Annex 1 – International spectrum concentration investigation

By Ofcom's own analysis[1], spectrum concentration in the UK is high compared to other four-player markets in Europe. Ofcom's analysis concludes that the UK has the second largest spectrum asymmetry in those countries.

Three carried out a comprehensive analysis of spectrum concentration across 95 different markets, which included all countries in the developed world.

By widening the scope of the analysis it can be shown that not only does the UK have one of the highest levels of spectrum concentration in Europe; it has one of the worst levels of spectrum concentration in the developed world.

In summary, the UK has:

- The 3rd largest spectrum imbalance amongst the 50 largest economies in the world (as measured by GDP) – only Thailand and Malaysia have more extreme distributions of spectrum;
- The worst spectrum asymmetry of all countries in the G20 – this is the international forum of all 20 major economies in the world;
- The 2nd largest spectrum imbalance in Western Europe – second only to Iceland (a thinly populated island of 300k inhabitants).

This annex sets out the detail of our analysis and method, discussing:

a. Summary of Three's analysis and Key findings
b. Data sources
c. Data considerations
d. Validation and review
e. Application of the Gini coefficient
f. Detailed findings

[1] Annex 6 to the Consultation Document

a. Summary of Three's analysis and key findings

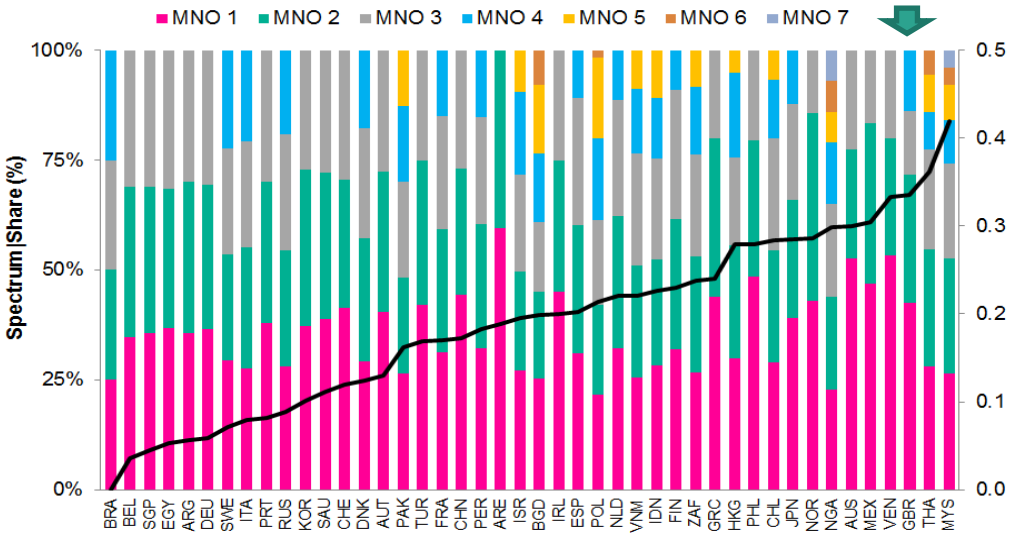
Like Ofcom, Three measured the degree of inequality in the distribution of spectrum according to the Gini index.

A Gini coefficient was calculated for each country, where zero would represent an equal distribution (each MNO has 1/n of total spectrum)[2]. The Gini coefficient calculated for the UK was **0.34**.

Three agrees with the conclusion of Ofcom's analysis in Annex 6 – the UK has the second largest spectrum asymmetry in European four-player markets. By widening the scope of the analysis it can also be shown that **the UK has the 3rd largest spectrum imbalance amongst the 50 largest economies in the world.**

The UK Gini coefficient of 0.34 is higher than all of the top 50 economies (measured by GDP) with the exception of Thailand (0.36, 6 operators) and Malaysia (0.42, 7 operators)

