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Comparison of spectrum distribution among network operators and market structure in mobile telecommunications

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Abstract

Spectrum is an essential input of mobile communication services. Spectrum auctions, in principle, are favorable to mobile telecom operators that have strong financing capabilities. For this reason, it has been argued that auctions induce bandwidth differences among operators and hinder competition within the retail market. To date, no empirical study has addressed this issue. Therefore, the current study examines trends in the spectrum distribution and market structure of 10 countries from 2001 to 2017, using the Hirschman–Herfindahl Index (HHI) calculation method. In some (but not all) countries, the Market HHI has been reduced to the Spectrum HHI level. We found that the spectrum distribution in Belgium, France, Germany, Spain, and Sweden remained almost even and unchanged for an extended period. Further research into what happened in these countries may contribute to more rigorous research and policies vis-à-vis spectrum allocation.

Keywords: spectrum distribution, market structure, mobile telecommunications

1. Research background

Within an approximately 10-year period, mobile telecommunications services have evolved from the first generation to the fifth. While spectrum is an input essential to mobile services and its bandwidth has a profound impact on the data transmission capacity and speed, with the growth of market demand, it has become increasingly scarce. For example, mobile operators demanded the digital dividend spectrum in the 700 MHz band that broadcasters and public safety agencies also claimed (Kim and Kim, 2014). Therefore, it has been reasonable for spectrum to be distributed via auctions where a competitive bidding process decides the winners of the spectrum bands auctioned.

However, given the nature of an auction, the spectrum is not likely to be distributed evenly among all mobile network operators (MNOs); rather, it will be dispersed among MNOs that value it more highly than others and are therefore likely to bid at higher prices and win more spectrum bandwidth. For this reason, the concern has been voiced that auctions may limit the ability for market competition to develop further (Park et al., 20011). Therefore, lagging MNOs have insisted that an equal amount of spectrum be distributed to all

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MNOs, stating that doing so would encourage market competition and ultimately benefit consumers. Peha (2017) argues that because of economies of scale, it is best to distribute the frequency equally among MNOs. On the other hand, leading MNOs have insisted that they receive more bandwidth than the lagging MNOs, simply because they serve more subscribers. Although the equal allocation of the spectrum may appear to contradict the market mechanism of resource allocation, it is more onerous for national regulatory agencies to disregard it completely when auctioning the spectrum for a new mobile generation. For example, in South Korea's 5G spectrum auction in 2018, the government set a very tight spectrum cap, so as to provide all MNOs with the opportunity to partake in 5G. That spectrum cap was designed so that all the MNOs could have at least 60 MHz of bandwidth in the 3.5 GHz band; consequently, the three MNOs involved won 100 MHz, 100 MHz, and 80 MHz of bandwidth (see also Kim [2016] for the 4G spectrum auction cases of South Korea).

Market competition is known to be a factor promoting the diffusion of mobile communication services. Parker and Rőller (1997) found that the proliferation of US mobile telecommunications services accelerated after the transition from monopoly to duopoly. Similarly, Gruber and Verboven (2001a) found that introducing market competition in European countries affected the proliferation of mobile telecommunications services. According to Gruber and Verboven (2001b), mobile communication services became more popular when new MNOs entered the market sequentially than when they enter the market simultaneously. Koski and Kretschmer (2005) found that market competition did not directly affect 2G market growth but promoted it through price declines. Rouvinen (2006), Bohlin et al. (2010), and Li and Lyons (2012) also reported that market competition promoted the spread of 2G and 3G.

However, it has not been confirmed whether an equal amount of spectrum distributed to all MNOs encourages market competition. Previous studies have focused on the effects of auctions on market structure, rather than spectrum allocation among MNOs. Kuroda and Forero (2017) found that 3G auctions lowered the HHI of the 3G market. Park et al. (2011) conducted an empirical analysis of the impact of the auction on the market structure, but found no statistically significant relationship between these two factors. On the other hand, Gruber (2007) found that the number of 3G MNOs in a country that allocated spectrum by auction in 2004 was less than that of 2G MNOs. With regard to the results of Gruber (2007), Park et al. (2011) point out that the number of MNOs launching the 3G service gradually increased, and 3G and 2G are not considered separate markets.

