobile market and general economic situation today.

1.4 Econometric analysis

Undertake econometric analysis of the 2012 1800MHz auction prices to determine value in the areas where spectrum was unsold. We argue that the approach of using econometric (multivariate regression) analysis to estimate spectrum values does have merit. Econometric analysis provides an objective way of controlling for market and economic factors, and therefore offers a more promising way forward than simply taking values from other auctions. Moreover, it does not rely on, say, Delhi or Mumbai being directly comparable to other LSAs – instead, it uses the estimated relationships between observed spectrum prices and the explanatory factors (e.g. economic/demographic factors) to predict a value for Delhi or Mumbai based on their own economic and demographic circumstances.

The TRAI has not published the dataset it used for its econometric analysis, so we started by compiling a dataset which replicates as closely as possible that used by the TRAI. Where possible we have used data from the TRAI Consultation Paper and official government sources. In some cases we have had to adjust state-level data (e.g. population and GDP data) to match the LSAs.

We first sought to replicate the correlation and multivariate regression analysis undertaken by the TRAI. For the correlation analysis our results are almost all within 20% of the TRAI’s, with the exception of the results obtained from correlations with residual teledensity in Delhi. For the multivariate analysis we again obtained results that were generally similar to those reported by the TRAI but not the same. While this may be caused by differences in the dataset used, we are concerned that we are unable to exactly match the TRAI’s results for the AGR correlation, despite using TRAI data from the Consultation Paper[2]. There needs to be more transparency in the data used by the TRAI and its analysis to give confidence in its results.

Generally, there are limitations to using simple single-variable correlations to predict a value per MHz for the four LSAs - it does not account for the effects of any other factors on the value per MHz. The TRAI partially compensates for this by narrowing the sample by the LSA category. However, this means that the results for Delhi, Mumbai and Karnataka are based on a sample of five data points, while that of Rajasthan is based on a sample of seven. With such small samples it is difficult to have a great deal of confidence in the results. Hence we suggest that the results from single variable correlations are not used to set reserve prices.

In respect of the TRAI's multivariate regressions we find there are potential issues of omitted variable bias and collinearity. To address the former we test/include some additional explanatory variables in our model (e.g. urbanisation, existing spectrum allocation, unsold spectrum). To address the latter we use price per MHz per person as our dependent variable, in line with other econometric studies of this kind[3], and exclude variables likely to be highly collinear. The results are summarized in Table 3-10.

Table 1-1: Predicted values/2x1 MHz from Plum regression analysis

Specification†	Estimated value/2x1 MHz (Rs. crore) (1)	(2)	(3)	(4)	(5)	Reserve price (March 2013)
Delhi	70.2	127.8	125.1	103.1	122.4	388.1
Mumbai	41.6	110.8	107.1	73.7	84.4	379.9
Karnataka	122.1	131.5	126.6	131.8	105.4	184.9
Rajasthan[4]	49.8	51.9	54.4	50.1	17.1	37.6

†For details of each model specification, refer to Section 3.

The results show consistency in that all of our regression models predict that the market price of spectrum in Delhi, Mumbai and Karnataka is significantly below the previous reserve prices – values in Delhi and Mumbai being less than half the 2013 reserve price. Furthermore, the estimated values are likely to have an upward bias. This is because they are derived from the results of the November 2012 auction in which there was unsold spectrum in all circles except Bihar and so no market clearing price was established in 21 circles.

There are limitations to using multivariate regression analysis, particularly given the small dataset available, however we consider that it provides useful results that can be used in combination with other benchmarks and value estimates to derive reserve prices for 1800MHz spectrum.

[2] Furthermore, we would be interested to know how the TRAI has achieved almost exactly the same value per MHz for Delhi and Mumbai, despite there being a 10% difference in AGR between these two circles.

[3] See Appendix A for details of these studies

[4] Note that the values for Rajasthan have been adjusted to account for the fact that 39% of the population is not covered by the spectrum on offer.

1.5 Producer surplus approach

We estimate the 'producer surplus' value based on the infrastructure cost savings from having additional spectrum. The producer surplus approach has been used by a number of regulators to determine spectrum value (e.g. in Australia, Hong Kong, New Zealand, the UK). It is preferable to the production function approach as it is based on actual network deployments. However, we find there are issues in its application to India.

The producer surplus values we obtained for Delhi and Mumbai are low and are significantly below the November 2012 and March 2013 auction reserve prices. We obtain disproportionately large values for rural areas in most circles, and in particular in Rajasthan because of the (assumed) growing take-up and use of 2G services in rural areas. The estimated value for Rajasthan greatly exceeds the November 2012 auction reserve price which means that the producer surplus value of spectrum is greater than the typical operator's willingness to pay for the resource i.e. the additional traffic/customers supported by the additional spectrum are not be profitable. However, the results are shown to be sensitive to the assumptions that need to be made about the evolution of the mobile market (including MOU) and the use of spectrum that may be released in future. We obtain low values for Rajasthan by making plausible assumptions about future spectrum use and average MOU in rural areas.

There are very large uncertainties in India about the policy environment which has a major impact on future spectrum supply and hence the producer surplus values – in those countries where this approach has been used future spectrum supply is often mapped out by regulators in their spectrum strategies and can generally be expected to respond to market pressures. In addition the market situation in India is also highly uncertain – migration to 3G could happen more quickly than we have forecast even in rural areas if 3G handsets (new or recycled) with costs comparable to 2G devices become available.

While we believe that we have made plausible assumptions in our modelling the results indicate that the producer surplus approach does not provide a robust basis for valuing spectrum and setting reserve prices in India.

1.6 Production function approach

This involves estimating the value assuming a theoretical relationship between minutes of use, base transceiver stations (BTS) and spectrum allocated (given by a Cobb Douglas production function) and a panel of data for different operators for the period 2007-2012. The theoretical nature of the production function approach, and in particular the assumption of optimal network deployment, means it will not give reliable results.

2 Pros and cons of the valuation approaches

The Telecom Regulatory Authority of India (TRAI) has issued a Consultation Paper titled "Valuation and Reserve Price of Spectrum"[5] (the Consultation Paper) which focuses on valuation of spectrum in the 800MHz, 900MHz and 1800MHz. Vodafone asked Plum to address Questions 9-13 in the TRAI's consultation which concern four different approaches to the valuation of 1800MHz spectrum, and consider whether a top-down or bottom-up approach to valuation should be used.

We conclude that a bottom-up approach should be used, and that econometric analysis provides the best such approach. The producer surplus approach did not give reliable results in an Indian context.

2.1 Valuation options

We are firmly of the view that a bottom-up approach should be used. Valuations are derived for each LSA based on its particular characteristics rather than a top-down apportionment of a pan-India value based on a single parameter. Evidence provided by the TRAI (para 3.32 of the Consultation Paper) and the correlation and econometric analysis given in Section 3 of this report show that there are multiple drivers of value in each LSA and their relative importance cannot be known without statistical analysis of historic data.

