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Value of Spectrum for Mobile Communications: Case of Korea

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Value of Spectrum for Mobile Communications: Case of Korea

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Abstract

Evaluation of spectrum price is important for most of the regulatory bodies and for most mobile operators. In some cases, regulatory authority faces a situation to evaluate the value of the radio spectrum which has been allocated already. In Korea, there was a reallocation of most of the LTE spectrum bands in 2020. In this paper, we propose a method to evaluate the value of each band based on the band's capacity out of total capacity. In addition, if we can find a reasonable value of the overall spectrum band, we can find a value for each band together with the information in the first stage. This method can be easily applied if only the regulatory authority has detailed geotype information on base transceiver stations(BTS).

Keyword: value of spectrum, base transceiver station, LTE, spectrum band, production function

1. Introduction

Estimating the value of the spectrum is very important for regulatory authorities and mobile operators. The price of spectrum for mobile communications that has not yet been allocated is often determined in the market, for example, by auction. However, how can we find the value of the spectrum that is already allocated and used for a while?

In this situation, the price of the spectrum can be evaluated by the present value of the cash flows earned by the spectrum. Suppose spectrum in multiple bands has been used for a service through carrier aggregation for a while. How can we evaluate the value of each band? This was a problem for the Korean regulatory authorities, which had to set the appropriate reallocation fee of spectrum in various bands in 2020. Korea regulatory authority allocated spectrum through auction initially and reallocated them before the allocation period ends. Most of the LTE spectrum was scheduled to be reallocated with a five-year usage period of use in 2021, and the regulatory authority announced the reallocation fee of 2.8 billion dollars for 290MHz. The fee was known to be set based on the initial allocation fee determined in the auction.

When a regulatory authority has limited information such as base transceiver stations (hereafter BTS), and bandwidth, it is hard to evaluate the exact contribution of each band for a service like LTE. However, if we can calculate the capacity of each band based on the BTSs installed for each band, we can get an idea of the degree of contribution in terms of the traffic. In addition, from the estimation of the production function for capacity, we can derive the price of spectrum band if we know the price of BTS, number of BTS and size of spectrum band used.

This paper attempts to assess the value of spectrum for mobile communication with limited information. In particular, we are going to evaluate the value of various spectrum bands when several bands are used for a service like LTE.

The paper is composed as follows: Section 2 reviews the related literature and presents the approach of this study. Section 3 introduces the current state of mobile communication in Korea and the price of LTE spectrum. Section 4 derives the value ratio for each spectrum band by the engineering method. In Section 5, we estimate the production function of traffic with BTSs and spectrum bandwidth to get the price of the spectrum band. In Section 6, the value of each band is derived by combining price of spectrum with the value weight of each band. We compare our result with the reallocation fee set by the regulator. Section 7 concludes.

2. Literature review

As is introduced well in Matinmikko-Blue, M. et al. (2019), there are many approaches to find the value of radio spectrum. Some of the representative approaches are the opportunity cost approach, income approach, and other approaches including the benchmark approach.

2.1 Opportunity cost approach

The opportunity cost approach is based on the theoretical background that more channel capacity can be achieved either from the additional spectrum or from the additional BTS sites installed over the number of baselines BTS sites (Clarke 2014, Sweet et al. 2002, Lundbord et al. 2012, Mölleryd and Markendahl 2014, Rana et al. 2020).

Sweet, R et al (2002) improved the administrative pricing methodology based on the theory of marginal value. Doyle (2007) outlined how economic principles can be applied to calculate administered incentive fees for radio spectrum.

Mölleryd and Markendahl (2011) have studied the spectrum value for mobile broadband services in comparison with estimates of engineering value versus willingness to pay. Plum consulting (2011) suggested the spectrum valuation on the basis of the opportunity cost approach. Settapong et al. (2015) concentrated on a literature review of spectrum valuation into two groups: the opportunity cost approach and econometrics approach. Rana et al (2020) estimated the spectrum value using the engineering-based opportunity cost approach.

In the context of the valuation of the spectrum, there are some papers using the production function approaches. The production function approach assumes that at the optimum, a service provider will allocate expenditure between spectrum and BTS to yield the same marginal productivity. Prasad and Sridhar(2008, 2009) estimated the production function of Indian wireless industry. Prasad (2015) examined the value of the spectrum through the estimation of Cobb-Douglas and translog production function. Rana et al (2020) also carried out the estimation of mobile production function to find the value of mobile spectrum in Bangladesh.

