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Valuation of Mobile Spectrum to be Reassigned

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Valuation of Mobile Spectrum to be Reassigned

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Keywords: Spectrum value, Spectrum reassignment fee, Cobb Douglas production function, Discounted cash flow(DCF), Engineering method

Abstract

Recently, many countries have been reassigning the mobile communication spectrum and determining their price. In South Korea, the mobile communication spectrum was reassigned in 2021 with a usage period from 2022 to 2026. This study focuses on the methods for calculating reassignment fee. We aimed to measure the value of the spectrum by combining production function approach and engineering approach. First, we estimated the Cobb-Douglas production function and derived the price per spectrum unit using the equal marginal principle. Then, we assessed the appropriateness of this price through a DCF (Discounted Cash Flow) analysis. Next, considering that the value of spectrum varies by band according to their radio wave characteristics, we derived the value of each spectrum band from an investment perspective. We applied each band's relative weight to the per-unit spectrum price obtained earlier to determine each spectrum band's value. The estimation results indicated that the reassignment fee in 2021 was somewhat high in terms of total and band-specific prices. This study might give some insights to regulators facing spectrum reassignment.

I. Introduction

Regulatory authorities and mobile communication operators need to assess the spectrum's value properly to utilize the scarce mobile spectrum efficiently. Since 2011, South

Korea has introduced spectrum auctions for the assignment of mobile spectrum and has conducted four auctions, including a recent 5G auction in 2018. Once the usage period expires, the Korean regulator reassigns the mobile spectrum upon reassignment fee. This study, therefore, is aimed at providing a comprehensive understanding of the methods for calculating reassignment fees, with a specific focus on the South Korean context.

In 2020, the South Korean government decided to reassign a total of 310 MHz bandwidth of (mostly LTE) mobile spectrum, whose usage periods were set to expire in June and December 2021, to 3 mobile operators. The government decided on a spectrum reassignment fee of \$2.64 billion over five years, subject to the condition that mobile communication operators establish a certain number of 5G BTSs by 2022.

The rules for determining the reassignment fee for these frequencies were set to reflect the past bid price for the spectrum according to the Radio Waves Act's clauses. Mobile operators criticized this rule as unreasonable since the value of the mobile spectrum is not as high as when it was first assigned (Kim, 2022).

Such reassignments of mobile communication spectrum are occurring in many countries worldwide. Germany mentioned that reassigning spectrum that is about to expire through an auction process is appropriate (Bundesnetzagentur, 2022). Australia extended the usage period of 800 MHz and 1800MHz bands in

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2013 and set an annual price of \$2.904 million per MHz. Spectrum in the 700MHz, 850MHz (original band and downshift), 1800MHz, 2GHz, 2.3GHz, 2.5GHz, and 3.4GHz bands are expected to expire between 2028 and 2032, and they are considering appropriate measures related to whether to renew expiring spectrum licenses (ESL) (ACMA, 2023). The Office of the Communications Authority in Hong Kong (2023) mentioned that the assignment of 20MHz of the 850MHz to 900MHz band and 90MHz of the 2.3GHz band is expected to expire in May 2026 and March 2027, respectively. Therefore, they have announced plans to reassign 110MHz of 4G and 5G frequencies through auctions in 2024.

In South Korea, it appears that spectrum reassignment fee will be determined by the government, not depending on spectrum auctions in the foreseeable future. In this regard, this study aims to explore proper methods to determine the fee for the reassigned spectrum. We sought to estimate the value of the spectrum by combining economic and engineering methods. Then, we tried to figure out whether the level of the reassignment fee is reasonable compared to the value from the discounted cash flow (DCF) methods and to the actual reassignment fee levied by the government.

This paper is composed as follows: Section 2 provides a literature review and introduces the methodology used in this research. Section 3 presents an overview of the mobile communication status in South Korea and the reassignment fee for LTE spectrum bands assigned through auctions. In section 4, we employ an economical approach to estimate Cobb Douglas production function and derive the price per unit of the spectrum from the price of Base Transceiver Stations(BTS), the number of BTSs, and the size of the spectrum band used. In addition, we apply the DCF analysis to determine whether the economic approach's total value is reasonable. Section 5 focuses on the engineering aspects to derive the relative value of spectrum bands based on the characteristics of each band. In Section 6, we integrate economic and engineering methods to determine the value of spectrum bands and compare it with the actual

reassigned fee. Section 7 concludes with a summary of the findings.