To derive an estimate of the market value of spectrum, two general approaches can be used:

- Derive values from market benchmarks
- Derive values from bottom-up calculations using business and network modelling.

The valuation approaches proposed by the TRAI fall into these two categories. Three benchmarking approaches are proposed, namely:

- Benchmark against 3G auction prices: Use prices obtained in the auction of 3G auction spectrum in 2010 as the basis for valuation in 2013.
- Benchmark against 2001 1800MHz prices: Index prices obtained in the 2001 1800MHz auction.
- Econometric analysis: Undertake econometric analysis of the 2012 1800MHz auction prices to determine value in the areas where spectrum was unsold.

And the TRAI proposes two approaches to making bottom-up calculations, namely:

- Producer surplus approach: Estimate the 'producer surplus' value based on the infrastructure cost savings from having additional spectrum
- Production function approach: Estimate the value assuming a theoretical relationship between minutes of use, spectrum allocated and BTS (given by a Cobb Douglas production function) and a panel of data for different operators for the period 2007-2012.

When determining spectrum values regulators elsewhere[6] have tended to use several approaches - there are uncertainties with all approaches and using several methods allows sense checking of the results.

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[5] Consultation Paper on Valuation and Reserve price of Spectrum, TRAI consultation paper No. 06/2013, 23 July 2013

[6] See for example work done for Ofcom Spectrum value of 800MHz, 1800MHz and 2.6 GHz, Dotecon and Aetha for Ofcom, July 2012 and for the Australian government http://www.dbcde.gov.au/radio/radiofrequency_spectrum/spectrumlicenses

2.2 Benchmarking approaches

As markets reveal the opportunity cost of resources, it might be thought that the best approach is to use values revealed by market processes, such as the prices of other spectrum that has been auctioned and/or traded. However, while market benchmarks can provide a helpful sense check, their use is not straightforward because it can be difficult to find data that allows good "like for like" comparisons. This is because spectrum prices vary according to many factors including:

- Market expectations and socio-economic value drivers such as the timing of when spectrum is sold, as expectations of and confidence in future market conditions; national income/capita; population density and/or level of urbanisation
- Competition in the auction and/or the mobile market - the market HHI, the number of bidders and/or the ratio of bidders to winners
- Spectrum supply: The amount of spectrum sold and the existing spectrum holdings of bidders
- Frequency characteristics – frequency range and technologies that may be supported
- Attributes of the auction and spectrum packages sold such as the technologies and services that are expected/permitted to use the band; coverage and other licence obligations, including other fees paid by mobile operators over the licence duration; reservations for particular types of bidders/spectrum caps; and the reserve price.

The variations caused by these factors can be reduced by using data from a set of *relevant auctions* i.e. auctions for the same or similar bands, that are recent and ideally are from the country in question (in this case India). Do either the 2001 1800MHz auction or the 2010 3G auction provide a good "like for like" comparison to an 1800MHz auction today?

It is self-evident that the mobile market in India 2001 in terms of both demand and supply side factors was very to different today, and hence that 2001 values will not be a reliable guide to the current value of spectrum, regardless of the method of indexation used.

The TRAI itself has provided ample evidence of the downturn in the Indian mobile market and economy more generally[7] since 2010 that would lead one to expect that market expectations will be much less optimistic today than in 2010. We therefore do not regard the 2010 3G auction prices as providing a good guide to the value of 1800MHz spectrum today.

However, econometric analysis provides an objective way of controlling for market and economic factors, and therefore offers a more promising way forward than simply taking values from other auctions. Moreover, it does not rely on, say, Delhi being directly comparable to other LSAs – instead, it uses the estimated relationships between observed spectrum prices and the explanatory factors (e.g. economic/demographic factors) to predict a value for Delhi based on Delhi's own economic and demographic circumstances. We examine the TRAI's econometric analysis and develop it further in Section 3.

[7] Indian government cuts growth forecast, Wall Street Journal, 31 July 2013, http://online.wsj.com/article/SB10001424127887324136204578639610904231512.html

2.3 Bottom-up approaches

Bottom-up approaches involve modelling the value of spectrum to an operator, much as an operator might do when deciding to bid for spectrum sold at auction. The value of an increase in spectrum holdings to a mobile operator comes from one or both of:

- Increased revenues: Additional revenues may be earned because additional spectrum allows service quality to be improved and/or more traffic (for new and existing services) to be supported.
- Reduced costs: Access to additional spectrum allows operators to reduce costs because fewer base station sites are needed to provide a given amount of traffic capacity and/or coverage.

There are two bottom-up approaches to estimating the value of spectrum:

- Discounted cash flow value
- Cost reduction value – this is called the producer surplus value by TRAI.

The discounted cashflow approach provides an upper bound on value. It gives uncertain estimates because it is reliant on forecasts of future revenues and costs over the next 20 years, but the results can provide a useful cross check on the results of other analyses. The cost reduction approach gives a conservative estimate of value and is more reliable because it is not reliant on revenue projections[8]. Rather the key inputs are forecast traffic and network costs.

There are several ways of implementing a cost reduction approach including:

- A production function approach – this approach is proposed by the TRAI but we are not aware of any other regulators that have used this approach.
- Optimal deprival approach - Modelling an optimal network based assuming the most advanced technology is deployed, sites are optimally deployed and performance is as predicted by engineering models – this is the optimal deprival approach. It was used by consultants advising the New Zealand government[9].
- Typical operator approach – The value of spectrum to an operator that wins spectrum at auction is estimated assuming typical or average network performance, traffic and costs for the license period. Technologies used today and likely to be used in future are assumed. This approach has been used in Australia[10] and the UK[11] to inform spectrum fees and auction reserve prices.

The production function and optimal deprival approaches both make unrealistic assumptions about the way networks operate. The Cobb Douglas production function proposed by TRAI has no economic or engineering foundation in mobile networks and ignores important inputs such as backhaul. It assumes operators can continuously optimise their balance of base station and spectrum inputs, which is clearly unrealistic. Similarly the optimal deprival approach assumes that network deployment is optimised in

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[8] Renewal of Spectrum Rights for Cellular Services pricing methodology, Discussion paper, July 2006, PriceWaterhouseCoopers and NZIER, Ministry for Economic Development,

[9] Renewal of management Rights for cellular Services (800/900 MHz), Network Strategies, Ministry of Economic Development, October 2007

[10]Synopsis of 15 year license valuation methodology, Plum for the Department of Broadband, Communications and the Digital economy, Australia, 2012 http://www.dbcde.gov.au/radio/radiofrequency_spectrum/spectrumlicenses ; Administrative incentive pricing of radiofrequency spectrum",Final Report for ACMA, Plum and Aegis, October 2008

[11]"An Economic Study to Review Spectrum Pricing", Indepen, Aegis Systems and Warwick Business School, for Ofcom, February 2004; Spectrum value of 800MHz, 1800MHz and 2.6 GHz, Dotecon and Aetha for Ofcom, July 2012

the sense that the most efficient technology is used and optimal base station deployment can be achieved[12].