2.2 Income approach

An income approach, which adopts the discounted cash flow method of financial theory, is often best alternative to assess the valuation of the spectrum. In the cash flow approach, the price per MHz of a block of spectrum is computed as a net present value of the cash flow from the spectrum over the license period. The discounted cash flow (DCF) value can be expected to present value access to the spectrum by forecasting a stream of future cash flows. Bazelon and McHenry (2013) evaluated future cash flows through the utilization of the spectrum that can be obtained by operators by using DCF analysis.

2.3 Other approaches

As other approaches, benchmarking approach is often used. For estimating 900MHz and 1800MHz spectrum value, the DotEcon (2013) conducted the research through benchmarking analysis. Plum consulting (2018) examined past values of particularly the 2600MHz TDD and the 3400- 3800MHz by using benchmarking approach.

2.4 Our approach

As is mentioned, we will employ both the engineering method and the production function approach to find out each value of various spectrum bands. In this approach, the necessary information is the amount of spectrum band employed, detailed information on BTSs and the price of BTS. The engineering method is used to find out the value weight of each and the production function approach is used to find the overall value of the spectrum. When we combine the two methods, we can derive the value of each band.

3. The spectrum allocation situation in Korea

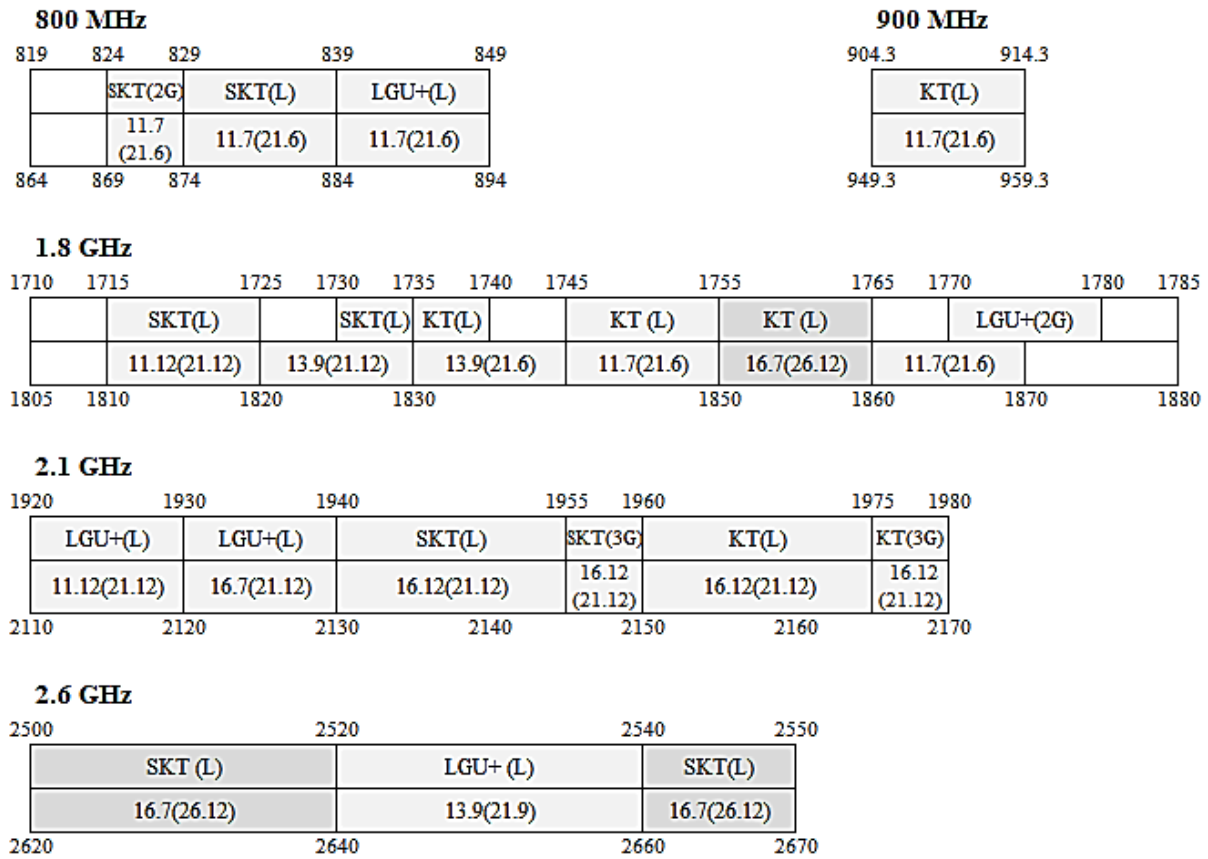
There are three network-based mobile operators in Korea, which are SKT, KT and LGU+. As of December 2021, the number of subscribers, average revenue per user (ARPU), used spectrum and LTE BTS of each operator are shown in the table below. The total number of subscribers in Korea is 70.5 million with 4G subscribers accounting for 66% and 5G subscribers possessing 30%. SKT uses a spectrum of 165MHz for 3G and 4G with 389 thousand of BTSs for LTE service. KT uses 125MHz bandwidth for 3G and 4G and has set up 236 thousand of BTSs for LTE service. LGU+ uses 120MHz wide spectrum for 2G and LTE, and has 300 thousand of BTSs for LTE service. The total number of BTSs for LTE in the nation reaches 925 thousand.