Previous studies often relate market structure to license fees. Standard economics tells us that market competition depends on the expected income of MNOs, not on license fees for spectrum. However, some objections to that argument have been (Kuroda and Forero, 2017). For example, Noam (1998) pointed out that an upfront license fee could have a negative impact on market competition because it acts as an entry barrier to a new MNO. Gruber (2001) argued that an auction has a high risk of an excessive license fee, and that the exorbitant license fee could weaken market competition due to bankruptcy of MNOs, or that it could incentivize collusive behavior among existing MNOs.

The current study examines trends in spectrum distribution and market structure. It investigates whether the market structure becomes more competitive as the spectrum becomes more evenly distributed.

2. Data and analysis

This section is organized into two parts. We first review previous studies on the sustainability of social network, and find the theoretical background of my research framework. We also review previous studies

related to virtual worlds and online games and identify the difference between this research and previous studies.

2.1 Data

The data used herein originate from 10 countries—namely, Austria, Belgium, Denmark, France, Germany, Netherlands, South Korea, Spain, Sweden, and the United Kingdom—and are from the 2001–2017 period. The main data source is the Merrill Lynch Global Wireless Matrix, which reports on the market performance of all active MNOs in each of the 10 country. Data on the spectrum holdings of individual MNOs were collected from the official documents of national regulatory authorities.

The data include many missing observations related to service revenue, average revenue per user, and earnings before interest, taxes, depreciation, and amortization. Given the absence of sufficient market information on MNOs, the number of subscribers was used as a proxy for the dynamics of market structure over time.

In terms of spectrum allocation and market structure for the 2001–2017 period, Table 1 lists the major events that took place in the mobile telecommunications markets of the countries studied. Generally, a decrease of spectrum concentration appears as the result of spectrum allocation through so-called "beauty contests" and "refarming." Because beauty contests allocate spectrum through administrative procedures rather than auctions, the difference in spectrum bandwidth among the MNOs tends to decrease in such cases. Refarming assigns to MNOs any spectrum returned to the government, through administrative procedures. In such cases, more bandwidth tends to be allocated to MNOs with small bandwidth holdings. Mergers and acquisitions (M&As), on the other hand, have the effect of increasing spectrum concentration. The spectrum concentration can also be increased by auctions, but if there is a spectrum cap, the effect can be mitigated.

Table 1. Major events related to spectrum awards and market structure, 2001–2017

	Spectrum-related events	Market-related events
Austria	Auction: 2010, 2013 Spectrum trade: 2004	M&A: 2013
Belgium	Auction: 2001, 2011, 2013 Refarming: 2014	M&A: 2015
Denmark	Auction: 2001, 2005, 2010, 2012, 2016 Returned to government: 2005 Refarming: 2011	M&A: 2005
France	Beauty contest: 2010 Auction: 2011, 2015 Refarming: 2013, 2014, 2016	New entrant: 2010
Germany	Auction: 2010, 2015	M&A: 2014
Netherlands	Auction: 2010, 2011, 2012 Returned to government: 2009 Refarming: 2012	M&A: 2005, 2007
S. Korea	Auction: 2011, 2013, 2016 Refarming: 2011	
Spain	Beauty contest: 2005 Auction: 2011	

	Refarming: 2011	
Sweden	Beauty contest: 2001 Auction: 2008, 2011, 2016 Refarming: 2004, 2009,	
United Kingdom	Auction: 2013 Returned to government: 2013, 2015 Spectrum trade: 2015	M&A: 2009

Note: M&A: merger and acquisition

Table 2 shows the number of MNOs in each country examined in the analysis. The number of MNOs by country is the number of companies included in the Merrill Lynch Global Wireless Matrix data, and in most countries, this number is equal to the total number of MNOs. However, a small business acquired by Mobilkom, Austria's largest MNO in 2003 and 2006, was excluded, as there was a lack of relevant information on it.

