The socio-economic benefits of greater spectrum policy harmonisation in the EU

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Executive summary

This report presents research conducted by the management consultancy Arthur D Little and the GSMA that examines how differences in spectrum policy across EU Member States impact the availability and take-up of mobile broadband services, and therefore how greater policy harmonisation could improve the quality, reach and adoption of mobile broadband services and support the EU's Digital Single Market objectives.

	OBSERVATION	CONSUMER IMPACT
1	**Citizens have benefitted where Member States licensed 800 MHz spectrum earlier**	There is a positive correlation between the availability of 800 MHz spectrum and the commercial launch of 4G services. Even when other bands were available, 4G coverage and penetration picked up later in countries that made 800 MHz available at a later date. As a result, consumers in "first mover" countries had earlier access to the higher speeds and larger data allowances made possible by 4G, facilitating the consumption of advanced digital services and applications.
2	**Unsynchronised releases have negatively affected residents of "first mover" countries**	Consumers in "first mover" countries had to cope with the problems caused by lack of scale and interferences in border regions. The most attractive handsets did not support the 800 MHz band due to lack of support from manufacturers uncertain about the timing of release in some big European markets. In addition, coverage and network quality in border regions suffered because operators could not use the 800 MHz due to interferences from DTT networks in neighbouring countries which were yet to release.
3	**Poor auction design has led to inefficient outcomes and roll-out delays**	Certain countries lacked the expertise or support to properly design an efficient auction, leading unnecessarily to years of delay in the award of frequencies and the deployment of 4G networks.
4	**Longer license duration provides greater certainty for network investment**	Consumers cannot benefit from network upgrades when the license term expires before investments can be recouped. Upgrades within current licences – such as 3G in the 900 MHz band and 4G in the 1800 MHz band and, in the future 5G, are difficult to justify if the current licence expires in just a few years and there is no certainty over renewal.
5	**Excessive spectrum pricing leads to lower 4G connections, penetration and coverage**	At a time of liquidity constraints, excessive spectrum prices crowd out network investments, resulting in worse network quality for consumers.

Background

The creation of an EU-wide Digital Single Market (DSM) is one of the European Commission's top 10 political priorities. The aim is to overcome the fragmented availability of digital goods and services across the European Union (EU) and enable better value, higher quality, more innovative and widespread pan-European networks and services.

The DSM should widen consumer choice in digital goods and services, as well as drive economies of scale, thus allowing the European Union to better compete with other large markets such as the United States and China. The nature of European fragmentation means only 15% of EU citizens bought digital goods and services from other Member States in 2014[1]. If the same rules for e-commerce were applied across the EU, 57% of companies would either start or increase their online sales to other EU countries[2]. For example, in the media segment, total online spending by consumers and advertisers in the EU5 will increase far faster than offline spending (plus €15.1 billion until 2017), with online by then representing 27% of total media industry revenues[3].

1. European Commission Digital Single Market fact sheet- available from https://ec.europa.eu/digital-agenda/sites/digital-agenda/files/digital_single_market_factsheet_final_20150504.pdf
2. European Commission Digital Single Market fact sheet
3. Arthur D. Little EU5 Media Flow of Funds 2014

Within the mobile sector specifically, the DSM could accelerate innovative new products, more extensive services, boost investment in mobile networks and deliver significant economic and social benefits. The mobile ecosystem already provides vital, and growing socioeconomic benefits, with its contribution to European GDP expected to reach €492 billion by 2020[4]. An effective Digital Single Market could help drive these benefits in future.

The European Commission's DSM strategy, which was proposed in May 2015 contains three central pillars:

1. **Access:** better access for consumers and businesses to digital goods and services, including mobile broadband, across Europe;

2. **Policy environment:** creating the right conditions and a level playing field for digital networks and innovative services to flourish; and

3. **Economy and society:** maximising the growth potential of the digital economy.

A key component of the strategy is creating a progressive regulatory environment, which is consistent and predictable across Europe, through a comprehensive review of the existing EU Telecoms Framework. This will include proposals for coordinated EU-wide conditions for spectrum policy management. As this report highlights, various factors - including the timing and design of spectrum auctions; the cost, the duration and the terms of licences - all have a major impact on the availability, cost, quality and reach of mobile broadband services.