Table 1. Current status of Koran mobile operators (as of Dec. 2021)

	No. of Subscribers (thousand)					Mobile ARPU(\$)	Using Bandwidth(MHz)			BTS for LTE (thousands)
	2G	WCDMA	LTE	5G	Total		2G, 3G, LTE	5G	Total	
SKT	0	1,040	18,782	9,874	29,696	26.9	165	900	1,065	389
KT	0	1,760	14,662	6,378	22,799	28.4	125	900	1,025	236
LGU+	57	0	13,304	4,626	17,987	26.5	120	880	1,000	300
Total	57	2,800	46,748	20,878	70,482		410	2,680	3,090	925

Note: BTS for LTE is as of 2019.

Meanwhile, the radio spectrum allocation status for 2G, 3G and LTE is shown in Fig.1. This Figure is the allocation status table before reallocation in 2021, and it can be seen that the usage period for most of the spectrum expire in June or in December, 2021. The Korean regulatory authority reallocated the period of use to five years for all spectrums that had expired in 2021. The current status of the LTE spectrum is shown in Figure 2. The LTE spectrum of SKT is 145MHz, KT's 105MHz, and LGU+'s 100MHz. The 800MHz band is the primary band of SKT and LGU+, and the 1800MHz band is the primary band of KT (Fig 3).



Note: L means LTE.

Number means the allocation year and month.

Number in parentheses means the expiration year and month.

Spectrum bands with darker shade expire in 2026.

Figure 1. The allocation status of radio spectrum for 2G, 3G, and LTE in Korea (as of Dec. 2020)

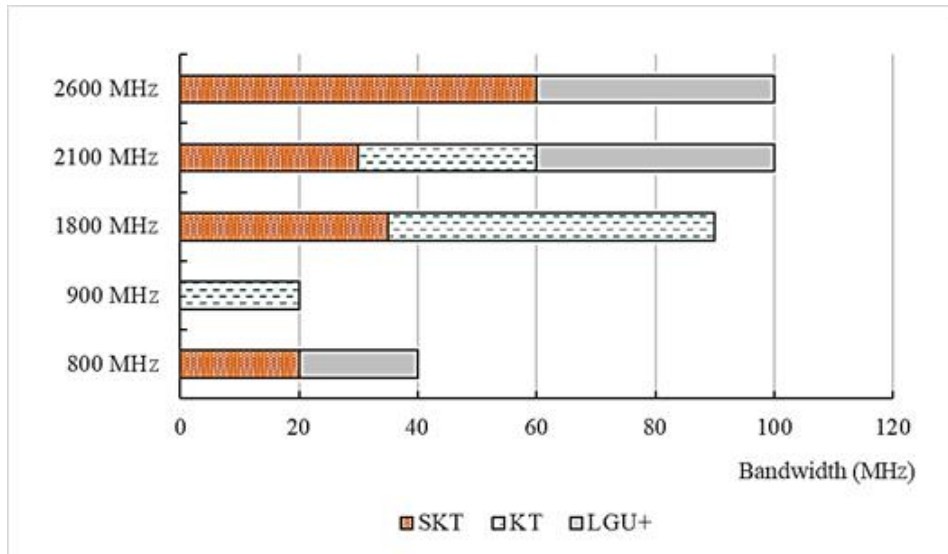


Figure 2. LTE spectrum bands by operator

There were three spectrum auctions for the allocation of these LTE spectrum, and each band was awarded at approximately 2~5 million dollar/MHz/year. Among them, the band with the highest price was KT's 1800MHz band in 2013, and it was awarded at 6.85 million dollar/MHz/year. This is because the band was adjacent to KT's existing band, easily yielding the broadband. The lowest price was for the 2600MHz taken by LGU+ in 2013 and 1.37 million dollars was paid per MHz/year.