Table 2. Number of MNOs in each country, 2001–2017

year	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17
Austria	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3
Belgium	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Denmark	4	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4
France	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4
Germany	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3
Netherlands	5	5	5	5	4	4	3	3	3	3	3	3	3	3	3	3	3
S. Korea	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Spain	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Sweden	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
U.K.	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4
Avg.	4.0	4.1	4.1	4.0	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.7	3.6	3.6	3.6	3.6

In most of the countries in Table 2, the number of MNOs is currently three or four. (By 2017, the number of MNOs in each of Denmark, France, Sweden, Spain, and the United Kingdom was four, and in each of the other countries it was three.) During the study period, the number of MNOs in Austria, Denmark, Germany, the Netherlands, and the United Kingdom decreased; in the other countries (except for France), there was no change in the number of MNOs. Exceptionally, in 2010, the number of MNOs in France increased from three to four.

2.2 Analysis

To investigate the status of spectrum distribution in each of the studied countries, the share of each MNO was calculated as the ratio of its spectrum bandwidth to the sum of all bandwidth among all MNOs in the country. Additionally, we calculated the share difference between the MNO with the largest spectrum holding

and that with the smallest holding. A "zero" share difference would indicate a uniform distribution of spectrum among all MNOs.

Although share difference can straightforwardly describe spectrum distribution by comparing two MNOs, as a measure it is not comparable to market structure, as it ignores the other MNOs within the market. Therefore, we use the Hirschman–Herfindahl Index (HHI) to investigate the overall spectrum distribution and market structure over time. We calculate the HHI for spectrum distribution using the spectrum share of each MNO. Additionally, we calculate the HHI for market structure by using the subscriber share of each MNO. Note, however, that this HHI is not suited for making inter-country comparisons, as the numbers of MNOs are not identical across all countries; for this purpose, we use the ratio of the actual HHI to a benchmark HHI. In countries with four MNOs, the benchmark HHI is 2500; in those with three MNOs, it is 3333. For example, when the actual HHI is 2750 in a country that has four MNOs, the ratio is 1.10. The HHI ratios for spectrum distribution and for market structure are referred to as "Spectrum HHI" and "Market HHI," respectively.

The HHI is significantly affected by the number of MNOs, which in the sample data varies from three to five and is not of research interest. Additionally, its use would make it difficult to pinpoint trends. The number of MNOs changes whenever there is an M&A or a new MNO enters the market. Such events affect both the Spectrum HHI and the Market HHI in the same direction, and are not caused by any changes in the distribution of spectrum holdings across MNOs. Therefore, we focus on a study period during which the number of MNOs did not vary.

3. Spectrum distribution and market structure trends

3.1 Spectrum distribution trends

3.1.1 Differences in spectrum share

Table 3 shows for each country the annual share difference between the MNO with the largest spectrum holding and that with the smallest holding, from 2001 to 2017. The overall trend varied substantially from country to country. Although spectrum auctions are assumed to favor financially stronger MNOs, this did not always increase the share difference; in fact, it sometimes reduced it.