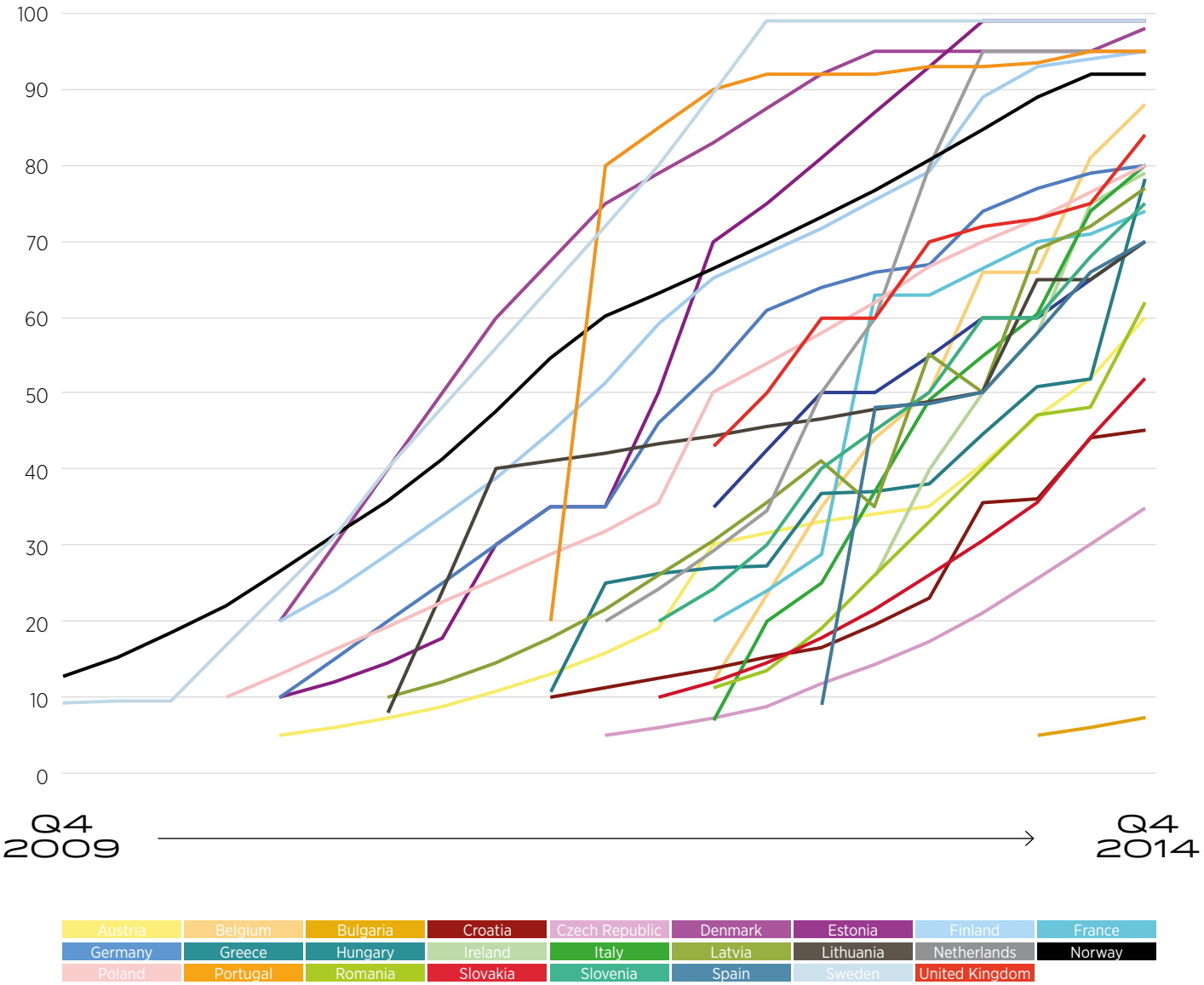
4. GSMA Mobile Economy Report 2014

Today, across Europe's Member States, there are considerable differences in citizen's access to mobile broadband services. Figure 1 shows the level of coverage achieved by 4G networks to the end of 2014, with some Member States already achieving 99% coverage but others so far still less than 50%.

Figure 1

4G network coverage

(Percentage)



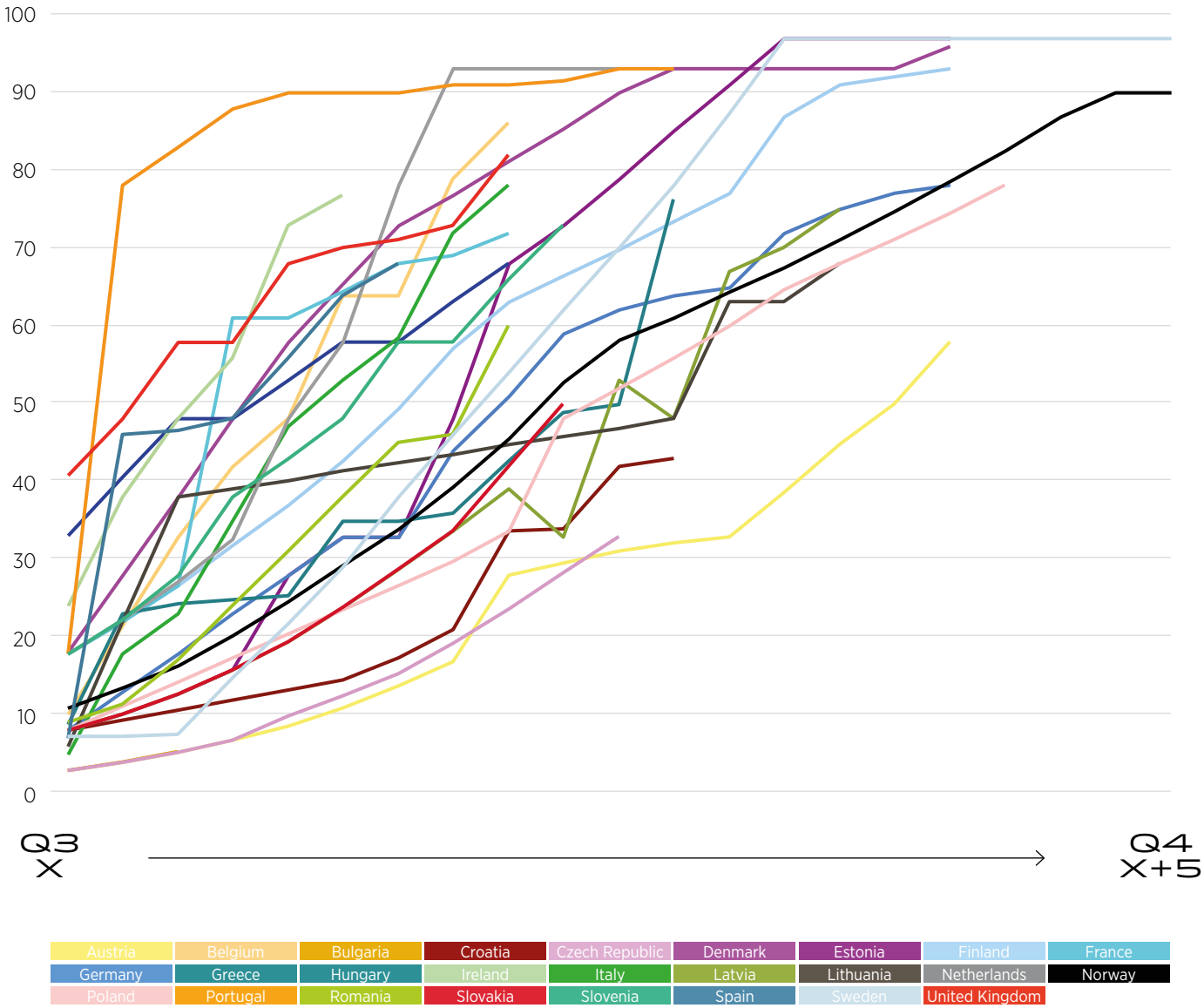
Source: GSMAi, Arthur D. Little

Differences in access to mobile broadband appears to be due in part to differences in timing of auctions and roll-out, but normalising by 4G launch date still indicates considerable differences in rates of roll-out.