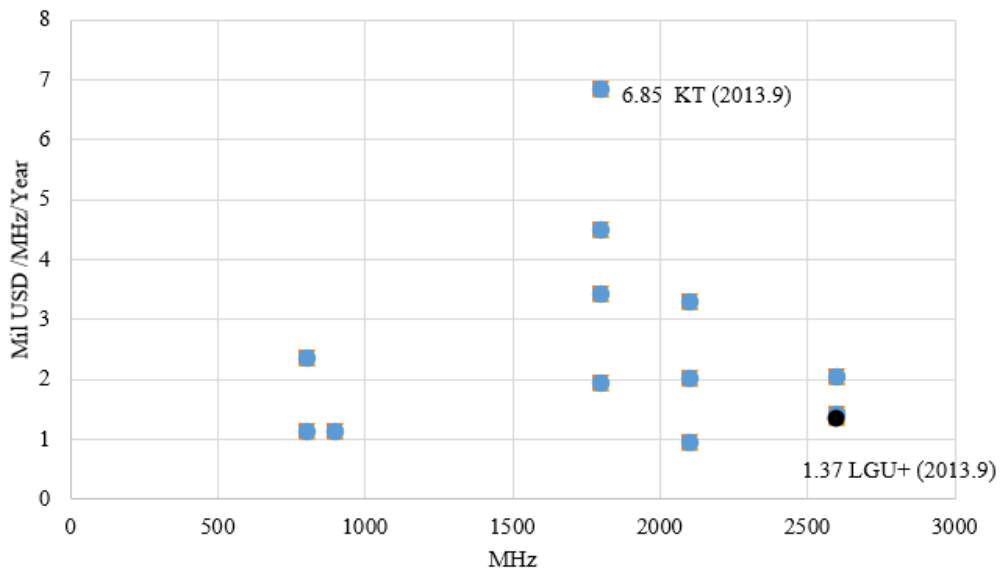


Figure 3. Spectrum price (Mil. USD/MHz/year) in auctions for LTE bands

4. Estimation of the proportion of spectrum value by band using the engineering method

In general, to accommodate LTE traffic while guaranteeing an appropriate transmission speed, a mobile communication service provider must secure sufficient LTE network capacity. The wireless network capacity is calculated as in Equation (1) below (Holma et al., 2016).

$$\text{Radio network capacity} = \text{number of cell} \times \text{bandwidth} \times \text{spectral efficiency} \quad (1)$$

According to equation (1), in order to accommodate traffic caused by an increase in the number of subscribers, it is necessary to expand the number of cells by constructing many radio stations following the growth in the number of subscribers. Besides, securing as wide a spectrum bandwidth as possible is essential, and spectrum efficiency should be increased by building an optimal network suitable for the service space with the latest base station equipment. Subscribers can be provided nationwide LTE service after mobile carriers have retained the network capacity on a large scale through many cells constructed, spacious bandwidth, and high spectral efficiency.

In the case of Korea, the first LTE spectrum was supplied in 2011, and the network was built that year. Fig.4 shows the relation between the average transmission and the used spectrum bandwidth by year.