Hence if a producer surplus approach is used it should involve cost reduction modelling based on a typical operator. In Section 4 we have undertaken this analysis.

[12] It is sometimes the case that optimal deprival models are calibrated with actual market information and so give similar results to the typical operator approach.

3 Econometric analysis

3.1 Introduction

This section addresses the econometric analysis reported by TRAI in paragraphs 3.44- 3.53 of the Consultation Paper. The TRAI bases its analysis on the results of the 1800 MHz auction in November 2012. In the auction, spectrum was sold in 18 licensed service areas (LSAs), but no bids were received for spectrum in the remaining four (Delhi, Mumbai, Karnataka and Rajasthan). The TRAI uses the sale prices[13] seen in the 18 LSAs where spectrum was sold to estimate the value of spectrum in the remaining four LSAs. It does this by using simple correlations and multivariate regression analysis.

The TRAI compiles a set of variables which could influence the value per MHz. These include economic factors (GDP per capita, GDP growth), demographic factors (population, urban population) and market factors (AGR, mobile subscribers, total minutes of usage, the existing allocation of spectrum and the existing teledensity[14]. Additionally, two variables are used to indicate potential mobile traffic – the residual teledensity (computed as the assumed maximum teledensity in each LSA less the existing teledensity) and the number of potential subscribers (the residual teledensity multiplied by the population).

We can form prior expectations of how the various factors in the dataset should influence the value per MHz, based on theory and prior studies (these studies are detailed in Appendix A). The expectations are useful for assessing the conceptual validity of an econometric model. If variables do not have the expected relationship in a model then that model may be incorrectly specified.

Factors we would expect to have a positive relationship with the value per MHz in a given LSA include:

- AGR
- Population
- Subscribers
- Per capita income
- Minutes of usage per subscriber
- Urban % of population

Factors we would expect to be negatively related to the value per MHz include:

- Existing allocation of spectrum
- Quantity of unsold spectrum

[13] In every LSA but Bihar spectrum sold at the reserve price

[14] The number of mobile cellular subscribers per 100 people

3.2 Data inputs

The TRAI has not published the dataset it used for its econometric analysis, so we started by compiling a dataset which replicates as closely as possible that used by the TRAI. Where possible we have used the TRAI's own data. A table of our data inputs and sources can be found in Appendix B.

We are somewhat sceptical of the applicability of the residual teledensity variable. It is computed using theoretical maximum cellular subscribers per 100 people (given as 200% for Metro LSAs, 150% for category A LSAs, 125% for category B LSAs and 100% for category C LSAs). However, it is unclear why the maximum subscribers per 100 would be significantly different in, say, Metro vs. Category A LSAs, once other factors (like per capita GDP) taken into account. Moreover, several LSAs (most notably Himachal Pradesh) are already very close to their theoretical 'maximum' teledensity, which raises questions about the assumed maxima.

3.3 Replication of the TRAI's analysis

3.3.1 Correlations

The TRAI initially correlates the value per 2x1 MHz in the 18 LSAs where 1800 MHz spectrum was sold with five other variables separately. It then uses these results to predict a value for the four LSAs where spectrum was unsold. For this analysis, the TRAI splits the sample of 18 into Metro/Category A LSAs (to estimate the value per MHz for Delhi, Mumbai and Karnataka) and Category B LSAs (to estimate the value per MHz for Rajasthan). There are 5 Metro/Category A LSAs and 7 Category B LSAs. We have sought to replicate these results with our dataset.

Our results and the TRAI's results are given in Table 3-1.

Table 3-1: Results of Plum and TRAI correlations

LSA	Model	Value per 2x1 MHz based on correlations with the following variables				
		AGR	ARPU	RPM	Existing Teledensity	Residual Teledensity
Delhi	Plum	164.8	301.5	247.0	290.8	61.5
Delhi	TRAI	181.8	250.7	219.7	321.9	106.4
Mumbai	Plum	150.3	273.7	238.3	276.2	88.6
Mumbai	TRAI	182.0	311.9	292.9	320.8	108.2
Karnataka	Plum	187.2	214.2	197.3	139.8	191.6
Karnataka	TRAI	191.1	201.1	186.4	169.5	194.5
Rajasthan	Plum	56.8	51.0	55.6	44.3	48.1
Rajasthan	TRAI	56.67	51.3	53.7	48.0	50.1

The percentage differences between the TRAI's results and ours are given in Table 3-2, where a positive difference means TRAI's result is larger than our result and negative one means it is smaller. Our results are almost all within 20% of the TRAI's, with the exception of the results obtained from correlations with residual teledensity in Delhi.

Table 3-2: Percentage differences between Plum and TRAI results

LSA	Difference in estimated value per 2x1 MHz based on				
	AGR	ARPU	RPM	Existing Teledensity	Residual Teledensity
Delhi	9.3%	20.3%	12.4%	-9.7%	-42.2%
Mumbai	-17.4%	-12.2%	-18.7%	-13.9%	-18.1%
Karnataka	2%	6.5%	5.9%	-17.5%	-1.5%
Rajasthan	-0.2%	-0.5%	3.6%	-7.7%	-3.9%

We are concerned that we are unable to exactly match the TRAI's results for the AGR correlation, despite using TRAI data from the Consultation Paper. Furthermore, we would be interested to know how the TRAI has achieved almost exactly the same value per MHz for Delhi and Mumbai from the AGR correlation, despite there being a 10% difference in AGR between these two circles. There needs to be more transparency in the TRAI's analysis if we are to have confidence in their results.

More generally, there are limitations to using simple single-variable correlations to predict a value per MHz for the four LSAs - it does not account for the effects of any other factors on the value per MHz. The TRAI partially compensates for this by narrowing the sample by the LSA category. However, this means that the results for Delhi, Mumbai and Karnataka are based on a sample of five data points, while that of Rajasthan is based on a sample of seven. With such small samples it is difficult to have a great deal of confidence in the results. Hence we suggest that the results from single variable correlations are not used to set reserve prices.

3.3.2 Multivariate regressions (econometric analysis)

The TRAI expands their analysis by running multivariate regressions. Multivariate regression analysis estimates a relationship between the dependent variable (i.e. what we are trying to explain – in the TRAI analysis this is the price per 2x1 MHz) and multiple explanatory variables (i.e. factors we expect to affect the price per MHz). Multivariate regression analysis allows the impacts of multiple factors on the dependent variable to be estimated simultaneously and disentangled. It can be a powerful tool but care must be taken to ensure that the models make both intuitive and statistical sense.

We begin our analysis by attempting to replicate the TRAI's results. Like the TRAI, we initially use the value of 1800 MHz spectrum per MHz as our dependent variable and run each of the regressions specified in Table 3.5 of the TRAI's consultation document for the sample of 18 LSAs where spectrum was sold.