Figure 2

4G network coverage

(Percentage) Normalised to first launch of 4G service



Source: GSMAi, Arthur D. Little

Drawing on research analysis, this paper provides empirical evidence of the socio-economic benefit of greater spectrum policy harmonisation for European citizens and businesses. The areas considered are:

Spectrum pricing

Auction design and the impact on spectrum prices and failure to sell licences

Licence duration

Timing the release of mobile spectrum

Coverage obligations

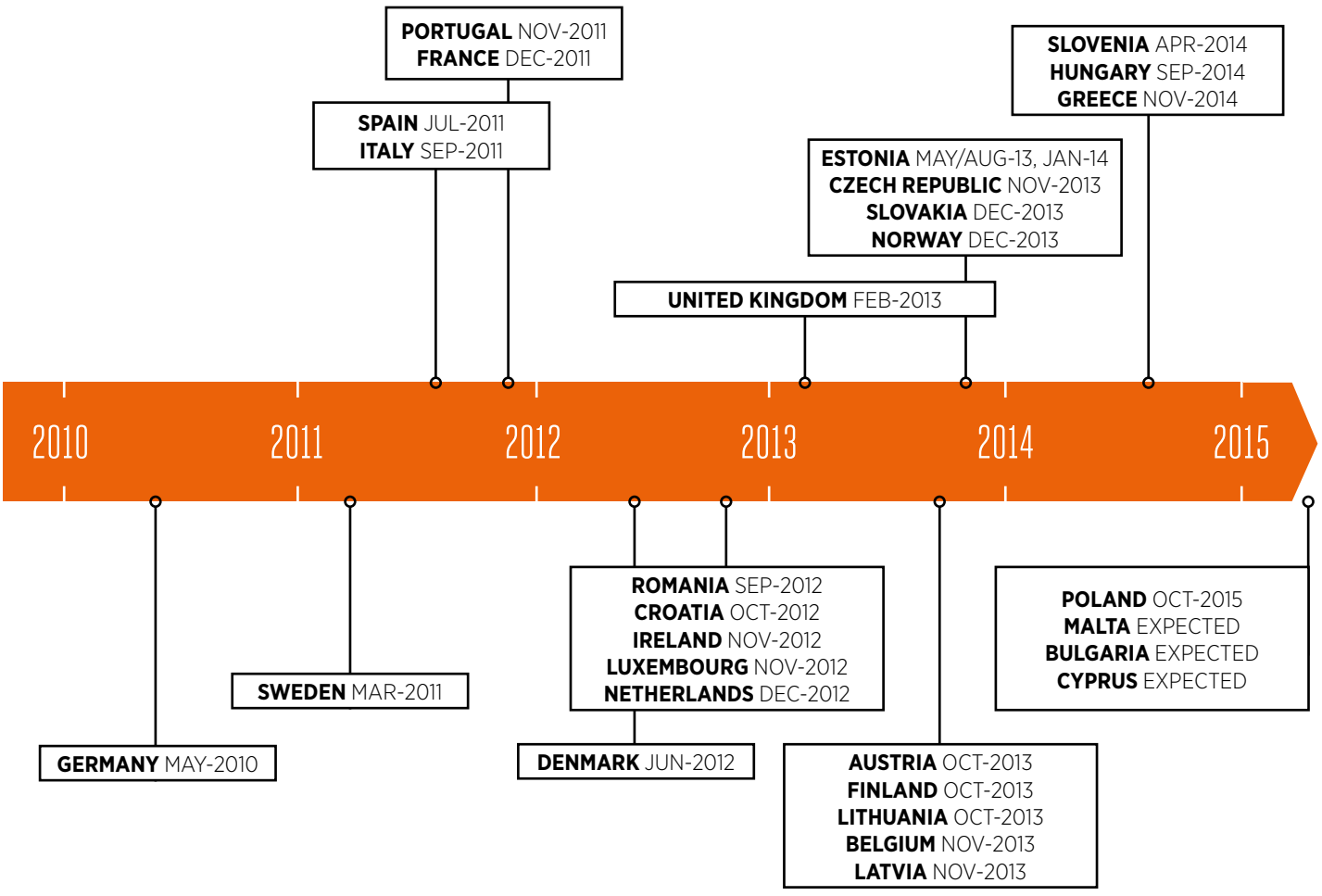
Research and findings

1. Citizens have benefitted where Member States licensed 800 MHz spectrum earlier

The licensing of the 800 MHz band for LTE services in Europe has spanned more than five years (figure 3), creating a significant gap between the first and last Member States to have the opportunity to roll-out nationwide 4G services. Indeed, some European countries are still yet to finalise their 800 MHz awards.