Figure 1: Spectrum distribution in 50 largest economies

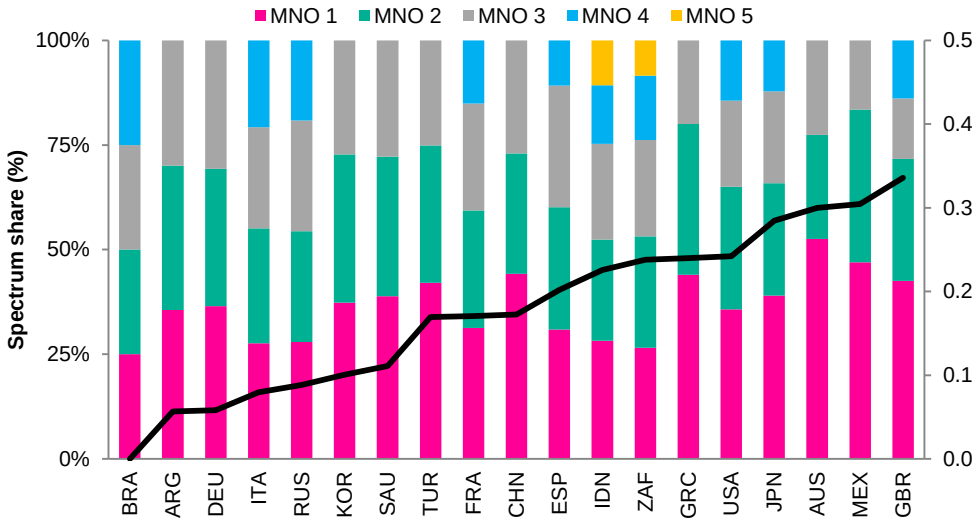


[2] In order to compare the UK to markets with a different number of MNOs, it was necessary to calculate the Gini coefficient using a slightly different method to Ofcom, which adjusts for the number of MNOs. This results in higher Gini coefficients for all countries (including the UK) and is discussed further in section (e)

The UK has the worst spectrum asymmetry of all countries in the G20

The UK Gini coefficient of 0.34 compares poorly to the G20 average of 0.18.
Mexico is the country with the next most unequal distribution of spectrum, with a Gini coefficient of 0.31.

Figure 2: Spectrum distribution in G20 countries

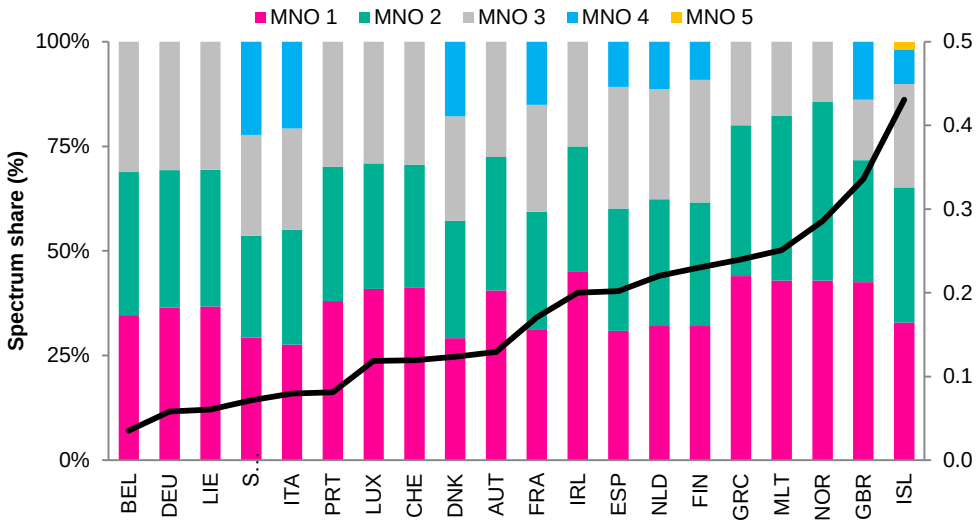


The UK has the second largest spectrum imbalance in Western Europe

Only Iceland has higher spectrum concentration (a Gini coefficient of 0.43).

Iceland is a sparsely populated island (approx 300k inhabitants).
Note that Three's analysis did not include Slovenia in the 'Western Europe' group, though our analysis also found that spectrum is more concentrated in Slovenia than in the UK. This should be considered in context – the fourth operator in Slovenia (T2) has 5% spectrum share, 3% subscriber share, has reportedly filed for bankruptcy and should arguably not be considered a credible national MNO.

Figure 3: Spectrum distribution in Western European Countries



b. Data sources

Our analysis used a number data sources:

Cullen

We sourced Spectrum holdings for Western Europe from the 26th April 2016 iteration of Cullen's Mobile operators' licences database[3]. Information on the following countries was available: Austria, Belgium, Switzerland, Germany, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Sweden, and the UK.

The dataset included licences in the following bands:
800MHz, 900MHz, L-band (1452 – 1492MHz), 1800MHz, 2.1GHz paired and unpaired, 2.6GHz paired and unpaired.