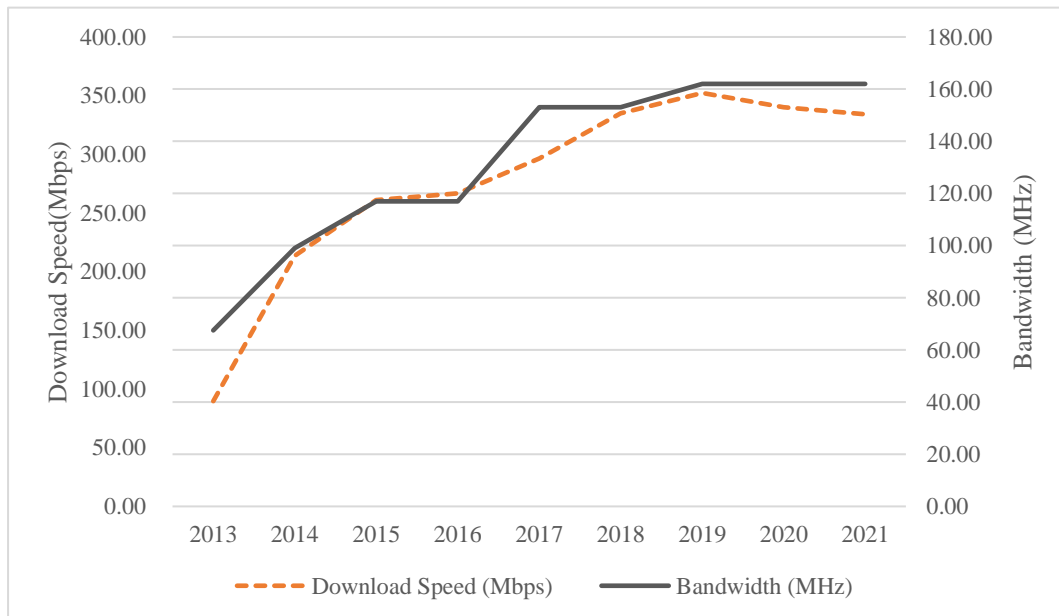


Figure 4. LTE average download speed and bandwidth

The figure shows that LTE spectrum was continuously supplied to maintain or to increase the average transmission speed of LTE downloads with the increase in the number of LTE subscribers.

As the video traffic surges, to improve the speed of LTE transmission, carrier aggregation technique, which ties several bands into one, was introduced. Since LTE services in Korea use multiple LTE spectrums, and since most LTE services occur in the downlink, we have considered estimating the total LTE capacity from the downlink point of view as follows:

$$C_t = C_{800} + C_{900} + C_{1800} + C_{2100} + C_{2600} \quad (2)$$

Table 2. LTE subscribers by year, radio stations, DL bandwidth and growth rate

year	Number of subscribers	growth rate of subscribers	Number of BTSs	growth rate of BTSs	Downlink bandwidth (MHz)	growth rate of bandwidth
2012	15,811,360		118,005		65	
2013	28,449,437	79.9%	255,452	116.5%	105	61.5%
2014	36,001,824	26.5%	365,478	43.1%	125	19.0%
2015	41,690,001	15.8%	526,300	44.0%	125	0.0%
2016	46,310,262	11.1%	626,121	19.0%	175	40.0%
2017	50,440,880	8.9%	845,143	35.0%	175	0.0%
2018	55,133,681	9.3%	993,743	17.6%	175	0.0%
2019	55,687,974	1.0%	1,045,203	5.2%	185	5.7%

As is shown in Table 2 above, with the number of LTE subscribers increasing, we notice the growth rate of the number of radio stations is higher than that of the bandwidth due to the LTE spectrum reuse characteristic.

Often, many studies fix the spectrum efficiency as 1.85bps/Hz or 1.98bps/Hz, in the calculation of the DL wireless network capacity (Oughton and Frias 2018, Rana et al., 2020). However, we believe that in terms of network capacity, the convention of fixing the spectral efficiency of such base station equipment could be improved. That's because the spectral efficiency is different depending on the

spatial radio environment in which the base station is installed. In the ITU-R report, the spectral efficiencies per cell in three different environments are presented Table 3 (ITU, 2019).

Table 3. Spectral efficiency per cell by region type according to ITU

Urban	Suburban	Rural
2.6 bps/Hz	2.2bps/Hz	1.1 bps/Hz

To estimate the spectrum value from the network capacity perspective, we have estimated the capacity for each spectrum bandwidth. The spectrum efficiency of the ITU-R report presented in Table 3 was applied after sorting the BTSs to urban, suburban and rural. Table 4 below shows the geotype data characteristics of Korea. It can be seen that the average site density in the urban area is quite high.

Table 4. Geotype data characteristics

Geotype	Area (km ²)	Percentage of total area (%)	Population	Percentage of total population (%)	Minimum population density (persons per km ²)	Site count	Average site density (sites per km ²)
Urban	12,544	12.5%	35,111,835	67.9%	124.79	488,160	38.9
Suburban	32,074	31.9%	12,325,621	23.8%	80.46	266,217	8.3
Rural	55,784	55.6%	4,258,760	8.2%	19.8	290,826	5.2

Finally, the aggregated capacity by bands was calculated in MHz units as shown in Table 5.