Figure 3

800 MHz spectrum awards

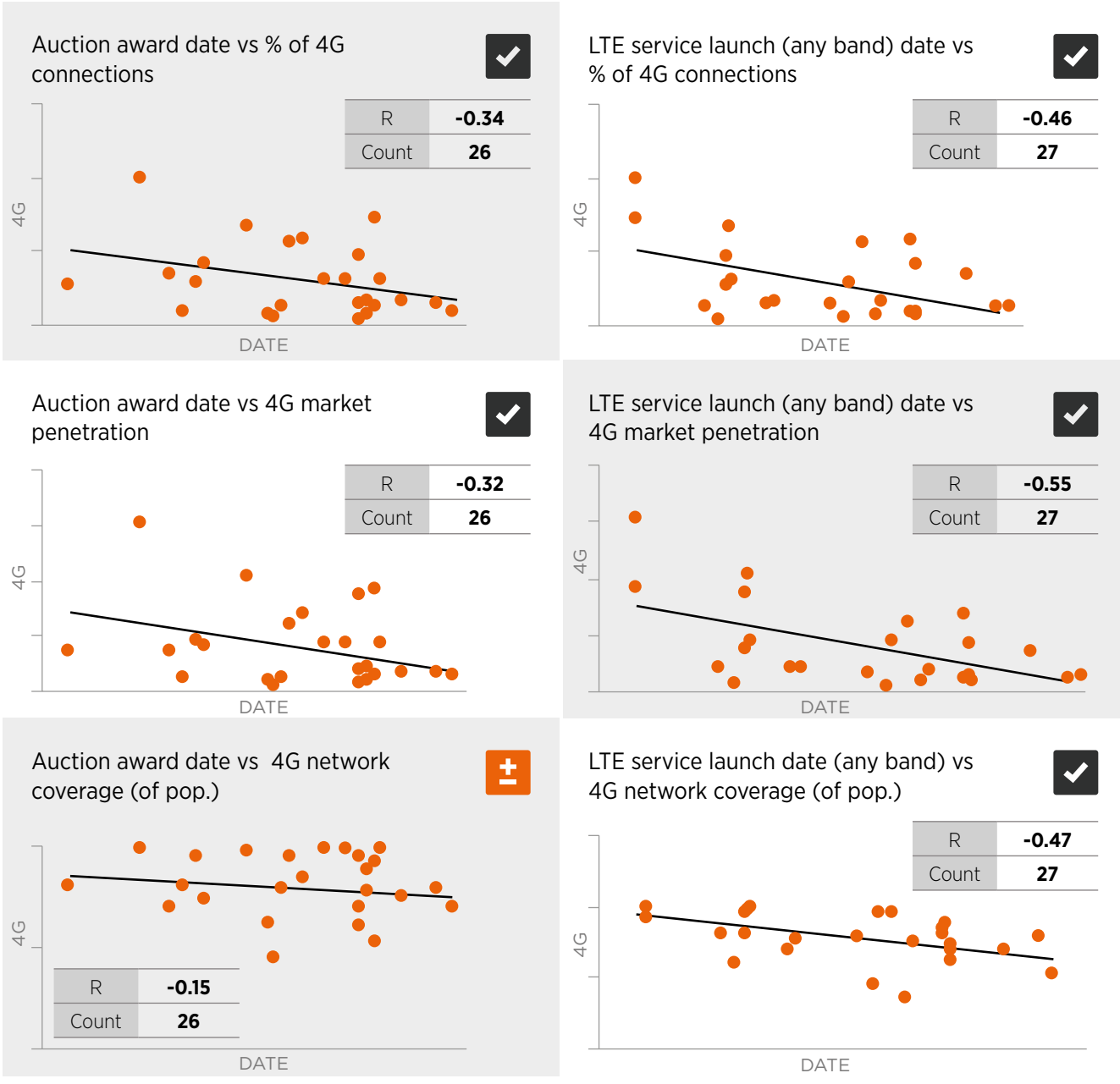


Source: Press releases; Arthur D. Little analysis

The research indicated that countries with earlier 800 MHz auctions and earlier LTE launches have higher levels of 4G take-up (i.e. connections), market penetration and coverage (see figure 4), resulting in large differences in access to mobile broadband services for Europe's citizens.

Figure 4

Hypothesis 1 – overview of trend lines



Trendline supports hypothesis

Trendline is weak

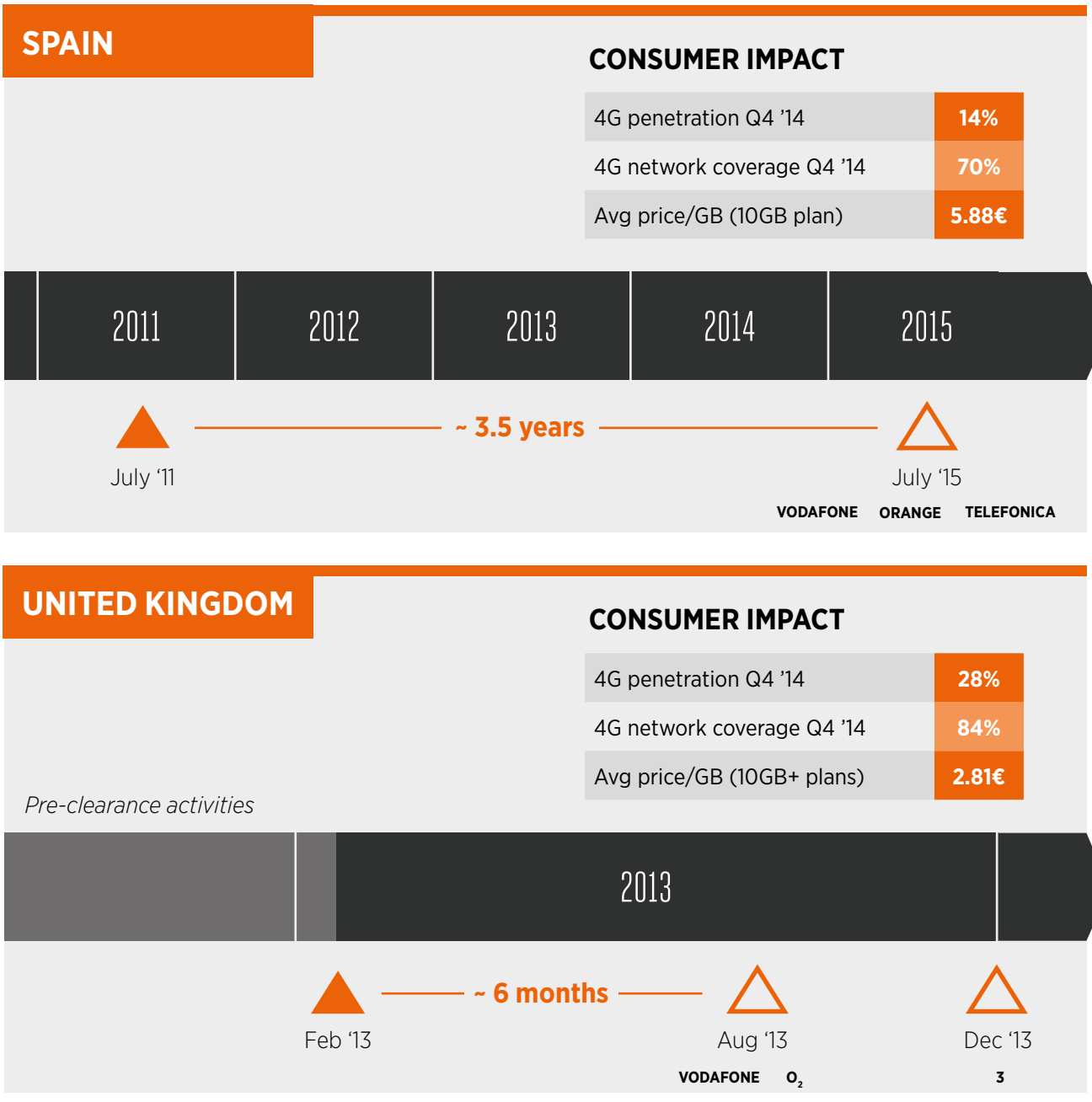
Source: GSMAi, Arthur D, Little

Interestingly, the analysis showed significant differences in the time taken to clear the 800 MHz band between countries, for example in the UK and Spain, despite similarly high dependence on terrestrial television. Digital television switch-over and clearance of the 800 MHz band was completed six months after licensing in the UK, but took more than three years in Spain (see figure 5)