II. Literature review

2.1 Literature review on spectrum assignment and reassignment

There are various studies on spectrum assignment and reassignment. ITU (2016a, 2016b) provides guidelines on the policy and economic aspects of spectrum assignment and use. These guidelines explain various spectrum assignment models to help national regulatory authorities and MNOs use spectrum more efficiently and optimally.

Hazlett & Munoz (2009) noted that a spectrum assignment policy must be designed considering that if the spectrum price is set too high, social costs may occur, and social welfare may decrease.

Several countries have also studied spectrum assignment and reassignment. According to Ofcom (2018), the reassignment fee for the 900MHz band was set at £1.093 million (\$1.457 million) per 1MHz of bandwidth annually, and for the 1800MHz band, it was set at £0.805 million (\$1.073 million).

Bundesnetzagentur (2022) conducted an initial survey regarding the future demand for spectrum for mobile communication, considering the expiration of frequency usage rights in the 800MHz, 1800MHz, and 2600MHz bands by the end of 2025.

According to ACMA (2023), spectrum in the 700MHz, 850MHz, 1800MHz, 2GHz, 2.3GHz, 2.5GHz, and 3.4GHz bands are scheduled to expire from June 2028 to December 2032. ACMA is considering approaches for determining the price and value of spectrum, and they have announced their intention to start considering expiring spectrum licenses(ESL), based on a four-stage approach, five years before their expiration.

H. C. Kim(2022) provides a detailed explanation of the process of calculating the reassignment fee of spectrum in South Korea in 2021.

2.2 Review of literature on the valuation of radio spectrum

As Matinmikko-Blue et al. (2019) mentioned, various approaches exist for determining the value of the radio spectrum.

The opportunity cost approach views the spectrum opportunity cost as the additional cost incurred when deploying additional BTS (Clarke 2014, Sweet et al. 2002; Lundborg et al. 2012; Mölleryd and Markendahl 2014; Settapong et al. 2015; Rana et al. 2020).

Some papers utilize the production function approach to evaluate the value of the spectrum. This approach derives the price per unit of spectrum from the condition that the marginal product of each input factor should be equal to the amount spent on that factor for profit maximization in production (ITU, 2017). Some examples include the work by Prasad & Sridhar (2008, 2009). Prasad (2015) estimated the production function of India's mobile communication industry. Rana et al. (2020) estimated Cobb-Douglas and translog production functions to determine the unit value of mobile communication spectrum in Bangladesh and derived the price per MHz of spectrum accordingly.

The income approach determines the value of the spectrum by calculating the present value of future cash flows from MNOs using those frequencies. Bazelon & McHenry (2013) employ the Discounted Cash Flow (DCF) analysis to derive the future cash flows that operators can obtain through frequencies, thus measuring the value of the spectrum.

The benchmarking approach estimates the economic value of spectrum based on existing spectrum assignment fees (DotEcon 2013, Plum Consulting 2018).

Besides, some studies classify regional types or estimate spectrum values according to cell radius. Wei and Hwang (2018a) classified the value of spectrum above 1.5GHz into urban and suburban environments and analyzed the relative spectrum values for specific spectrum ranges at various locations within cells. Wei and Hwang (2018b) used an engineering-economic modeling

methodology to assess the value of spectrum in rural environments, evaluating spectrum bands from 1.5GHz to 3GHz and from 3GHz to 11GHz. They selected three indicators for evaluating the value of spectrum: maximum cell radius, annual infrastructure cost per square kilometer, and spectrum value per MHz-POP. ZTE (2013) analyzed cell radius and cell area by categorizing LTE coverage radius by region type. ITU-R (2013) has compared the coverage of IMT-Advanced systems across various spectrum bands.

2.3 The contribution of this study

Many studies have aimed at understanding the value of spectrum, but few have focused on determining the spectrum reassignment fee. This study combines economic and engineering approaches to derive the value of the spectrum. In this process, the value of the spectrum obtained through the economic method is compared with DCF analysis. Furthermore, we compare the value of the spectrum for each band with the actual reassignment fee.

III. Mobile network operators and spectrum assignment status in South Korea

3.1 Status of mobile network operators in South Korea

There are three network-based mobile network operators, SKT, KT, and LGU+, in South Korea. As of March 2024, the number of subscribers, average revenue per user (ARPU), spectrum in use, and BTS for LTE for each mobile network operator are shown below in Table 1-1 and Table 1-2.