We then use these results to estimate a value per MHz for the four LSAs where no spectrum was sold. We give our results and the TRAI's for each of the six regressions specified in Table 3.5 of the

Consultation Paper in the six tables below[15]. In general our results are similar to (but not equal to) the TRAI's.

Table 3-3: Predicted values from TRAI regression 1

Variables: AGR, Population, Residual teledensity	Value per 2x1 MHz (Rs. in crore)		Reserve price per 2x1 MHz (March 13)
	TRAI	Plum	
Delhi	193	173	388.1
Mumbai	203	164	379.9
Karnataka	180	182	184.9
Rajasthan	100	96	37.6
Model R^2	-	91%	-

Table 3-4: Predicted values from TRAI regression 2

Variables: AGR, Potential subscribers, Population, GDP growth	Value per 2x1 MHz (Rs. in crore)		Reserve price per 2x1 MHz (March 13)
	TRAI	Plum	
Delhi	221	196	388.1
Mumbai	224	174	379.9
Karnataka	157	176	184.9
Rajasthan	103	69	37.6
Model R^2	-	92%	-

[15] We have numbered the regressions in table 3.5 1 through 6 for ease of reference. In every case, the dependent variable is price per MHz.

Table 3-5: Predicted values from TRAI regression 3

Variables: MoU (total), Residual teledensity, Population and GDP growth	Value per 2x1 MHz (Rs. in crore)		Reserve price per 2x1 MHz (March 13)
	TRAI	Plum	
Delhi	224	174	388.1
Mumbai	158	183	379.9
Karnataka	172	190	184.9
Rajasthan	105	116	37.6
Model R^2	-	90%	-

Table 3-6: Predicted values from TRAI regression 4

Variables: MoU (total), Residual teledensity, Population	Value per 2x1 MHz (Rs. in crore)		Reserve price per 2x1 MHz (March 13)
	TRAI	Plum	
Delhi	186	179	388.1
Mumbai	131	184	379.9
Karnataka	192	189	184.9
Rajasthan	89	107	37.6
Model R^2	-	90%	-

Table 3-7: Predicted values from TRAI regression 5

Variables: AGR per MHz, Residual teledensity, Population	Value per 2x1 MHz (Rs. in crore)		Reserve price per 2x1 MHz (March 13)
	TRAI	Plum	
Delhi	166	166	388.1
Mumbai	197	149	379.9
Karnataka	143	184	184.9
Rajasthan	134	99	37.6
Model R^2	-	89%	-

Table 3-8: Predicted values from TRAI regression 6

Variables: AGR, Existing teledensity	Value per 2x1 MHz (Rs. in crore)		Reserve price per 2x1 MHz (March 13)
	TRAI	Plum	
Delhi	214	220	388.1
Mumbai	214	197	379.9
Karnataka	153	156	184.9
Rajasthan	93	90	37.6
Model R^2	-	84%	-

In the Consultation Paper, the TRAI reports that the R^2 in their estimations is over 80% and that their coefficient estimates are statistically significant. However, these findings alone do not imply a model that makes intuitive sense or is a valid model. For example, the table below gives the t-statistics (a measure of the significance of an explanatory variable) from our estimation of TRAI Regression 4:

Table 3-9: t-statistics from Regression 4

Variable	t-statistic
constant	-3.7
Total minutes of usage	9.5
Residual teledensity	2.6
Population	-7.9
Model R^2	90%

All the independent variables are statistically significant at the 5% level and the model has a high R^2. However, population has a *negative* sign - i.e., the model predicts that the greater the population, the lower the value per MHz. This is contrary to prior expectations and suggests that the model may not make intuitive sense. Removal of the population variable significantly lowers the model's explanatory power (the R^2 falls to 40%).

The negative sign is possibly a consequence of collinearity. Collinearity occurs when there are high levels of correlation among predictor variables. This can lead to unreliable estimates of regression coefficients – it might, for example, lead us to over-estimate the impact of a given factor on the value per MHz. There are high levels of correlation among some of the explanatory variables - for example, between the population and the total minutes of usage there is a correlation of 0.92[16]. We note that some of the TRAI models are likely to be vulnerable to the problems of collinearity.

We take Regression 3 as an example:

Regression 3:

Value per 2x1 MHz = $\alpha + \beta_1$*[total minutes of usage] + β_2*[residual teledensity] + β_3*population + β_4* GDP growth rate + ε

In the above equation there are three terms that are highly correlated with one another – total minutes of usage, population and residual teledensity[17]. We can assess whether collinearity might be an issue by regressing one explanatory variable against another. The output from this is shown in Figure 3-1 for population and total minutes of usage.

Figure 3-1: Output for regression of population on minutes of usage

Dependent Variable: TOTAL_MOU_2012
Method: Least Squares
Date: 01/08/13 Time: 16:58
Sample: 1 18
Included observations: 18

Variable	Coefficient	Std. Error	t-Statistic	Prob.
POP	0.004213	0.000240	17.52098	0.0000

R-squared	0.784513	Mean dependent var	262266.8
Adjusted R-squared	0.784513	S.D. dependent var	153109.6
S.E. of regression	71074.41	Akaike info criterion	25.23480
Sum squared resid	8.59E+10	Schwarz criterion	25.28426
Log likelihood	-226.1132	Hannan-Quinn criter.	25.24162
Durbin-Watson stat	1.768773		

The high R^2 value indicates a strong correlation between these two factors. To assess the degree that this may pose a problem we can compute the variance inflation factor (VIF) for the model. We do this by regressing one predictor variable against all the others, and using the resultant R^2 to compute $1/(1-R^2)$. The R^2 we derive from the regression is 85%, which gives us a VIF of 6.7. This means that the standard errors of Regression 3 are 6.7 times larger than they would be in the absence of collinearity; i.e. we have an inaccurate estimate of a variable's effect on the value per MHz. Therefore, using these predictors to estimate the values per MHz for say, Delhi, may give an inaccurate result. The model's low level of stability can also be illustrated if we replace total minutes of use with minutes of use *per subscriber*. In this case, the R^2 falls to 30% and *none* of the explanatory variables are significant.

What other variables might instead be used to improve the explanatory power of the models? One option not explored in the TRAI's modelling is the inclusion of variables relating specifically to the auction itself, for example, the amount of spectrum unsold in each auction (we would expect a greater quantity of spectrum unsold to indicate that the market clearing price of spectrum is lower than that observed). In addition, the amount of spectrum already available to operators in each LSA is not included in any regression – it would be expected that the higher the available supply the lower the value/MHz of additional spectrum (all else being equal). Such exclusions mean that the models may suffer from omitted variable bias, potentially affecting the accuracy of the estimated coefficients.

[17] The method used to compute residual teledensity involves the population and the number of subscribers

3.4 Plum econometrics

To expand on the TRAI's econometric analysis we have run some of our own regressions on the dataset[18]. In particular, we attempt to address the potential issues of omitted variable bias and collinearity in the TRAI's models. To address the former we test/include some additional explanatory variables in our model (e.g. urbanisation, existing spectrum allocation, unsold spectrum). To address the latter we use price per 2x1 MHz per person as our dependent variable, in line with other econometric studies of this kind[19], and exclude variables likely to be highly collinear. The results are summarized in Table 3-10.