Table 5. LTE downlink capacity by year and band

	800MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz	Total
2012	11,782,874	-	2,869,522	9,043	-	14,661,440
2013	21,490,016	56,090	18,194,357	162,936	-	39,903,398
2014	23,710,676	350,266	29,435,922	1,504,307	2,163,765	57,164,935
2015	29,246,353	1,543,725	39,047,228	6,749,397	3,605,611	80,192,313
2016	33,547,550	2,701,938	55,834,616	8,938,623	12,798,194	113,820,921

2017	35,529,782	2,996,283	75,437,583	19,025,555	27,597,340	160,586,543
2018	38,211,066	3,202,262	84,376,320	25,184,477	39,413,242	190,387,367
2019	39,956,557	3,253,309	86,833,142	34,435,112	42,625,657	207,103,777

In terms of wireless network capacity, the weight of spectrum value per band has been estimated as (capacity per band)/(total capacity). Table 6 shows the relative spectrum values based on the MHz value of 800MHz spectrum as the baseline. Since 1800MHz is KT's primary band and since SKT also has a lot of BTSs in 1800MHz, it has the largest capacity weight and thus the highest relative value. 900MHz has the lowest weight because there are few base stations in the band.

Table 6. Relative value of spectrum (based on 800MHz, as of Dec. 2019)

	800MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz
Capacity weight	19.3%	1.6%	41.9%	16.6%	20.6%
Relative value	1	0.08	2.17	0.86	1.07

5. Derivation of spectrum value from production function approach

In the production function approach, we assume that a channel capacity can be produced by BTSs and radio spectrum. As a functional form, we use the Cobb-Douglas production function as follows:

$$Y = AX_1^\alpha X_2^\beta$$

where the dependent variable Y is channel capacity, X_1 is the deployed number of BTSs and X_2 is the employed amount of spectrum. The production function approach assumes that at the optimum, a service provider will allocate expenditure between spectrum and BTSs to yield the same marginal productivity. The optimum condition is given by $\frac{MP_{X_1}}{P_{X_1}} = \frac{MP_{X_2}}{P_{X_2}}$, where MP_{X_1} and MP_{X_2} are respectively the marginal product of BTSs and the spectrum (Prasad, 2015). From the above optimum condition, P_{X_2} is derived as follows:

$$P_{X_2} = \frac{\beta X_1}{\alpha X_2} P_{X_1}$$

In the estimation, data traffic is used as a proxy of channel capacity, under the assumption that the mobile operators will maintain channel capacity to accommodate the data traffic. A data set of 32

observations for data traffic, number of BTSs, and the number of bandwidths for 4G LTE covering the period from the first quarter of 2012 to the fourth quarter of 2019 is used to estimate the above log-linear Cobb-Douglas production function by OLS method. The estimation result seems acceptable.

Table 7. Results of OLS estimation for Cobb-Douglas production function.

Parameter	Coefficients	Standard error	t-stat	P-value
ln_BTS	1.26	0.05	22.52	0.000
ln_spectrum	0.16	0.06	2.55	0.016
Intercept	-4.19	0.44	-9.45	0.000

$$\bar{R}^2 = 0.9916$$

To estimate the spectrum value, we used the estimated coefficients, data for the BTSs and the bandwidths, and the price per BTS, which is assumed to be USD 15,940. The average of the estimated value is 4.01 million USD per MHz per year.

Table 8. Estimated value of the spectrum for LTE

Year	Estimated Value of spectrum (Unit: million USD/MHz/year)
2012	1.84
2013	2.47
2014	2.97
2015	4.28
2016	3.74
2017	5.05
2018	5.94
2019	5.90
Average	4.01

As is shown in the table, the estimated value of spectrum increases as the number of BTSs increases from 118 thousand to 1,045 thousand during the analysis period.

6. Estimation of spectrum values by bandwidth and discussion

In this chapter, we derive the value of each band and compare it with the reallocation price set by the Korean regulatory authority to examine the policy implications in this section. The spectrum price is derived as 4.01 million USD/MHz/year. Fig 5 shows our the spectrum value and reallocation fee set by the regulatory body. We assumed that 4.01 million USD is applied to the 800MHz band. Since the value is calculated a bit large, it could be more meaningful to examine the relative value of each band rather than the absolute value of each band.