The result was significant delays to the launch of nationwide LTE services in Spain, and thus by Q4 2014, 4G market penetration had reached 28% in the UK but only 14% in Spain.

Figure 5

DTT spectrum clearing: Spain vs United Kingdom



Source: GSMAi, Press releases, Arthur D. Little

2. Uncoordinated releases have negatively affected residents of "first mover" countries

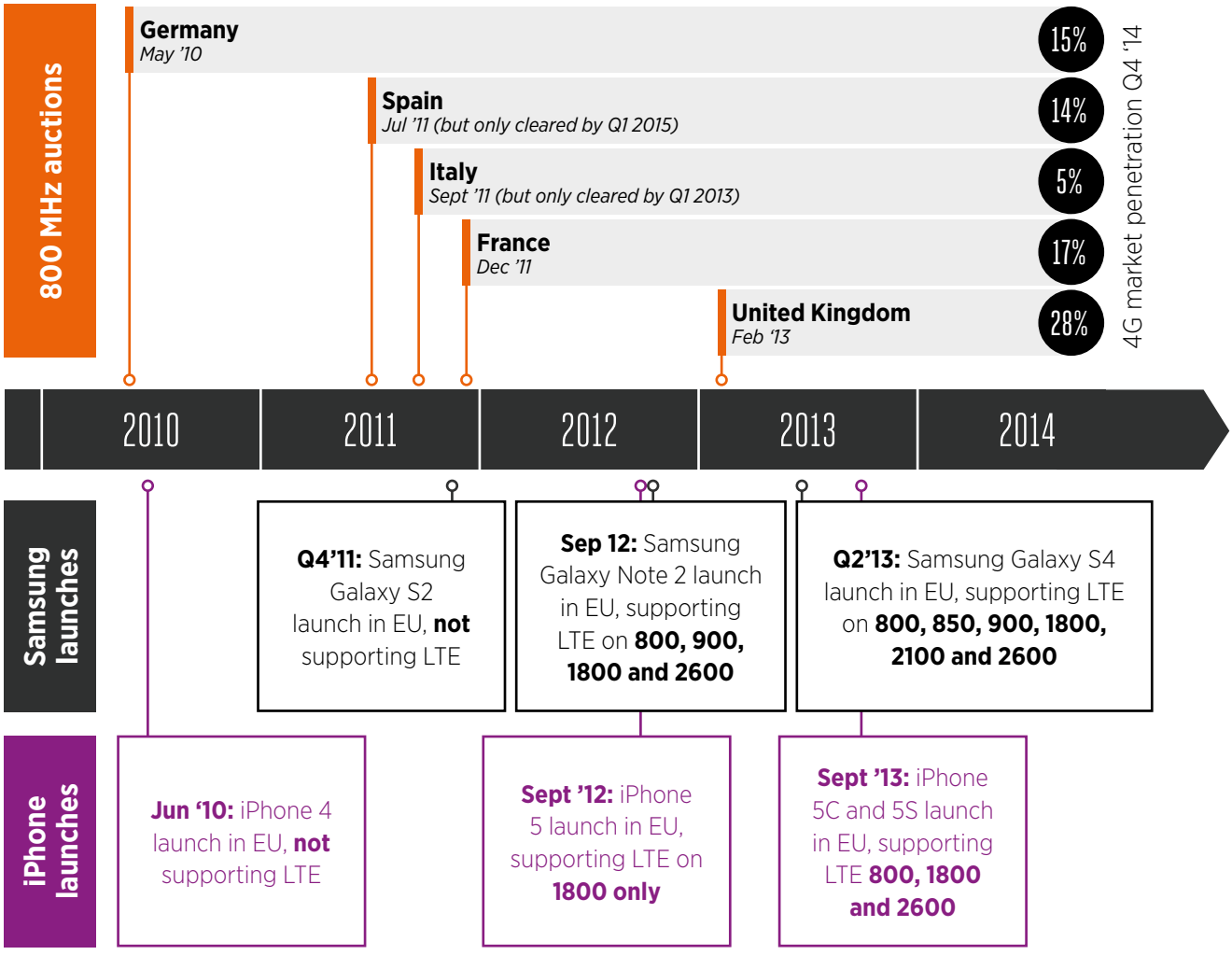
Introducing a new mobile standard such as 4G in the 800 MHz band (or 5G in the future) requires support from handset manufacturers. They, in turn, require market scale to support the standard. The Digital Single Market in Europe should provide sufficient scale, but it requires the release of the spectrum band to be better coordinated across all Member States.

The analysis examined the timing of 800 MHz auctions around Europe and found that, in Germany, France, Spain and Italy, the spectrum was auctioned (and services launched in most cases) before leading handsets were available to support the band (the iPhone 5c, the first iPhone to support the band, was launched in Europe in September 2013 - see figure 6).

The fragmented nature of 4G licensing in Europe meant there was no guarantee for leading handset providers that there would be sufficient market scale at that time.