In Austria, the spectrum share difference started at 0.23 in 2001, peaked at 0.30 during 2006–2010, decreased to 0.02 in 2013 due to an M&A, and finally increased to 0.23 in 2016. That of Belgium remained below 0.04, which indicates that the country has a nearly uniform distribution of spectrum across MNOs. In Denmark, it peaked at 0.27 in 2004 before showing a downward trend. France distributed an equal amount of bandwidth over the MNOs in the 2000s, but its share difference showed a sudden increase to 0.29 in 2010, due to the entry of a fourth MNO. In Germany, the share difference remained at 0.04 before it surged to 0.24 in 2014. This surge was due to the acquisition of the third-largest MNO by the fourth-largest MNO. South Korea's share difference was the highest of the 10 countries during 2006–2010, as its third-largest MNO returned its 3G license to the government in 2006. In the Netherlands, the share difference increased in 2005 (when the largest MNO acquired the fifth-largest MNO), and it decreased in 2007 (when the third-largest MNO acquired the fourth-largest MNO). Additionally, following the spectrum auctions, the share difference dropped further in 2010 and 2012. In Sweden, the share difference dropped in 2005 due to the withdrawal of some bandwidth from all the MNOs. The spectrum auction in Spain reduced the share difference in 2012. The United Kingdom experienced a large increase in the share difference in 2010 because of M&As between

MNOs. As of 2017, Belgium showed the most uniform spectrum distribution, while the United Kingdom showed the largest spectrum share difference.

3.1.2 Spectrum HHI trends

The Spectrum HHI is the ratio of actual HHI to benchmark HHI. The actual HHI was calculated by squaring the spectrum share of each MNO and then summing the resulting numbers. Therefore, it depends significantly on the number of MNOs which is not identical across all countries. However, it does not indicate the number of MNOs involved in the calculation. As a result, the actual HHI on its own is not suited for making inter-country comparisons. A better measure can be the Spectrum HHI attained by dividing the actual HHI by the benchmark HHI, which is indicative of the uniform spectrum distribution among MNOs. It allows for easy measurement of the proximity of the observed spectrum distribution to the uniform situation.

Table 3. Differences in bandwidth share between the MNOs with the largest and smallest spectrum holdings in each country, 2001–2017

	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17
AUS	0.23	0.23	0.23	0.29	0.26	0.30	0.30	0.30	0.30	0.30	0.17 (a)	0.17	0.02 (m)	0.08 (a)	0.08	0.23 (a)	0.23
BEL	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.03 (a)	0.02 (a)	0.00	0.01	0.01	0.01
DEN	0.14 (a)	0.20	0.20	0.27	0.27	0.24	0.24	0.24	0.24	0.12 (a)	0.05	0.05	0.07 (a)	0.07	0.07	0.07	0.07
FRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29 (e)	0.27	0.21	0.20	0.20	0.18	0.17	0.12
GER	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.24 (m)	0.24	0.11 (r)	0.08
NET	0.11	0.11	0.11	0.11	0.31 (m)	0.31	0.25 (m)	0.25	0.21	0.12 (a)	0.12	0.12	0.06 (a)	0.06	0.06	0.06	0.06
S. KOR	0.13	0.13	0.13	0.13	0.13	0.37 (r)	0.37	0.37	0.37	0.37	0.20 (a)	0.19	0.08 (a)	0.08	0.08	0.11 (a)	0.11
SPA	0.22	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.18 (a)	0.18	0.18	0.19	0.20	0.20
SWE	0.20	0.20	0.20	0.20	0.11 (r)	0.11	0.11	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.13
U.K.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.38 (m)	0.38	0.38	0.35	0.35	0.35	0.28 (r)	0.28
Avg.	0.13	0.13	0.13	0.14	0.15	0.18	0.17	0.17	0.17	0.20	0.16	0.15	0.11	0.14	0.14	0.14	0.13

Notes: (a) denotes changes arising from spectrum auctioned; (e) denotes changes arising from the entry of a new MNO; (m) denotes changes arising from an M&A between MNOs; and (r) denotes changes arising from spectrum withdrawn by the government, or spectrum that has been reframed or traded.

Table 4 shows the Spectrum HHI of the 10 aforementioned countries during the 2001–2017 period. Note that a Spectrum HHI value approximating 1 indicates a uniform spectrum distribution across all MNOs in that country. The Spectrum HHI trends are similar to those of the share difference (Table 3); this implies that the Spectrum HHI is a good measure of overall spectrum distribution.