Table 1-1. Current status of mobile service subscribers in South Korea (as of March 2024)

	No. of Subscribers (thousand)				
	2G	3G	LTE	5G	Total
SKT	0	293	6,918	15,931	23,142
KT	0	102	3,416	9,948	13,466
LGU+	0	0	3,759	7,190	10,949
MVNO	0	249	8,615	302	9,166
Total	0	644	22,708	33,371	56,723

As of March 2024, the total number of subscribers is 56.72 million, with 4G subscribers accounting for 40.0% and 5G subscribers possessing 58.8%. This indicates a steady increase in the number of 5G subscribers since the launch of the 5G service in 2019.

Table 1-2. Current status of mobile ARPU, spectrum usage (as of March 2024)

	Mobile	Using Bandwidth(MHz)			BTS for LTE** (thousands)
	ARPU(\$)*	2G, 3G, LTE	5G	Total	
SKT	22.0	155	100	255	389
KT	25.9	115	100	215	236
LGU+	18.5	100	100	200	300
Total		370	300	670	925

Note: *In mobile ARPU, IoT lines are included.

**BTS for LTE is as of the end of 2019.

SKT and LGU+ experienced a 1.7% and 14.5% decrease in ARPU, respectively, compared to the same period last year. On the other hand, KT showed a 2% increase over the year, reaching \$25.9. Unlike other mobile operators, this difference can be attributed to KT excluding IoT and M2M lines in its ARPU calculations.

SKT utilizes a bandwidth of 155MHz for 3G and 4G services and has 389,000 BTS for LTE service. KT operates with a bandwidth of 115MHz for 3G and 4G and has 236,000 BTS for LTE service. LGU+ uses a bandwidth of 100MHz for 2G and LTE services and possesses 300,000 BTS for LTE service. In total, there are 925,000 BTS for LTE services in South Korea.

The current status of LTE spectrum bands for the three mobile network operators in South Korea is shown in Figure 1.

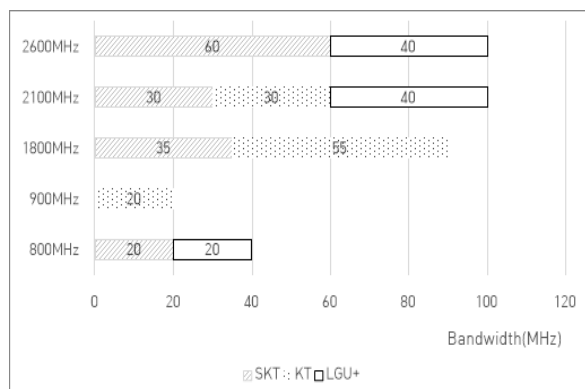


Figure 1. LTE spectrum bands by 3 operators

SKT and LG U+ utilize the 800MHz band for their nationwide networks, while KT uses the 1800MHz band.

3.2 Assignment status of mobile communication spectrum in South Korea

Most spectrum usage periods in South Korea were set to expire in June or December 2021. The regulatory authority has reassigned the usage period for all expired spectrum to 5 years in 2021. As a result, the 800MHz and 900MHz, which are assigned for 3G and LTE use by the three major telecom companies (SKT, KT, and LGU+), are scheduled to expire in June 2026. Similarly, the 1800MHz, 2100MHz, and 2600MHz spectrum bands will expire in December 2026. In 2021, the Korean government set the reassignment fee of the mobile communication spectrum, totaling up to 310MHz, at around \$2.64 billion for a five-year period.

This logic is introduced because if MNOs invest heavily in 5G, the contribution of the existing LTE spectrum to revenue may decrease. As a result, it is suggested that the reassignment fee could be reduced. This reason is considered to have its rational basis, and it is anticipated that MNOs will meet this condition.

The 28GHz spectrum band was assigned for 5G use through an auction in 2018. The South Korean government obliged the three MNOs, each allocated an 800MHz bandwidth, to install more than 12,000 BTSs within three years. However, since the three MNOs failed to meet the conditions for the number of BTSs, the government canceled the spectrum assignment. In December 2022, both KT and LGU+ returned the already assigned spectrum band, and in May 2023, SKT also discontinued using the 28GHz spectrum band. In February 2024, through a spectrum auction, the 800MHz bandwidth in the 28GHz for 5G mobile communication services was scheduled to be assigned to Stage X. However, it is expected that the assignment will be canceled due to its capital problem.