Figure 6

Early 800 MHz auctions vs availability of flagship handsets

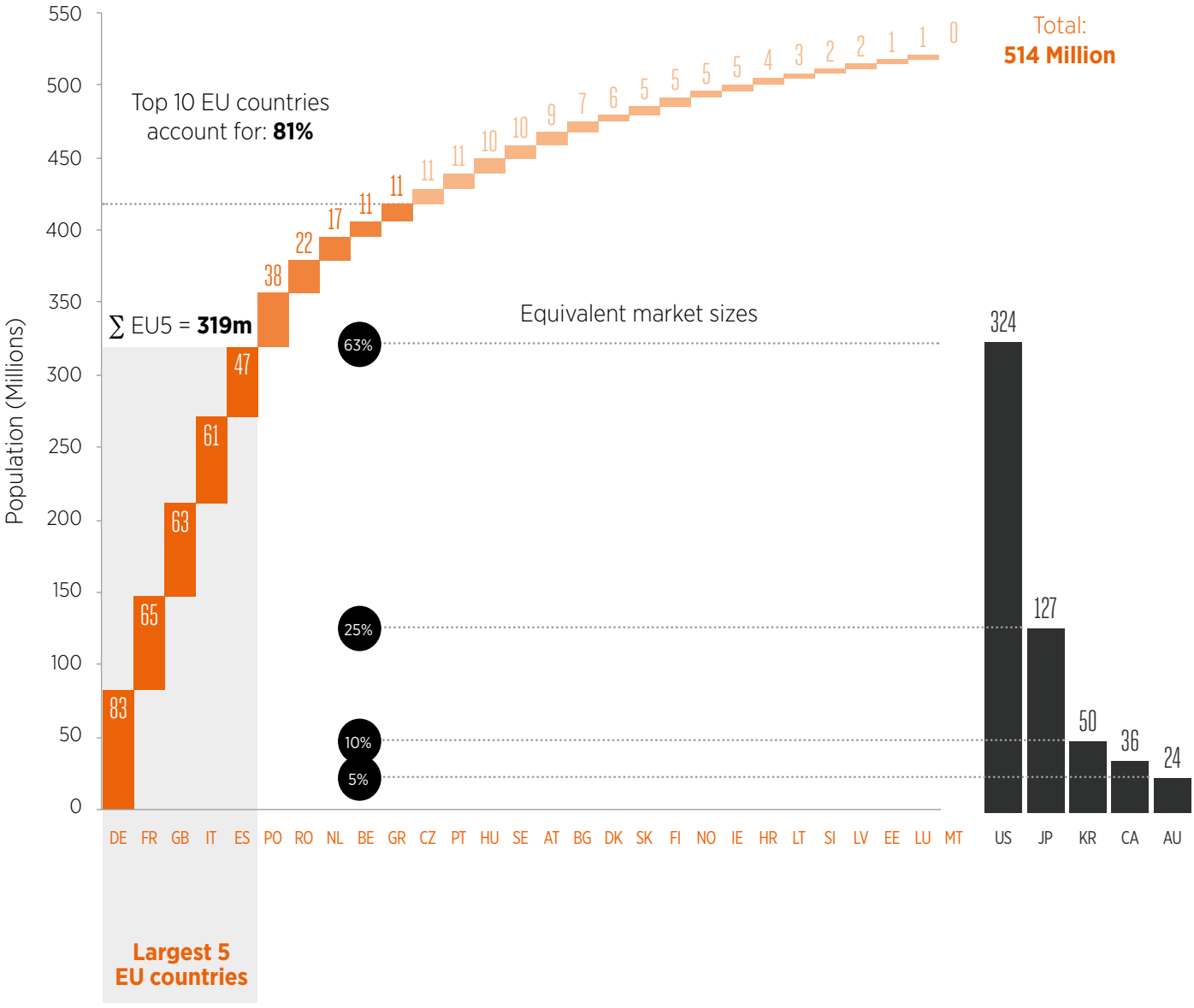


Source: Press releases, Arthur D. Little

With better coordinated release of new spectrum, Europe can achieve scale. The results (see figure 7) indicate that the largest 5 EU mobile markets would provide equipment manufacturers with the same market scale as the United States.

Figure 7

Population of Europe versus other large markets



Source: GSMA

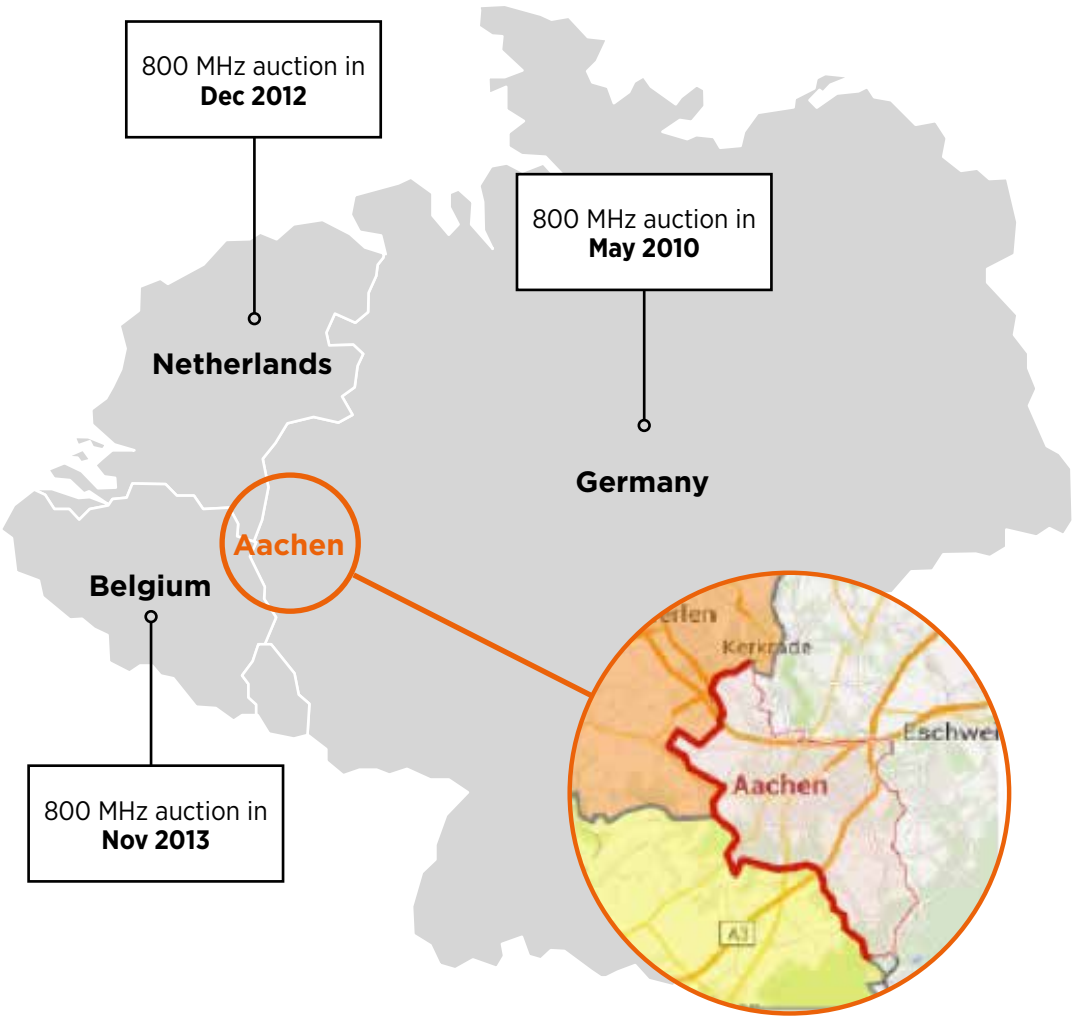
The analysis also looked at the impact on Member States rolling out 800 MHz mobile networks from neighbouring Member States that were delayed in their roll-out. It identified examples where the 800 MHz mobile network could not be built close to the borders because of interference with others users of the band.