Table 4. Changes in Spectrum HHI in each country, 2001–2017

	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17
AUS	1.12	1.12	1.12	1.18	1.16	1.22	1.22	1.22	1.22	1.22	1.09	1.09	1.00	1.01	1.01	1.08	1.08
BEL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DEN	1.05	1.11	1.11	1.19	1.19	1.13	1.13	1.13	1.13	1.03	1.00	1.00	1.01	1.01	1.01	1.01	1.01
FRA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.26	1.20	1.11	1.11	1.11	1.08	1.06	1.03
GER	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.12	1.12	1.03	1.01
NET	1.04	1.04	1.04	1.04	1.26	1.26	1.10	1.10	1.06	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.01
S.KOR	1.03	1.03	1.03	1.03	1.03	1.24	1.24	1.24	1.24	1.24	1.06	1.06	1.01	1.01	1.01	1.02	1.02
SPA	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.08	1.08	1.08	1.10	1.10	1.10
SWE	1.09	1.09	1.09	1.09	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.04
U.K.	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.32	1.32	1.32	1.28	1.28	1.28	1.21	1.21

Note: The numbers in this table are ratios of actual HHI to benchmark HHI.

3.2 Market structure trends

3.2.1 Differences in market share

Table 5 shows for each country the market share difference between the largest MNO and the smallest MNO with respect to the number of subscribers, from 2001 to 2017. The share difference between MNOs with the largest number of subscribers and the smallest number of subscribers increases significantly in the year when a new MNO started to provide its services to customers. But, if a new MNO was awarded spectrum in a year prior to the year in which it started providing its services, the spectrum share difference does not change.

In 2001, the differences in market share was large in most countries such as Belgium (0.40), Denmark (0.42) and Korea (0.38). But in the United Kingdom it was only 0.06. In 2017, this number increased in the United Kingdom and declined in the rest of the countries compared to 2001.

In Austria, the market share difference has decreased since 2010. It increased from 0.24 in 2002 to 0.43 in 2003 due to the launch of Hutchison's 3G service, the fourth MNO. However, there was no change in spectrum share because Hutchison secured spectrum for 3G service in 2000. The decline in the market share difference in 2013 was due to the M&A between the third-largest and the fourth-largest MNOs.

In Belgium, the market share difference has shown an upward tendency since it declined from 0.42 in 2001 to 0.08 in 2011. In Denmark, it has generally declined except for 2003. This is because the fourth MNO (Hi3G), which already had acquired spectrum previously, started service in 2003.

France's share difference continued to decline overall, but rose to 0.19 in 2017. In Germany, the difference in market share decreased steadily from 0.35 in 2001 to 0.09 in 2014, but remained at 0.11 since then. In the Netherlands, the share difference increased to 0.38 as the largest MNO took over the fourth-largest MNO in

2005, but it dropped sharply to 0.17 in 2007 as the third-largest MNO acquired the fourth-largest MNO in 2007. Subsequently, the number increased from 0.11 in 2011 to 0.21 in 2017.

In South Korea, the market share difference gradually decreased from 0.38 in 2001 to 0.27 in 2017. In Spain, it increased sharply from 0.24 in 2005 to 0.46 in 2006 due to the launch of the fourth MNO (Yoigo). In Sweden, Hutchison, which already possessed 3G spectrum, launched 3G service in 2003 and the market share difference widened. In the United Kingdom, Hutchison's launch of 3G service in 2003 and the M&A between the third-largest MNO (T-Mobile) and the fourth-largest MNO (Orange) in 2010 increased the difference in market share.