Figure 2 illustrates the current spectrum assignment status of MNOs as of March 2024, primarily indicating the assignment status for the 3G, LTE, and 5G mobile communication spectrum. SKT holds 145MHz of LTE spectrum, KT has 105MHz, and LGU+ has 100MHz.

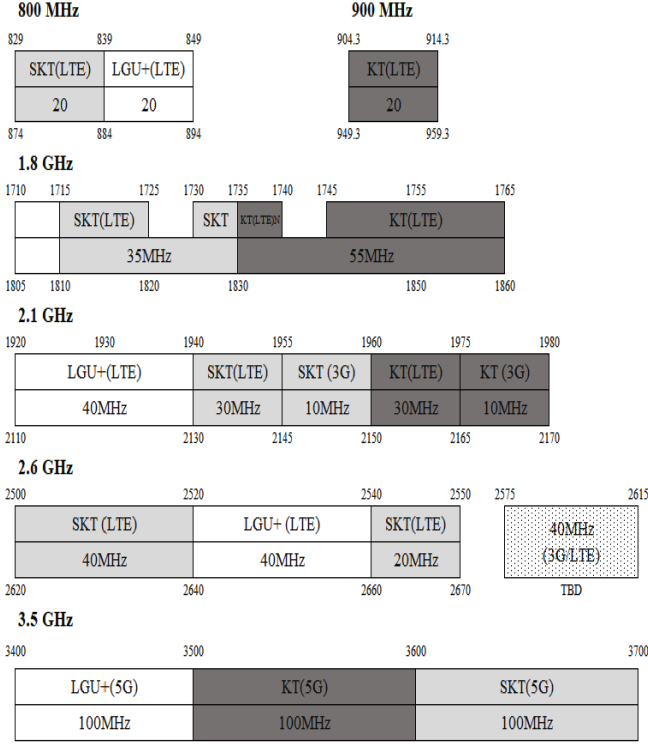


Figure 2. The assignment status of radio spectrum for 3G, LTE and 5G (as of March, 2024)

Auctions for LTE spectrum were held in 2011, 2013, and 2016, and each band was awarded at a price of approximately 2~5 million dollars/MHz/Year. Among them, the highest price paid for a band was the 1800MHz band of KT in 2013, and it was awarded 6.85 million dollars/MHz/Year. This high price was due to its proximity to KT’s existing spectrum band, which easily yields broadband services. On the other hand, the lowest price in 2013 was for the 2600MHz band taken by LGU+, which cost \$1.37 million was paid per MHz/Year.

Table 2. The past LTE spectrum auction results

	2011	2013	2016
800MHz	10MHz (KT)	-	-

900MHz	-	-	-
1800MHz	20MHz (SKT)	35MHz (SKT) 15MHz (KT)	20MHz (KT)
2100 MHz	20MHz (LGU+)	-	20MHz (LGU+)
2600MHz	-	40MHz (LGU+)	40MHz (SKT) 20MHz (SKT)
Total bandwidth	50MHz	90 MHz	100 MHz
Total price (mil USD)	1,519	2,168	1,884

IV. Estimation of spectrum value through production function approach

4.1 Derivation of spectrum value through production function approach

We estimated to derive the value per spectrum unit from the equal marginal principle through production function approach(Prasad, 2015). We assume that channel capacity is produced based on the number of BTSs and the amount of radio spectrum. As a functional form, we adopt 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. From the above optimum condition, P_{X_2} is derived as follows:

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

We transformed the production function into a log-linear form to estimate the spectrum's price. In the estimation, we assumed that mobile operators would maintain channel capacity to

accommodate data traffic and used data traffic as a proxy variable for channel capacity. The data used in the estimation covers quarterly data from the first quarter of 2012 to the fourth quarter of 2019. The estimation result seems acceptable.

Table 3. Basic statistics for the variables

Variables	Average	Standard Deviation	Minimum value	Maximum value
Data Traffic (TBps)	599,989	439,959	12,544	1,390,173
No. of BTSs	535,325	322,250	30,000	1,045,203
Spectrum (MHz)	261	101	50	360

The results of the estimated production function are presented in the following Table 4.