According to our study, the price of the 1800MHz band should be about twice as high as that of the 800MHz band, but the reallocation fee is not so. Second, in the case of the 900MHz band, the reallocation fee turned out quite large, in spite of the small value calculated on our part. Third, the price of the 2600MHz band should be higher than that of the 800MHz band, but it turned out to be set considerably lower.

Table 9. Comparison of reallocation fee with our estimate

	800MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz
Reallocation Fee	1.99	1.24	2.74	1.80~1.91	0.95
Our estimate	4.00	0.33	8.71	3.45	4.28

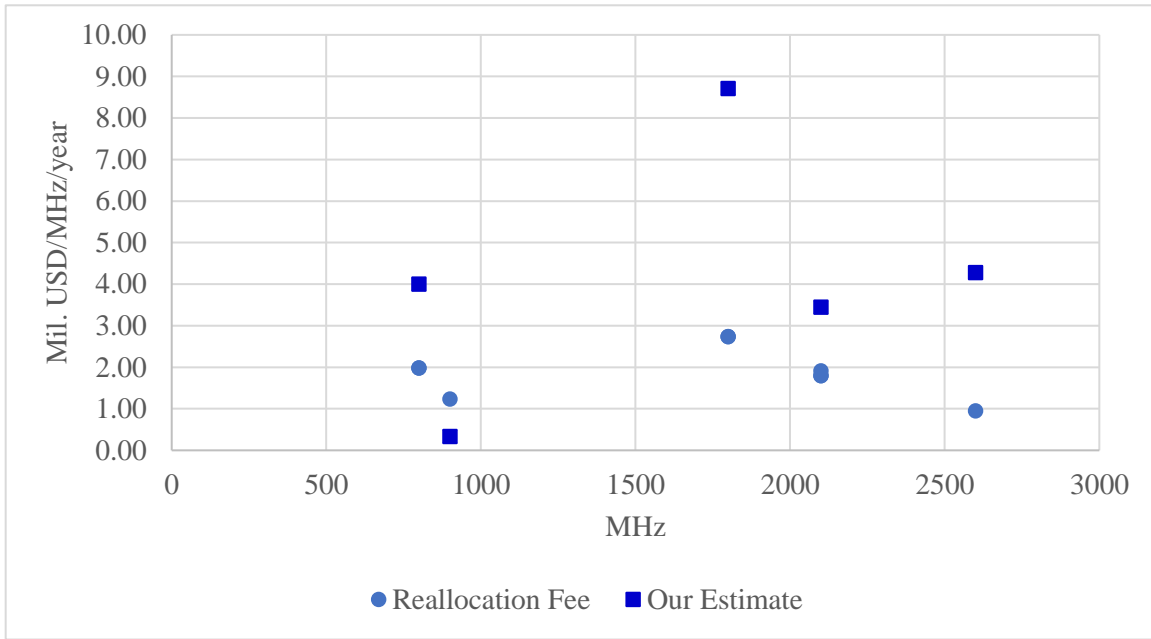


Figure 5 Comparison of reallocation fee with our estimate

Although the Korean government should set the reallocation price by reflecting past auction prices due to laws and regulations, the spectrum value for each band should reflect the traffic it deals with.

7. Conclusion

Appropriate pricing for spectrum is an important issue for both regulators and mobile operators. This study has started with the question of how to reflect the economic value to the price of spectrum.

It has been considered that the economic value of the spectrum is highly related to the data capacity that each spectrum can process for each band. We focused on the fact that it is linked to the number of BTSs equipped for each band and the location of the base stations. Hence, almost 1 million BTSs were classified into urban, suburban, and rural to reflect the right spectrum efficiency to obtain the capacity for each band. The relative value of each spectrum band was obtained through that process. Together with the value of spectrum and the relative value, we could derive the value of each band. With this we could examine how the reallocation fee is apart from our calculation.

This study is still in the early stage and needs a lot of improvements. First, it is necessary to reflect the bandwidth of the spectrum in deriving the relative value of the spectrum. Moreover, it is essential to examine whether the price of the spectrum obtained through the estimation of the production function is appropriate since it turned out a bit large.

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