Table 5. Differences in market share between the largest and the smallest MNO, 2001–2017

	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17
AUS	0.24	0.24	0.43	0.39	0.36	0.35	0.35	0.37	0.36	0.33	0.30	0.27	0.17	0.14	0.12	0.12	0.13
BEL	0.40	0.39	0.38	0.30	0.30	0.23	0.21	0.17	0.12	0.11	0.08	0.13	0.12	0.14	0.16	0.20	0.26
DEN	0.42	0.37	0.50	0.46	0.46	0.47	0.41	0.37	0.36	0.33	0.35	0.34	0.30	0.22	0.22	0.21	0.21
FRA	0.30	0.35	0.33	0.31	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.36	0.29	0.26	0.27	0.14	0.19
GER	0.35	0.34	0.32	0.28	0.25	0.24	0.24	0.23	0.22	0.18	0.17	0.15	0.17	0.09	0.11	0.12	0.11
NET	0.34	0.33	0.29	0.27	0.38	0.39	0.29	0.17	0.19	0.15	0.11	0.12	0.13	0.16	0.22	0.21	0.21
S. KOR	0.38	0.38	0.40	0.35	0.34	0.33	0.33	0.32	0.33	0.33	0.33	0.31	0.30	0.30	0.29	0.29	0.27
SPA	0.31	0.25	0.22	0.22	0.24	0.46	0.44	0.43	0.41	0.38	0.36	0.31	0.29	0.30	0.28	0.28	-
SWE	0.34	0.30	0.46	0.44	0.42	0.43	0.40	0.40	0.38	0.36	0.36	0.35	0.34	0.30	0.28	0.27	0.28
U.K.	0.06	0.02	0.25	0.21	0.20	0.20	0.19	0.19	0.19	0.28	0.25	0.23	0.19	0.18	0.18	0.18	0.16
Avg.	0.31	0.30	0.36	0.32	0.33	0.34	0.32	0.29	0.29	0.27	0.26	0.26	0.23	0.21	0.21	0.20	0.20

Note: In Spain, information on the number of subscribers is missing in 2017

3.2.2 Market HHI trend

Table 6 shows the Market HHI trends during 2001-2017. The Market HHI is the ratio of actual HHI to benchmark HHI. The benchmark HHI represents the situation in which the market shares of all MNOs for a given country are identical. Therefore, the market HHI measures the level of competition given the number of MNOs. It can be seen that market structure has become more competitive over time in most countries.

In Denmark, the Market HHI surged in 2002 because Hi3G, which already had 3G spectrum, started service in 2003. Specifically, the number of MNOs increased from 4 to 5, and the benchmark HHI decreased, but the Market HHI increased because the Hi3G did not start service and the actual HHI did not change. Therefore, when analyzing the Market HHI, it is necessary to exclude the period in which only the number of MNOs changes with no services provided by a new company.

In the Netherlands, the number of MNOs decreased and the benchmark HHI increased due to the acquisition of the fourth-largest MNO (Telfort) by the largest MNO(KPN) in 2005. However, the actual HHI increased further due to the increase in the market share of KPN. As a result, the Market HHI increased. In

2007, the Market HHI declined, as the benchmark HHI declined due to M&A between the third-largest and the fourth-largest MNOs

Table 6. Changes in Market HHI, 2001–2017

	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17
AUS	1.45	1.45	1.44	1.38	1.34	1.29	1.29	1.31	1.28	1.24	1.21	1.16	1.05	1.03	1.02	1.02	1.03
BEL	1.23	1.23	1.21	1.14	1.13	1.08	1.07	1.04	1.03	1.02	1.01	1.03	1.02	1.03	1.04	1.07	1.11
DEN	1.40	1.71	1.78	1.44	1.43	1.45	1.34	1.27	1.27	1.23	1.27	1.25	1.20	1.11	1.10	1.09	1.10
FRA	1.14	1.18	1.16	1.15	1.14	1.14	1.14	1.14	1.14	1.51	1.51	1.31	1.23	1.21	1.19	1.06	1.08
GER	1.37	1.37	1.33	1.28	1.23	1.20	1.19	1.17	1.14	1.10	1.08	1.06	1.06	1.01	1.02	1.03	1.02
NET	1.45	1.36	1.21	1.14	1.36	1.37	1.15	1.05	1.07	1.04	1.02	1.02	1.03	1.04	1.07	1.07	1.07
S. KOR	1.21	1.22	1.24	1.18	1.17	1.16	1.16	1.16	1.16	1.16	1.16	1.15	1.14	1.14	1.13	1.13	1.12
SPA	1.56	1.47	1.44	1.43	1.45	1.45	1.41	1.40	1.36	1.31	1.28	1.21	1.19	1.19	1.19	1.19	-
SWE	1.57	1.52	1.51	1.46	1.44	1.40	1.35	1.35	1.33	1.31	1.30	1.29	1.26	1.21	1.19	1.18	1.18
U.K.	1.26	1.25	1.24	1.16	1.14	1.14	1.13	1.12	1.11	1.17	1.14	1.11	1.09	1.09	1.08	1.08	1.06