Table 4. Results of the 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

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

In this paper, we measured the value of the LTE spectrum using data on estimated coefficients of BTS and bandwidth, along with a BTS price of USD 26,786. The estimated value of the spectrum was found to be \$6.74 million USD per MHz.

4.2 Rough estimation of spectrum value through DCF approach

Here, we assess the spectrum's value through the DCF approach. To understand the flow of operating profit from telecommunication services provided by MNOs, we referred to the accounting data of mobile sector in the 'Operating Reports' of MNOs. It was excerpted from the Telecommunication Market Competition Assessment Report of KISDI published annually.

From 2012 to 2022, the average operating profit was \$2,179 million USD, which is assumed to continue at the same level from 2022 to 2026. We used the weighted average cost of capital (WACC) of 5.32% as the discount rate to calculate the present value. The equity and debt ratios are determined to be 42.5% and 57.5%, respectively. The cost of equity and debt are determined to be 6.97% and 5.46%, respectively, using the Technology Valuation Practice Guide(2021). A corporate tax rate of 25%(as of 2022) is applied.

As shown in the table below, the present value of the operating profit of the three MNOs from 2022 to 2026 is 9,849 million USD. The reassignment price for the LTE spectrum will be calculated as the sum of the LTE spectrum's contribution to operating profit each year.

Table 5. Present values of operating profit for each year (discount rate: 5.32%)

Year	Present values of operating profit for each year (million USD)
2022	2,179
2023	2,069
2024	1,964
2025	1,865
2026	1,771
TOTAL	9,849

If we assume that the contribution of LTE spectrum to operating profit decreases annually by 5% from 40% in 2022, then the sum of its value would be approximately \$3,006 million USD. Dividing this by the allocated bandwidth of 290 MHz, we get a value of \$10.36 million USD per MHz of spectrum. The following table shows the prices per spectrum unit estimated using the production function approach and the DCF method. While the results obtained from the production function approach are slightly smaller than those from the DCF method, there is no significant difference. However, if the contribution of the LTE spectrum to traffic is smaller, the estimates from the production function are likely to become more similar to those from the DCF method.

Table 6. Comparison of the value of spectrum per unit

	Cobb Douglas Production function	DCF analysis
The value of spectrum per MHz (MHz/mil USD)	6.74	10.36

Note: The value of spectrum obtained through DCF assumes a decrease in the contribution of LTE frequency to operating profit from 40% in 2022, decreasing by 5% annually.

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

In the case of South Korea, LTE spectrum service began to be provided in 2011, with the network being established in the same year. As the number of LTE subscribers gradually increased, it can be observed that the LTE spectrum was continuously supplied to maintain or improve the average transmission speed of LTE downloads. As shown in Table 7 below, it can be observed that the rate of increase in the number of BTSs is higher than the increase in bandwidth due to the reuse characteristics of LTE frequencies as the number of LTE subscribers increases.

Table 7. LTE subscribers by year, radio stations, DL bandwidth and growth rate

year	No. of subscribers	Growth rate of subscribers (%)	No. of BTSs	Growth rate of BTSs (%)	DL 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

Table 8 below provides geo-type data characteristics of South Korea. It shows that the

average site density in urban areas is approximately 39%, which is significantly higher than in suburban(8.3%) and rural(5.2%) areas.

Table 8. Geo-type data characteristics of South Korea

Geo-type	Area (km ²)	Percentage of total area (%)	Population	Percentage of population
Urban	12,544	12.5	35,111,835	67.9
Suburban	32,074	31.9	12,325,621	23.8
Rural	55,784	55.6	4,258,760	8.2

Geo-type	Minimum population density (persons per km ²)	Site count	Average site density (site per km ²)
Urban	124.79	488,160	38.9
Suburban	80.46	266,217	8.3
Rural	19.8	290,826	5.2

In this analysis, we decided to use the characteristics of the spectrum from the perspective of BTS investment costs when calculating the value of the spectrum by band. Specifically, we obtained the typical cell radius and cell area for each LTE spectrum band. The ITU-R (2013) provides the typical cell radius by spectrum band and cell location, from which we derived the cell area as shown in Table 9.