Table 3-10: Predicted values/2x1 MHz from Plum regression analysis

Specification	Estimated value/2x1 MHz (Rs. crore)					Reserve price (March 2013)
	(1)	(2)	(3)	(4)	(5)	
Delhi	70.2	127.8	125.1	103.1	122.4	388.1
Mumbai	41.6	110.8	107.1	73.7	84.4	379.9
Karnataka	122.1	131.5	126.6	131.8	105.4	184.9
Rajasthan[20]	49.8	51.9	54.4	50.1	17.1	37.6

The specifications are as follows. For every specification, our dependent variable was price per 2x1 MHz per person:

1) Per capita GDP, number of unsold lots, existing spectrum holdings, AGR, a dummy variable for Kolkata[21]
2) Per capita GDP, number of unsold lots, existing spectrum holdings, AGR, urbanisation
3) Per capita GDP, number of unsold lots, existing spectrum holdings, ARPU, urbanisation
4) Per capita GDP, AGR, existing tele-density *(Kolkata dropped from sample)*
5) Per capita GDP, number of sold lots, existing spectrum holdings, AGR, urbanisation *(Kolkata dropped from sample)*

Detailed results for each specification can be found in Appendix C. Since Kolkata is a notable outlier in terms of price per 2x1 MHz it was dropped from specifications 4 & 5.

There are limitations to this type of cross-sectional modelling, particularly given the small dataset available. We note in that in some of our specifications some variables are not statistically significant and/or do not have the expected sign (in common with some of the published studies of this kind). Although we would therefore recommend that caution should be taken when assessing the results of this analysis, we do note that they show a degree of consistency in estimated value per 2x1 MHz. All

[18] All our estimation was done using Eviews 8

[19] See Appendix A for details of these studies

[20] Note that the values for Rajasthan have been adjusted to account for the fact that 39% of the population is not covered by the spectrum on offer.

[21] A dummy variable is a 1/0 variable – in this case, the variable was 1 for Kolkata and 0 for all other LSAs.

of our regression models predict that the market price of spectrum in Delhi, Mumbai and Karnataka is significantly below the previous reserve prices.

3.5 Conclusions

Multivariate regression analysis can be a useful tool to estimate a value of spectrum. We initially attempt to replicate the TRAI's results, obtaining per 2x1 MHz spectrum values that were similar (but not equal to) the TRAI's. We then build upon the TRAI's analysis by adding variables not included in the TRAI models, and removing variables that might lead to collinearity problems in the model. The spectrum values we derive from this approach are consistent and, in general, lower than both the TRAI results and the auction reserve prices. Furthermore, the estimated values are likely to have an upward bias. This is because they are derived from the results of the November 2012 auction in which there was unsold spectrum in all circles except Bihar and so no market clearing price was established in 21 circles.

While there are limitations to using multivariate regression analysis and we would not recommend relying solely on it, it does provide useful results for setting reserve prices.

4 Producer surplus analysis

4.1 Introduction

The TRAI has proposed that spectrum could be valued based on 'Producer Surplus' that arises from network cost savings (i.e. less investment in network capacity and/or coverage) when additional spectrum is acquired[22]. The producer surplus approach to valuation (which is also called the avoided cost approach) has been used by a number of regulators to inform reserve prices and set annual spectrum fees and spectrum license renewal fees.

In principle the producer surplus approach gives a lower bound on value because it does not include any revenue related impacts from having additional spectrum. However, as will be shown below there are circumstances where the producer surplus approach can give misleading values – namely where the assumed counterfactual network investments in additional capacity or coverage are not profitable and so would not have been made. In these circumstances the producer surplus approach overestimates the value of spectrum. More generally, we find that the results are very sensitive to changes the input assumptions and so cannot be relied upon.

4.2 Modelling approach

We start by assuming that additional 1800MHz spectrum will be used by operators to deliver 2G services – voice and data - over the license period[23]. We assume that voice traffic will be prioritised over data traffic on the 2G network, and so we dimension the network based only on capacity requirement for voice traffic during the busy hour. 2G mobile data will be assumed to be delivered on a best-effort basis over a fixed number of channels within each of the 200 kHz RF channels.

The model estimates the cost savings from additional 1800MHz spectrum by calculating the potential reduction in the number of 2G sites for a "typical" large operator and multiplying this by an average cost per site. The "typical" operator's spectrum holdings, network, costs and traffic do not reflect those of any operator in particular, but are intended to be representative of the three large operators. The calculations are made for the five representative circles (Delhi, Mumbai, Karnataka, Rajasthan and Orissa) and within each circle for four different geo-types – dense urban, urban, suburban and rural.

In each case the model takes the following steps:

- Step 1: Divide each circle into four geotypes – dense urban, urban, suburban and rural, where geotypes are defined by population density
- Step 2: For each circle estimate the number of base station sites in 2013 for a "typical" operator in each geotype and calculate the annualised network and other costs per site. Forecast per site costs over the license period.

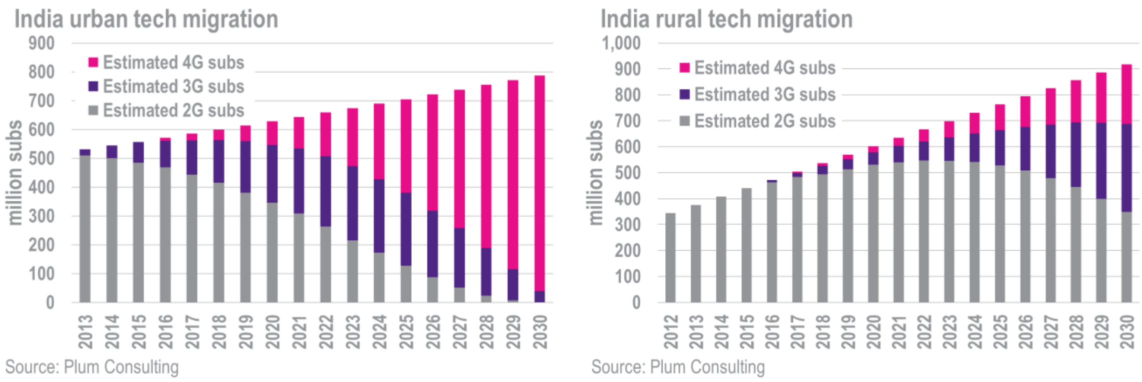
[22] Paras 3.54-3.60 of the Consultation Paper.

[23] Voice traffic generated by 3G subscribers is assumed to be only carried over the 3G network, placing no burden on the 2G network/spectrum.