Note: The figures in this table are ratios of actual HHI to benchmark HHI.

## 3.3 Comparisons of Spectrum HHI and Market HHI

As the addition of bandwidth adds to the overall service capacity, the Spectrum HHI is likely to relate to market structure. Therefore, the research question in the current study is whether market structure is more competitive in a country where the spectrum distribution across MNOs is more uniform. More precisely, the Market HHI should approach the Spectrum HHI in the long term, and in the shorter term the two HHI values should move in the same direction within the same year. The former scenario assumes that additional spectrum will be used gradually over time, as network rollout for that spectrum does take time; the latter scenario, on the other hand, assumes that all the additional bandwidth is used immediately.

As Figure 1 shows, the Spectrum HHI of Belgium, France, Germany, Spain, and Sweden not only remained almost unchanged, but also remained lower than the Market HHI. Since the Spectrum HHI has not changed, it is useful in understanding trends.

Between 2001 and 2011, Belgium's Market HHI decreased to its Spectrum HHI level, but it increased again starting in 2012. In France, the Spectrum HHI remained at the same level, but the Market HHI did not diminish. In Germany and Sweden, the Market HHI has been steadily decreasing, and approaching the Spectrum HHI level. In Spain, the Market HHI has decreased in the absence of Spectrum HHI changes.

In other countries, the Spectrum HHI changed over time. In Denmark, while the Spectrum HHI declined, the Market HHI was also in decline; however, the Market HHI increased in 2006 and 2011. In Austria, the Spectrum HHI increased in some cases, but the Market HHI showed a tendency to decrease to the Spectrum HHI level. In South Korea between 2006 and 2010, the Spectrum HHI exceeded the Market HHI. The Netherlands seems to have no trend. In the United Kingdom, the Spectrum HHI exceeded the Market HHI.