Table 9. Coverage comparison of IMT-Advanced systems at various frequency ranges

Cell radius (km)			
	Urban	Suburban	Rural
Below 1GHz	2	2	8
Between 1-2GHz	0.5	1	5
Between 2-3GHz	0.4	0.8	4

Cell area (km ²)			
	Urban	Suburban	Rural
Regional	0.5	0.3	0.2

type ratio			
Below 1GHz	12.57	12.57	201.09
Between 1-2GHz	0.79	3.14	78.55
Between 2-3GHz	0.50	2.01	50.27

In sequence, considering that the distribution ratio of base stations in urban, suburban, and rural areas is typically 0.5, 0.3, and 0.2, respectively, we derived the average cell area. From this, we determined the value of each spectrum band. In other words, when considering the value of the 800MHz and 900MHz bands as 1, the 1.8GHz band was found to have a value of 0.34, while the 2.1GHz and 2.6GHz bands each had a value of 0.22. The relative proportions are obtained as shown in Table 10.

Table 10. The proportion of each spectrum band derived from cell area

	Below 1GHz		Between 1-2GHz	Between 2-3GHz	
	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz
Value by spectrum band	50.27	50.27	17.05	10.91	10.91
Relative value	1	1	0.34	0.22	0.22

VI. Estimation of spectrum values by band and comparison with the reassignment fee

6.1 Calculation results

In Section 6, we aim to derive the value of each spectrum band obtained earlier and compare it with the spectrum reassignment fee set by the South Korean regulatory. First, the auction prices in 2011, 2013, and 2016, along with estimates based on the production function approach, are presented in Table 11. The total spectrum value by using the production function was 1,953 million USD. As mentioned earlier, the auction-winning bid for the 1800MHz band was high in the 2013 auction, resulting in the highest bid in 2013.

Table 11. Comparison with estimate of spectrum value

	Production function estimate	Auction 2011	Auction 2013	Auction 2016
Comparison with spectrum value (unit: mil USD)	1,953	1,519	2,168	1,884

Table 12 summarizes the actual reassignment fee and the estimated spectrum value by band using the Cobb-Douglas production function method.

Table 12. Comparison of reassignment fee and production function estimate from this study (unit: mil USD)

	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz	TOTAL
Actual Reassignment fee	405	126	978	1,103	193	2,805
Our estimate	269	135	472	808	269	1,953

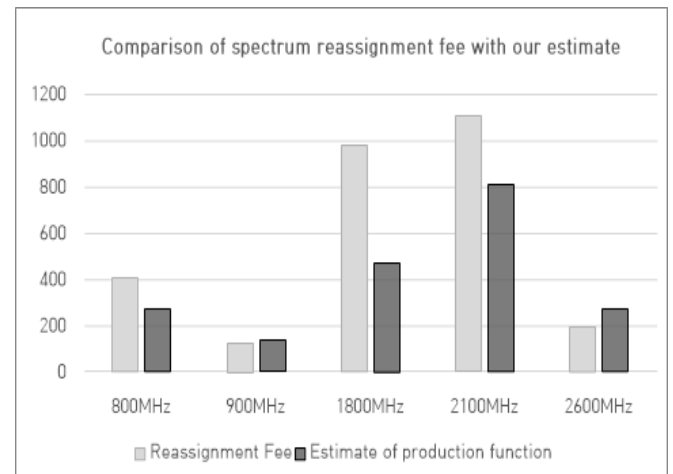


Figure 3. Comparison of reassignment fee and the estimate from this study

Our estimate was calculated by multiplying the price per spectrum unit by the bandwidth assigned for each band. The estimated values by the band using the production function method in this study are lower than the actual reassignment fee, except for the 900MHz and 2600MHz band.

Particularly, the significant difference for the 1800MHz band is noticeable. This band was found to have a 2.07 times higher actual reassignment fee. It appears to be because the reassignment fee largely reflects past auction prices.

The differences become even more apparent when examining the price per MHz. This result reflects differences in value across each spectrum band. All of the high-frequency bands appear to be significantly lower than the actual reassignment fees (Table 13, Figure 4).

Table 13. Comparison of spectrum fees with applied relative weights and actual reassignment fees (unit: million USD per MHz)

	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz
Actual Reassignment fee	10.1	6.3	13.9	9.1	4.8
Our estimate (applying the relative value)	6.7	6.7	2.2	1.4	1.4

Since we considered the characteristics of frequencies such as path-loss by band, it is observed that the value of the low-frequency band has increased compared to the previous estimate. Also, the value of the high-frequency band has decreased. In particular, the estimate of 900MHz band in this study is higher than the actual reassignment fee.