- Step 3: Estimate capacity per site based on service standard requirements (i.e. blocking rate) and on a current and future view of how channels are allocated between voice and data
- Step 4: Forecast 2G voice traffic in all geotypes of all circles for the entire license period, including as the basis for forecasting a view of subscriber growth, the technology migration path and future changes in voice minutes/user. Calculate busy hour voice traffic for each geotype/circle, as a fraction of total voice traffic.
- Step 5: Divide busy hour 2G traffic for each geotype/circle in each year by site capacity to get the number of sites required for two scenarios – one with additional 1800 MHz spectrum and one without this spectrum. These scenarios will include assumptions about additional spectrum that might be acquired in bands other than 1800MHz over the next 20 years.
- Step 6: Calculate the producer surplus (or avoided cost) per year as the product of the difference in the number of sites between the two scenarios and the cost per site for each geotype and circle. (If the number of sites required is below the operator's current site number in both spectrum scenarios, no new sites are required and avoided cost for that geotype in that year is zero.)
- Step 7: Calculate the net present value of the annual producer surplus values by discounting the cost savings by the WACC for the mobile industry. This gives the lump sum value of the additional 1800MHz spectrum.

The tables below list the variables for which input assumptions are required to derive the 3 key components of the model – the voice traffic forecast, the 2G voice capacity per site, and the cost per 2G site. As can be seen the model requires numerous market and operator specific assumptions for the license period. For example, we have made assumptions about technology migration in urban and rural areas in order to derive a forecast of the number of 2G subscribers, as shown in Figure 4-2.

Figure 4-1: Technology migration plans for urban and rural areas



Values of input variables and the detailed derivation of the voice traffic forecast, the 2G voice capacity per site and the raw data used in computing the cost per 2G site are given in Appendix D. It should be noted that we made forecasts out to 2030 and not the full license period on the grounds that, in practice, the discounted value of any (highly uncertain) benefits by 2030 with a 15% WACC[24] is negligible.

[24] This is the WACC proposed by the TRAI in the Consultation Paper.

Table 4-1: Input assumptions for voice traffic forecast

Input variable	Use of input variable
Operator's market characteristics: Number of 2G sites Current 2G voice traffic – minutes of use and number of subscribers	To establish the starting point for traffic and the number of sites at present for the operator
Urban/ rural population and corresponding growth rates	To form a view of total demand for mobile services over time
Forecast of mobile penetration	To project the number 2G subscribers split by urban and rural areas as well as the number of voice minutes per subscriber for the entire license duration
Number of subscribers using 2G, 3G and 4G technology over time	
Evolution of 2G voice minutes of use/subscriber over time	

Table 4-2: Input assumptions for individual site capacity

Input variable	Use of input variable
Cell reuse factor	These network parameters are required for the entire license duration to determine the voice capacity per 2G site for each year. This requires the current values as well as a view of how they will evolve over time.
Number of sectors per site	
Spectrum assignment in all bands supporting 2G traffic – current and future	
RF resource reserved for 2G data service	
Mobile voice service standards	
Network inefficiencies	

Table 4-3: Input assumptions for cost per site

Input variable	Use of input variable
Passive site infrastructure costs: Rentals Power Maintenance Backhaul Payroll contribution Others e.g. insurance, security, managed services	To determine the annual payment required for the passive component of each site. This requires the current values as well as a view of how they will evolve over time.

Input variable	Use of input variable
Active site component costs (CAPEX & OPEX): BTS Transceivers	To determine the annual payment required for the active component of each site. This requires the current values as well as a view of how they will evolve over time.
Useful life of assets	To convert value into annual value at current prices
Weighted average cost of capital	
Inflation on network infrastructure component costs	

4.3 Results

We discuss below the results that we obtained from the applying the approach to a "typical" operator as detailed in Appendix D. Table 4-4 shows the estimated NPV of the producer surplus value of the additional 1800 MHz spectrum and the value per MHz conversion for each service area for this operator.

Table 4-4: Estimated values of additional 1800 MHz spectrum

Service area	Estimated NPV of avoided costs i.e. producer surplus for 2x5 MHz	Implied value per 2x1 MHz
Delhi	INR 133 crore	INR 26.6 crore
Mumbai	INR 179 crore	INR 35.8 crore
Rajasthan	INR 2,442 crore	INR 488.4 crore
Orissa	INR 270 crore	INR 54.0 crore
Karnataka	INR 170 crore	INR 34.0 crore

The values obtained are generally low. Larger values are mostly attributable to capacity shortfall in rural areas, where the number of 2G sites per square kilometre is lower and the number of 2G subscribers (and hence 2G voice traffic) is expected to continue growing until 2024. This is what drives the very high value in Rajasthan, and the relatively high value in Orissa, compared to Delhi and Mumbai.

We have also conducted sensitivity analyses around the assumptions regarding the use of future additional 900 MHz in rural areas (which we assume to become available in 2017) and the assumptions regarding average minutes of use (MOU) in rural areas. Specifically we tested the effect of assuming that the additional 900MHz spectrum would be used to support 2G services in rural areas and of assuming constant average minutes of use over time – this being the net effect of additional subscribers having below average MOU and existing subscribers having growing MOU. The results are shown in Table 4-5.

Table 4-5: Estimated producer surplus values/2x1MHz for the Base Case and three sensitivity tests

Service area	Base Case	Additional 900 MHz used for 2G in rural areas	Constant rural MOU	Additional 900 MHz used for 2G in rural areas and constant rural MOU
Delhi	INR 26.6 crore	INR 26.6 crore	INR 26.6 crore	INR 26.6 crore
Mumbai	INR 35.8 crore	INR 35.8 crore	INR 35.0 crore	INR 35.0 crore
Rajasthan	INR 488.4 crore	INR 96.4 crore	INR 196.8 crore	INR 38.8 crore
Orissa	INR 54.0 crore	INR 3.4 crore	INR 1.6 crore	INR 0.0 crore
Karnataka	INR 34.0 crore	INR 34.0 crore	INR 34.0 crore	INR 34.0 crore

As expected, Orissa and Rajasthan's avoided-cost values decrease significantly. This is because the values for both service areas are derived largely from the rise in shortfall of 2G capacity in rural areas under the Base Case. When a different set of plausible assumptions is introduced, in which additional 900MHz spectrum is used to support 2G traffic and MOU remain constant then the producer surplus value falls to zero in Orissa and less than 10% of the Base Case value in Rajasthan.

4.4 Conclusions

The producer surplus estimates obtained for Delhi and Mumbai are low and are significantly below the November 2012 and March 2013 auction reserve prices. We obtain disproportionately large values for rural areas in most circles, and in particular in Rajasthan because of the (assumed) growing take-up and use of 2G services in rural areas. The estimated value for Rajasthan greatly exceeds the November 2012 auction reserve price which means that the producer surplus value of spectrum is greater than the typical operator's willingness to pay for the resource i.e. the additional traffic/customers supported by the additional spectrum are not be profitable. However, the results are shown to be sensitive to the assumptions that need to be made about the evolution of the mobile market (including MOU) and the use of spectrum that may be released in future. We obtain low values for Rajasthan by making plausible assumptions about future spectrum use and average MOU in rural areas.