Germany was the first European country to auction the 800 MHz band in 2010, but was unable to use it in Aachen, a German border town neighbouring both Belgium and the Netherlands (see illustration 1), for several years. Roll-out was blocked due to interference with terrestrial TV services that were still being operated in the 800 MHz band in Belgium and the Netherlands (until 2012 and 2013 respectively). Terrestrial TV services transmit from high tower sites at much higher power levels than mobile networks. Their signal is carried over long distances even across borders and thus restricts the use of mobile services.

As a result, LTE services in Aachen could only be operated over the 1800 MHz band, which required more cell sites, resulting in higher costs and poorer in-building coverage.

Illustration 1

Border interference issue – Aachen (Germany)



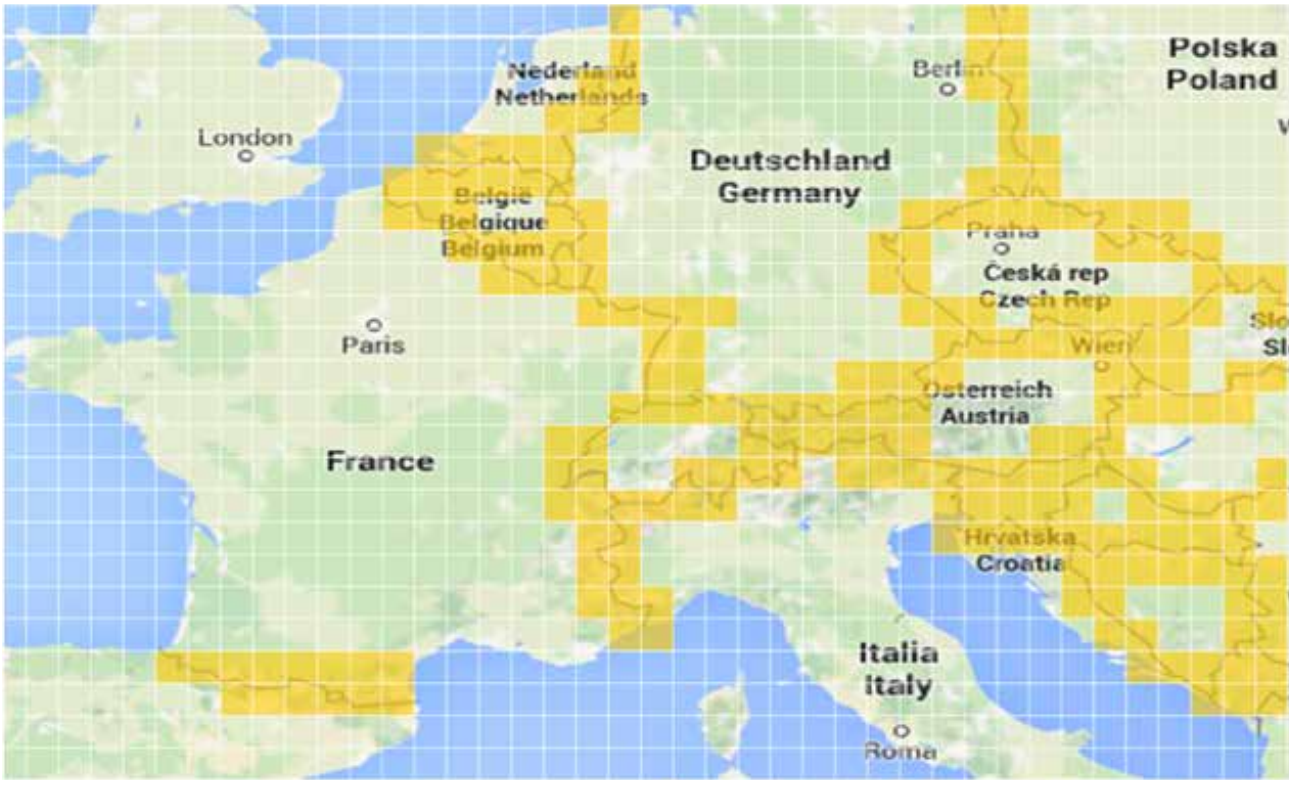
Source: Operator interviews, Arthur D. Little

In addition to Aachen, various border regions throughout the EU have to deal with the same issue, most notably, between France and Spain (see illustration 2). The Basque and Catalan regions of Spain where the release of the 800 MHz only happened in April 2015 caused significant delays and interference on both sides of the Pyrenees with cities such as Perpignan, Montpellier, Bavonne and even those in Bordeaux, Marseille and Aix-en-Provence being adversely affected. Furthermore, the large city of Toulouse and its suburbs, although situated halfway between the Mediterranean sea and Atlantic ocean, have also been impacted.

Due to the different auction dates, there was a negative impact on the release of mobile services, including delays in launching 4G services and reduced quality of service. Although, in some cases it was possible to switch-on LTE800 stations, despite the reduced quality of service, some areas were impossible and caused delays as the reduction in quality of service was considered too severe to provide 4G coverage.