Spectrum Monitor

On 24th June 2016 we gathered a cut of raw data for non-Western European countries from Spectrum Monitor[4]. Information was available for countries in all three ITU regions: 1 (Europe, Middle East, Africa), 2 (Americas), 3 (Asia Pacific).

[3] http://www.cullen-international.com/product/documents/CTTEEU20160061 (subscription required)
[4] http://www.spectrummonitoring.com/frequencies/ Note: we also used this dataset to identify 700MHz licences in Western Europe.

The dataset included spectrum holdings, by operator, for the following bands: 450MHz, 700MHz, 800MHz, 900MHz, 1800MHz, 2.1GHz (paired), 2.6GHz (paired and unpaired).

Policy Tracker – Global Spectrum Database

We purchased the 20th June 2016 iteration of Policy Tracker's Global Spectrum Database. Our licence included initial research by the Policy Tracker team to:

i. Isolate & identify national MNOs.
ii. Allocate spectrum holdings between joint ventures where relevant.
iii. Apply filters to the dataset enabling inclusion / exclusion of licences in 450MHz, 2.1GHz unpaired, and above 3GHz.

The database held licence information for the following bands: 450MHz, 700MHz, 800MHz, 850MHz, 900MHz, AWS-1, AWS-3, L-band, 1800MHz, 1900MHz, 2.1GHz, 2.3GHz, 2.6GHz, 3.5GHz, 3.7GHz.

We used Policy Tracker data primarily for cross checking and gap analysis of the raw data sets acquired from Cullen and Spectrum Monitor.

Analysys Mason spectrum awards database and desk research.

As discussed in part (d) of this annex, Analysys Mason audited our data. In doing so, they incorporated information sourced from their Spectrum Auction Tracker into the dataset.

Analysys Mason's Spectrum Auction Tracker contains accurate data and analysis of concluded and planned auctions of mobile and fixed wireless spectrum. Information about concluded auctions is available from 2005 and includes;

- geographical region, country and date of the auction,
- frequency and bandwidth,
- duration of licence,
- name of controlling regulatory agency.

All of which is compiled using publicly available information on the results of spectrum auctions held around the world. An Analysys Mason consultant is responsible for updating the Spectrum Auction Tracker on a monthly basis.

Additionally, they supplemented this with material gathered from desk research of regulator websites and other responsible national and regional bodies; as well as reviewing reputable third party sources, such as Telegeography.

c. Data considerations

We reduced inaccuracy and missing data by using a diverse set of reputable sources. However, we are conscious that it can be challenging to collate an accurate global picture of spectrum distribution.

Therefore, to simplify our analysis and ensure consistency, we:

i. Included licences between 700MHz and 2.6GHz.
ii. Excluded licences above 3GHz because of limited use information for these bands; and, the quantity of spectrum available in the band can distort the analysis.
iii. Included only national mobile operators (rather than regional licensees).
iv. Excluded the following countries:
    - Canada and India – due to the regional nature of some large operators.
    - Colombia and Iran – due to lack of available data.
v. Excluded unpaired 2.1GHz because Ofcom doesn't consider it to be 'relevant mobile spectrum'. And, this band is rarely used for mobile.

d. Validation and review

We produced a first draft spectrum licence database for bands between 700MHz and 2.6GHz and sent it to Analysys Mason for audit.

Analysys Mason cross checked information against their own data and undertook further desk research. They worked closely with Three's analysts to address discrepancies and refine the database into a final version containing licence data on 95 countries.

e. Application of the Gini coefficient

The Gini coefficient[5] is a measure of inequality in a distribution, in this case, the distribution of spectrum between national mobile operators in a given country.

When comparing spectrum distribution between countries we expressed the Gini coefficient as a zero to 1 index. Zero represented perfect equality and 1 denoted maximum inequality.

The Gini coefficient is typically used to estimate inequality in a distribution across a large population, such as the distribution of wealth in a country. Where the 'population' is a small number of MNOs the Gini coefficient will be understated unless it is normalised for the number of MNOs in the country.[6]

This is less important when all of the countries included in the analysis have the same number of operators (as in the Ofcom analysis). Regardless of whether the Gini coefficients are normalised, their value *relative to other countries in the sample group* is the same.

It becomes important when the countries included in the analysis have different numbers of MNOs (as in the Three analysis).