Figure 1. Comparisons of Spectrum HHI and Market HHI
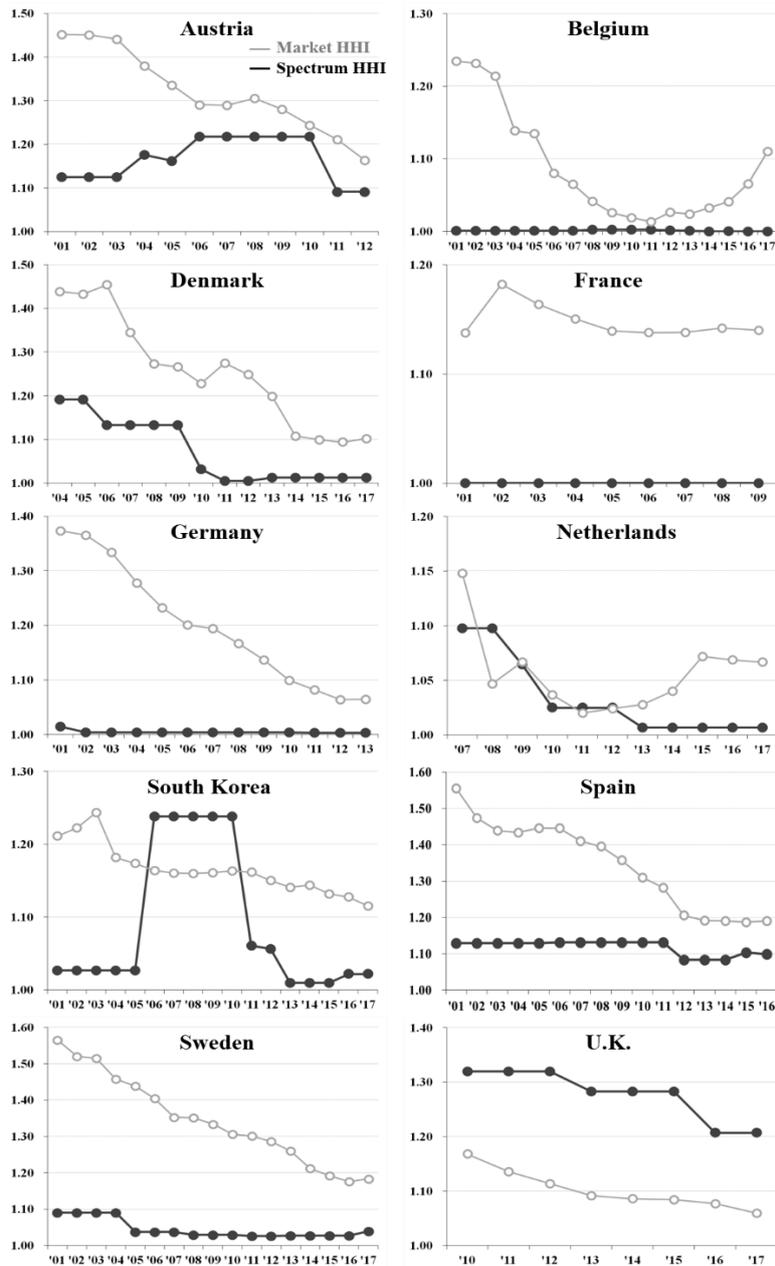
4. Study implications

To the best of our knowledge, this study is the first to compare spectrum distribution and market structure by using actual data.

In Germany and Sweden, the market has gradually become more competitive as the spectrum becomes more evenly distributed. In other countries, however, it is difficult to determine the relevance of, and relationship between, these two measures. In particular, for Belgium and Spain—both of which had trends similar to those in Germany and Sweden—the market became less competitive, even as the spectrum distribution remained unchanged. In France, furthermore, the spectrum distribution and the market structure seem to be wholly independent of each other.

Although the trends are difficult to interpret, it turns out that the spectrum distribution in Belgium, France, Germany, Spain, and Sweden has remained virtually steady and unchanged over a protracted period. A better understanding of what has occurred in those countries may contribute to more rigorous research and inform more effective spectrum allocation policies.

This study, like any, has limitations. The spectrum is an input factor of mobile communication services, and those services can be made available through base station construction. As a result, the effects of additional bandwidth can be seen over an extended period. The time-delay effect will be minimized when initiating a new mobile communication service: network construction will be swiftly achieved, given the intense competition for infrastructure construction and how it tends to stay ahead of market demand. Therefore, it is essential to distinguish the allocation of the first lot of spectrum for a new mobile communication service and the allocation of additional spectrum: if equalizing the initial spectrum distribution can make the market more competitive, a tightening of the spectrum cap in the auction may be considered. Likewise, if an equal or unequal allocation of additional spectrum does not significantly change the market structure, there will be a limited need to establish a spectrum cap. Finally, this study does not take into account that various factors can affect spectrum allocation and market structure. In general, spectrum policy tends to take into account market structure: if the market is less competitive, regulatory authorities are more likely to try to allocate additional spectrum to the MNO with the smallest spectrum holding than to the one with the largest, to make the overall spectrum distribution more uniform.

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