There are very large uncertainties in India about the policy environment which has a major impact on future spectrum supply and hence the producer surplus values – in those countries where this approach has been used future spectrum supply is often mapped out by regulators in their spectrum strategies and can generally be expected to respond to market pressures. In addition the market situation is also highly uncertain – migration to 3G could happen more quickly than we have forecast even in rural areas if 3G handsets (new or recycled) with costs comparable to 2G devices become available.

While we believe that we have made plausible assumptions in our modelling the results indicate that the producer surplus approach does not provide a robust basis for valuing spectrum and setting reserve prices in India.

Appendix A: Summary of econometric studies of spectrum auction results

Study	Dataset	Dependent variable	Independent variables	Functional form of regression
CTIA-CEA (2011)[25]	6,048 data points – winning bids from 13 Commercial Mobile Radio Service (CMRS) auctions in US, 1995-2007	Winning prices (per MHz per pop in $US, CPI adjusted to Nov 2010 dollars)	S&P 500 12-month total return** US Treasury 10-year bond yields** US cellular market size** Bidding credits (D)* Incumbent clearing issues** Build-out requirements License size (MHz-POPs in License)**	Logarithmic, OLS regression
Bohlin, Madden and Morey (2010)[26]	83 data points – winning bids from 23 3G auctions, 2000-2007	Winning prices ($US per MHz per pop)	Available licenses to bidders ratio (IV)* Population density (IV) GDP per capita (IV)* 2000/01 auction (D) (IV)** Average winning bid price** Asian country (D)** License duration Revised offering (D)** Entrant priority (D) Minimum spectrum bid price** Initial deposit required Mean annual license fee** Infrastructure sharing requirement (D)** Population coverage required**	Logarithmic, 2-Stage Least Squares (2SLS) regression, Instrumental Variable (IV) technique

[25] Broadband Spectrum Incentive Auctions, White Paper, 15 February 2011

[26] An econometric analysis of 3G auction spectrum valuations, EUI Working paper RSCAS 2010/55

Study	Dataset	Dependent variable	Independent variables	Functional form of regression
			Time required to achieve required network coverage**	
Dotecon (2009-2012) The 2012 specification is shown here.[27]	Five sets of analyses conducted over the period 2009-2012. The 2012 study used: 98 data points – all mobile spectrum auctions (2000-2011) 65 data points – GSM auctions only 53 data points – Europe auctions only	Price per MHz per pop (€ PPP, real terms)	GDP per capita** Area per capita** Ratio of winners to bidders in auction** Market competitiveness (inverse MNOs)** National license (D) 2.5 GHz auction (D)** Africa or Middle East country (D)** Before Italy 3G auction (D)** Year (D)**	Linear , OLS regression

[27] Award of 800 MHz, 900 MHz and 1800MHz spectrum, Fifth Benchmarking Report, Comreg 12/23, March 2012

Study	Dataset	Dependent variable	Independent variables	Functional form of regression
NERA (2009)[28]	2,300 data points – AWS, 700 MHz and 2.5 GHz auctions in US, Norway and Sweden (2006-2008)	Winning prices ($US)	Area Auction set-aside (D) Auction type Auction year Block Country Country GDP Employment percentage Final license bid amount Household income License bandwidth* License length (years) License population over 16 License set-aside ID Market name Median family income Mobile data ARPU Mobile penetration Mobile voice ARPU Name of winning party Number of licenses offered Number of registered bidders Population* Population density Unemployment percentage	Linear and quadratic, OLS regression

[28] Regulatory Policy Goals and Spectrum Auction Design, NERA, July 2009

Study	Dataset	Dependent variable	Independent variables	Functional form of regression
Ford (2008)[29]	72 data points – AWS, 700 MHz auctions in US (2006, 2008)	Winning price ($US)	Population* Size of auctioned block* Regional Economic Area (D)* Auction 73 (D)* Auction 73 B block (D)* Unpaired spectrum (D)	Logarithmic, OLS regression
STM Consulting (2008)	164 data points – auctions for 30 countries (2000-2008) for mobile, fixed wireless access, fixed link, broadcast	Price/MHz/Pop ($US)	Year GDP per capita Quantity of spectrum auctioned* Country size (area)* Band* Operators post award	Linear, OLS regression
Network Strategies (2007)[30]	11 data points – auctions for 800 MHz and 900 MHz bands (2000-2008)	Annualised price per MHz per pop ($US PPP)	Mobile penetration* Mobile revenue per subscriber Number of operators* HHI GDP per capita* Urbanisation Year license was issued	Linear, OLS regression

Notes: ** statistically significant at 1% level; * statistically significant at 5% level; D – dummy variable; IV – instrumental variable

[29] Calculating the value of unencumbered AWS-III spectrum, June 2008

[30] Renewal of management rights for cellular services (800/900 MHz), November 2007

Appendix B: Data sources for the econometric analysis

The following table lists the sources used in compiling our econometrics dataset.

Data Supplied	Source
AGR, ARPU	TRAI Consultation Paper
MoU, OG SMS (for GSM & CDMA)	TRAI's Quarterly Indian Telecom Services Performance Indicators
Teledensity (rural, urban, total)	TRAI's Quarterly Indian Telecom Services Performance Indicators
Spectrum Allocations (800, 900, 1800, 2100 & ors)	TRAI, DoT website
Population, Population (Rural, Urban) /Area density	Census of India 2011, (adjusted for few cities, towns to align with respective Telecom circles e.g. UPE, UPW, Delhi, WB etc)
Wireless Subscribers (GSM, CDMA)	TRAI's Quarterly Indian Telecom Services Performance Indicators
Wireless Subscriber share (overall India for Telcos)	TRAI's Quarterly Indian Telecom Services Performance Indicators
Circle wise, Telco wise wireless subscriber share - For period Feb-2013 and Jan-2012 (pre SC Order)	Calculated based on TRAI's Monthly subscriber base for the relevant periods
Residual Wireless Teledensity – circle wise	Calculated based on TRAI's method indicated in its consultation paper
Gross State Domestic Product (GSDP) at Current Prices	Planning Commission's Brief of Annual Plans for Respective States 2012-13/2011-12 [issued by Financial Resources Division of Planning Commission]
States' GSDP growth rate	As above, calculated over previous years in cases where growth rates not given by the Planning Commission
Per Capita Income (Net State GSDP at current prices) for 2011-12	Economic Survey 2012-13 (statistical appendix), Table 1.8
1800MHz auction results for November 2012 Auctions (reserve prices, spectrum offered, sold, Telco wise break-up)	As consolidated from DoT website
Industry Voice Traffic volume	Calculated & aggregated for CDMA & GSM for respective OG and IC wireless voice MoUs basis TRAI's Quarterly Indicator reports for 2012
RPM data for a class of circle – between Jun-11 and Mar-12 for CDMA and GSM	TRAI's Quarterly Indicator Reports for the period
Rajasthan – no of Districts and Population census and areas where spectrum is not available as per NIA 2012/13	Census of India 2011 for districts and their populations, DoT's NIA 2013 for spectrum unavailability

Appendix C: Plum regression outputs

The following table gives coefficient values and statistical results from the econometric models we estimated.