Three calculated the Gini coefficient as half of the relative mean absolute difference of operators' spectrum holdings, i.e. the mean of the difference between every possible pair of operators, divided by the mean size μ. The Gini coefficient G of a sample size n is given by

[5] http://www3.nccu.edu.tw/~jthuang/Gini.pdf

[6] For example, in a four-player market the Gini coefficient will be between zero and 0.75; however, in a three-player market the Gini coefficient will be between zero and 0.67; this makes comparison across markets with different numbers of MNOs difficult

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left|x_i - x_j\right|}{2n^2\mu}$$

This is equivalent to the method used by Ofcom to derive and Gini coefficient and is a biased estimator for the coefficient of a population. It ranges from zero to a maximum of (n-1)/n (where every individual except one has a size of zero).

To give an unbiased population coefficient it is necessary to multiply the sample Gini coefficient defined above by $n/(n-1)$[7]; that is:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left|x_i - x_j\right|}{2n(n-1)\mu}$$

f. Detailed findings

Figure 4 lists all of the countries included in the analysis, along with the Gini coefficient. The UK was ranked 16th most unequal out of 96 countries considered.
The 15 countries found to have a more unequal distribution of spectrum were:

Nepal, Cambodia, Slovenia, Iceland, Malaysia, Papua New Guinea, Slovak Republic, Bulgaria, Mongolia, Thailand, Belarus, Armenia, Latvia, Côte d'Ivoire, Costa Rica

[7] http://mathworld.wolfram.com/GiniCoefficient.html, also http://www.statsdirect.co.uk/help/nonparametric_methods/gini_coefficient.htm

Figure 4: Gini coefficient by Country

Country	Rank	Gini	Country	Rank	Gini	Country	Rank	Gini
Nepal	1	0.53	United States	33	0.24	Austria	65	0.13
Cambodia	2	0.47	Greece	34	0.24	Denmark	66	0.12
Slovenia	3	0.44	South Africa	35	0.24	Switzerland	67	0.12
Iceland	4	0.43	Finland	36	0.23	Luxembourg	68	0.12
Malaysia	5	0.42	Paraguay	37	0.23	Saudi Arabia	69	0.11
Papua New Guinea	6	0.40	Qatar	38	0.23	Laos	70	0.11
Slovak Republic	7	0.40	Indonesia	39	0.23	Korea	71	0.10
Bulgaria	8	0.37	Vietnam	40	0.22	Russia	72	0.09
Mongolia	9	0.37	Netherlands	41	0.22	Portugal	73	0.08
Thailand	10	0.36	Poland	42	0.21	Italy	74	0.08
Belarus	11	0.36	Spain	43	0.20	Tunisia	75	0.07
Armenia	12	0.36	Ireland	44	0.20	Sweden	76	0.07
Latvia	13	0.35	Bangladesh	45	0.20	Bahrain	77	0.07
Côte d'Ivoire	14	0.35	Israel	46	0.19	Liechtenstein	78	0.06
Costa Rica	15	0.34	United Arab Emirates	47	0.19	Germany	79	0.06
United Kingdom	16	0.34	Peru	48	0.18	Afghanistan	80	0.06
Myanmar	17	0.33	Moldova	49	0.18	Ghana	81	0.06
Venezuela	18	0.33	Albania	50	0.17	Argentina	82	0.06
Hungary	19	0.33	China	51	0.17	Egypt	83	0.05
Taiwan	20	0.31	Sri Lanka	52	0.17	Singapore	84	0.05
Uruguay	21	0.31	Romania	53	0.17	Kuwait	85	0.04
Mexico	22	0.30	France	54	0.17	Belgium	86	0.04
Bolivia	23	0.30	Turkey	55	0.17	Morocco	87	0.03
Australia	24	0.30	Estonia	56	0.17	Serbia	88	0.03
Nigeria	25	0.30	Pakistan	57	0.16	Czech Republic	89	0.01
Norway	26	0.29	Macedonia	58	0.16	Cyprus	90	0.01
Japan	27	0.28	New Zealand	59	0.16	Azerbaijan	91	0.00
Georgia	28	0.28	Croatia	60	0.15	Lithuania	92	0.00
Chile	29	0.28	Panama	61	0.14	Algeria	93	0.00
Philippines	30	0.28	Honduras	62	0.14	Bosnia	94	0.00
Hong Kong	31	0.28	Kenya	63	0.14	Brazil	95	0.00
Malta	32	0.25	Montenegro	64	0.14	Nicaragua	96	0.00