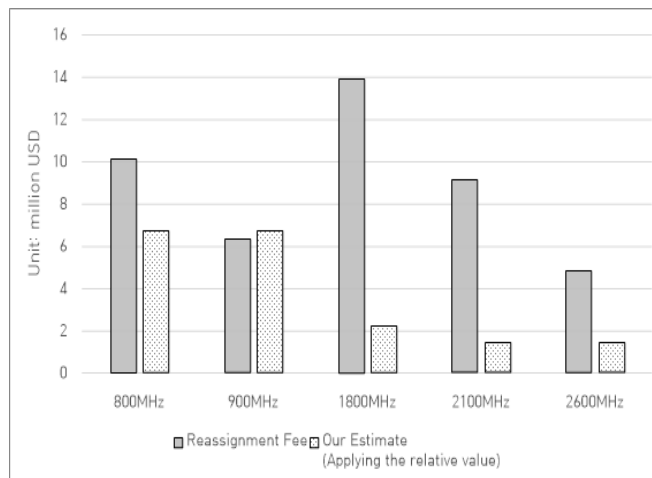


Figure 4. Comparison of spectrum fees with applied relative weights and actual reassignment fees

6.2 Discussion

Overall, it can be noted that the actual reassignment fee of 2,805 million USD is considerably higher than the production function estimate of 1,953 million USD in this study. Besides, comparing the reassignment fee by band also indicates that they are relatively high. For example, in the 800MHz band case, the actual reassignment fee is approximately 1.5 times higher than the estimate in this study. Similarly, compared to the estimates, reassignment fees for the 1800MHz and 2100MHz bands are set 2.07 times and 1.37 times higher. This difference is interpreted as being because the reassignment fee in South Korea largely reflects past auction prices.

Like those in other countries, South Korea's mobile communication services generated relatively high profits with the introduction of LTE in the 2010s. The high auction prices for LTE spectrum are attributed to this phenomenon. Considering the reassignment fee based on auction prices at that time may seem excessive even according to the DCF analysis. This is because each of the three MNOs has been assigned 100MHz for the 5G 3.5GHz band, and the contribution of the LTE spectrum is gradually decreasing. To accurately assess the value of the LTE spectrum, it is necessary to determine the proportion of traffic handled by LTE bands in 5G services. From this, multiplying the traffic handling proportion by the reassignment fee calculated using the DCF method can provide an approximate estimate of the contribution of LTE bands.

VII. Conclusion

In this paper, we've estimated to derive the value of spectrum by combining economic and engineering methodologies. Then, we compared the value of spectrum for each band with the actual reassignment fee.

We assumed that traffic capacity is produced by two factors of production: BTS and spectrum. Using quarterly traffic data from 2012 to 2019, we estimated the spectrum production

function based on the traffic data and derived the value of the unit spectrum from it. The total spectrum value was 1,953 million USD. Furthermore, we conducted the DCF analysis by applying the WACC of 5.32% as the discount rate to roughly assess the value of the spectrum from 2022 to 2026 and compared it with the result of the production function. The estimated value per MHz of spectrum by using Cobb Douglas production function was 6.74 million USD, while the estimate of DCF was 10.36 million USD.

Also, we derived the value of the spectrum for each band from the perspective of investment, assuming that the value varies according to the characteristics of the radio waves. In this process, we applied different ratios for urban, suburban, and rural areas to determine the relative weights. The value of the spectrum for each band was calculated by applying the relative weights of each band to the total value of frequencies obtained earlier. The results generally indicate that the reassignment fee in 2021 was calculated to be high, both in absolute amounts and for each spectrum band.

These results were anticipated as South Korea benchmarked its spectrum reassignment fee based on past auction prices. Considering that the proportion of LTE spectrum in mobile traffic is decreasing over time, a more reasonable calculation method appears needed.

The method attempted in this study is expected to serve as a reference not only for South Korea, which faces spectrum reassignment but also for other countries in calculating their spectrum reassignment fees.

Lastly, the limitations of this study are as follows. First of all, there is the data constraints. If we could quantitatively determine the extent to which the LTE spectrum contributes to processing traffic for current 4G and 5G services, we could more accurately calculate the price of the LTE spectrum. Next, we assumed that there is only one type of BTS and used average investment costs in this study. However, considering the diversity of BTS types, it would be more desirable to reflect this diversity in the analysis. These limitations will

remain a task for future research.

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