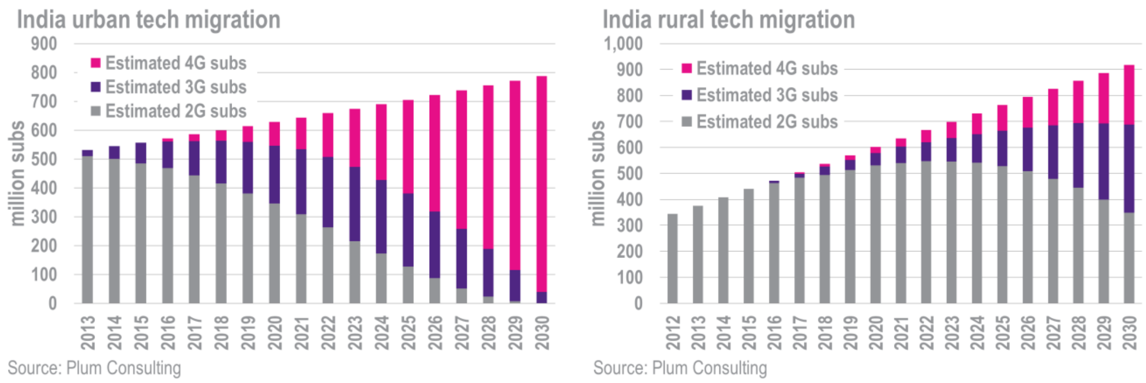
Variable	Specification				
	(1)	(2)	(3)	(4)	(5)
Constant	4.9	-22.1	-14.5	-19.3**	-12.9
Per capita GDP	1850**	12	-11	1010**	939*
Unsold lots	0.062	0.39	0.47		
Existing spectrum	-0.135	0.095	0.079		-0.37**
AGR	0.0027**	0.00023		0.0022**	0.0027**
Kolkata dummy	59.8**				
ARPU			-0.057		
Urbanisation		62.8**	64.1**		5.3
Sold lots					1.21**
Teledensity				20.1**	29.9*
Adjusted R^2	89%	76%	76%	83%	86%

* denotes statistical significance at the 15% level, ** denotes significance at the 5% level. We report the *adjusted* R^2 value since this accounts for the number of variables included in the model.

Appendix D: Detailed description of avoided cost modelling

Here we explain in more detail how the intermediate inputs in the avoided-cost value calculation are derived. First, we construct a technology migration plan in terms of the number of subscribers on 2G, 3G and 4G networks in urban and rural areas. The key constraints we impose here are that total subscribers across both urban and rural areas by 2030 translate to a mobile penetration rate of between 110% and 120% and that growth in subs is smooth. These assumed migration plans are shown in Figure 4-2.

Figure 4-2: Technology migration plans for urban and rural areas



Year-on-year change in 2G subscribers from this migration plan is then used as one input variable for projecting forward the typical operator's voice traffic. The other input variable that we use for this projection is the year-on-year growth in minutes of use (MOU) per subscriber per month. The growth rates are assumed to be 2.5% per annum in Mumbai and Delhi and 5% per annum in Rajasthan, Orissa and Karnataka for the period 2014-2019 and zero thereafter.

In projecting 2G voice traffic, we start with the traffic volumes in Erlang by geotype in 2013 shown in Table 4-6.

Table 4-6: Assumed 2013 traffic and site count for typical operator

Service Area	Geotype	2013 BTS count	2013 traffic (Erlang)
Delhi	DU	2,500	140,000
Delhi	U	2,000	110,000
Delhi	SU	700	34,000
Delhi	R	200	11,000
Karnataka	DU	250	10,500
Karnataka	U	1,000	47,500
Karnataka	SU	2,000	80,000
Karnataka	R	5,000	95,000
Mumbai	DU	500	30,000

Service Area	Geotype	2013 BTS count	2013 traffic (Erlang)
Mumbai	U	5,000	135,000
Mumbai	SU	300	30,000
Mumbai	R	25	3,000
Orissa	DU	350	12,000
Orissa	U	200	7,000
Orissa	SU	500	14,000
Orissa	R	2,300	64,000
Rajasthan	DU	200	5,000
Rajasthan	U	300	10,000
Rajasthan	SU	600	25,000
Rajasthan	R	5,500	195,000

Note: DU=dense urban; U= urban; SU = suburban; R= rural

Once we have a traffic projection in Erlang for each geotype of each service area, we convert it into a 2G site requirement. This is done by calculating the total number of Erlangs that a site can support under different spectrum scenarios and dividing this Erlang-per-site number into the total traffic projection for each year.

In the absence of new 1800 MHz spectrum, it is assumed that the typical operator has a total of 2x10 MHz in Delhi and Mumbai and 2x8 MHz in Rajasthan, Orissa and Karnataka to support 2G voice traffic (this is the total of spectrum at 900MHz and 1800MHz). It is assumed that the operator wins 2x5 MHz in each circle in the 1800MHz auction. Furthermore, we assume that there will be no further release of 1800MHz spectrum after the forthcoming auction and that any 900MHz spectrum released in future will be used by operators to support 3G subscribers.

It is then assumed that each TRX supports one RF channel of 200 kHz, which provides between 7 and 8 voice channels. Therefore, in Delhi and Mumbai, the total maximum number of transceivers (TRX) that can be deployed in each sector of a 3-sector site arranged in a reuse configuration of ¼ is 4 and 6 in the scenario with and without spectrum respectively. In the other three circles, the assumed spectrum assignment translates to 3 and 5 TRX per sector in the same deployment configuration. We then use the required service standard of 2% blocking rate to calculate the total number of Erlangs available at each site in the 2 spectrum scenarios[31].

Other input assumptions are given in the following tables.

Table 4-7: Demographic and economic assumptions

Input variable	Value	Sources
Population growth rate Urban Rural	 2.5-2.2% per annum 0.78-0.02% per annum	UN World Urbanization Prospects: 2011 Revision

[31] For more details see Appendix D.

Input variable	Value	Sources
2011 Population	1.21 billion	Census 2011
WACC	15% per annum	TRAI
Inflation rate	10.7-4.7%	IMF and Plum analysis

Table 4-8: Network cost assumptions

Input variable	Value	Sources
Site rental Delhi Mumbai Rajasthan Orissa Karnataka	 INR 55,000 per month INR 80,000 per month INR 68,000 per month INR 45,000 per month INR 50,000 per month	VF
CAPEX of 2G site	INR 1,100,000	VF
OPEX as % of CAPEX	10% per annum	Plum's estimate