Illustration 2

Border interference issues – Europe



Land area potentially experiencing border interference

50 square km

Source: Operator interviews, Arthur D. Little

Note: Simplified analysis, using 50km radii for DTT deployments near borders and orthogonal grid squares, to illustrate the effects

3. Poor auction design has led to inefficient outcomes and roll-out delays

Efficient and effective allotment of spectrum is critical to ensure that the full economic and societal value of mobile can be realised in Europe. Mobile services are not only used by retail consumers but are also critical for many other sectors in the economy to realise their full economic potential, enabling, for example, significant productivity improvements and innovation. It is for those reasons that economically and technically efficient allocation of harmonised European spectrum is critical to ensure operators have the opportunity to secure the spectrum resources required to invest in infrastructure and innovation as well as to deliver services to consumers and businesses.

Unfortunately, inappropriate auction design can fail to achieve optimal results for a number of reasons:

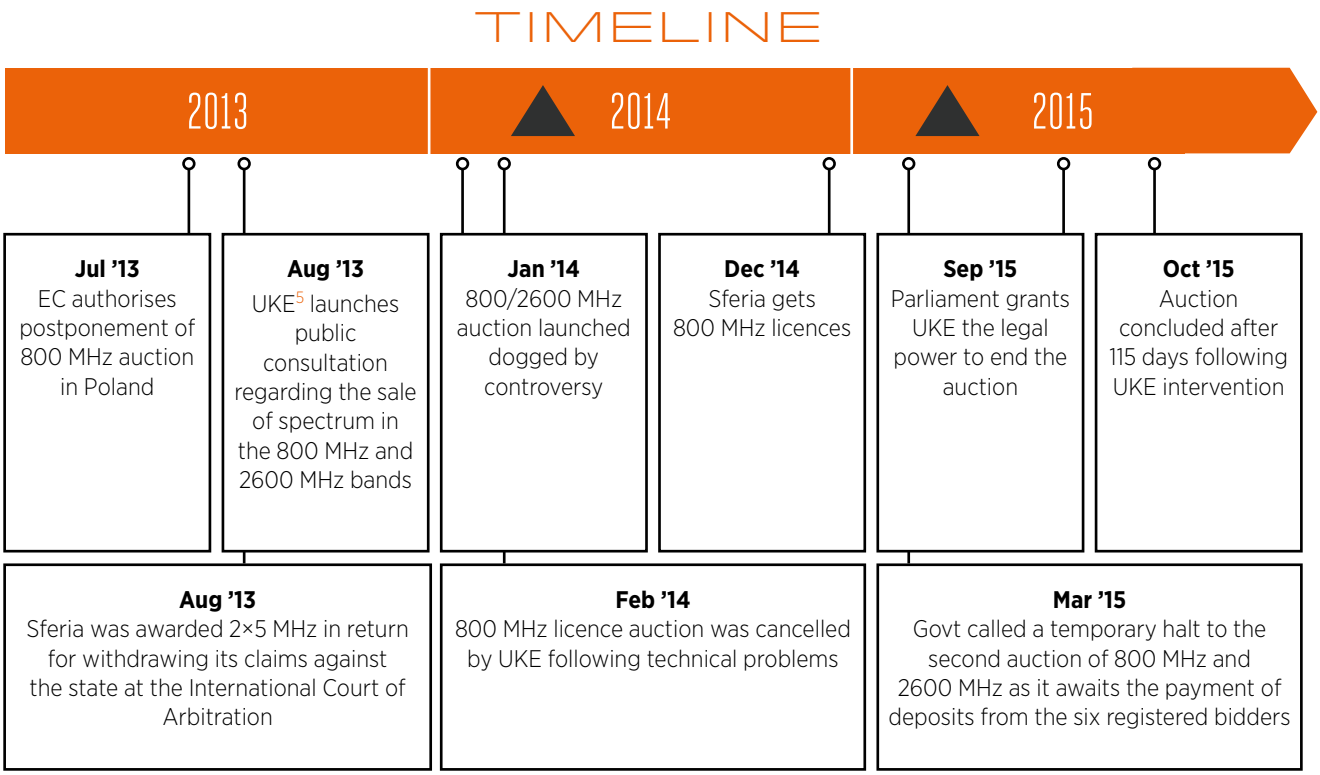
- reservation of spectrum for a new entrant may result in artificial scarcity for existing operators, forcing them to pay more for their spectrum, and may result in one of the existing operators being denied spectrum and unable to compete in network roll-out - an example is the 4G auction in the Netherlands
- auction rules may fail to cause the auction to settle as prices reach market value – examples of this occurred in the Czech Republic and Polish 4G auctions

The analysis examined the Polish 4G auction process (see figure 8), which began in 2014 and which ran seventeen months before being halted by government intervention, as a result of a range of shortcomings in auction design:

- operators were unable to properly access documents relating to the sale. This left potential bidders with insufficient time - just a few hours - to read the regulator's response to requests for clarification on the terms of the sale
- one existing operator threatened to boycott the tender over allegations that the terms were discriminatory
- in March 2015, the Polish government called a temporary halt to its auction to allow payment of a [further] deposit
- In October 2015, the regulator intervened further and called a halt to the auction. By this point, prices had exceed €2.2 billion, and were awarded to five companies.

Figure 8

Polish 800 MHz and 2600 MHz auction



AUCTION DETAILS

Process: Simultaneous multiple round ascending (SMRA) auction

Spectrum sold: 5 blocks of 2×5 MHz in 800 MHz + 14 blocks of 2×5 MHz in 2600 MHz

Reserve price: PLN250 million per block for 800 MHz; PLN50 million per block for 2600 MHz

License duration: 15 years

Limits: Bidders limited to a max of 2 blocks of 800 MHz and 3 of 2600 MHz. Bidders that already use frequencies in the 800 MHz or 900 MHz ranges will be not be allowed to exceed a combined total spectrum holding of 40 MHz

Winning operators: Orange, T-Mobile, NetNet, P4, Polkomtel

▲ 800 MHz Auction attempts

Source: Telegeography, PolicyTracker, Arthur D. Little

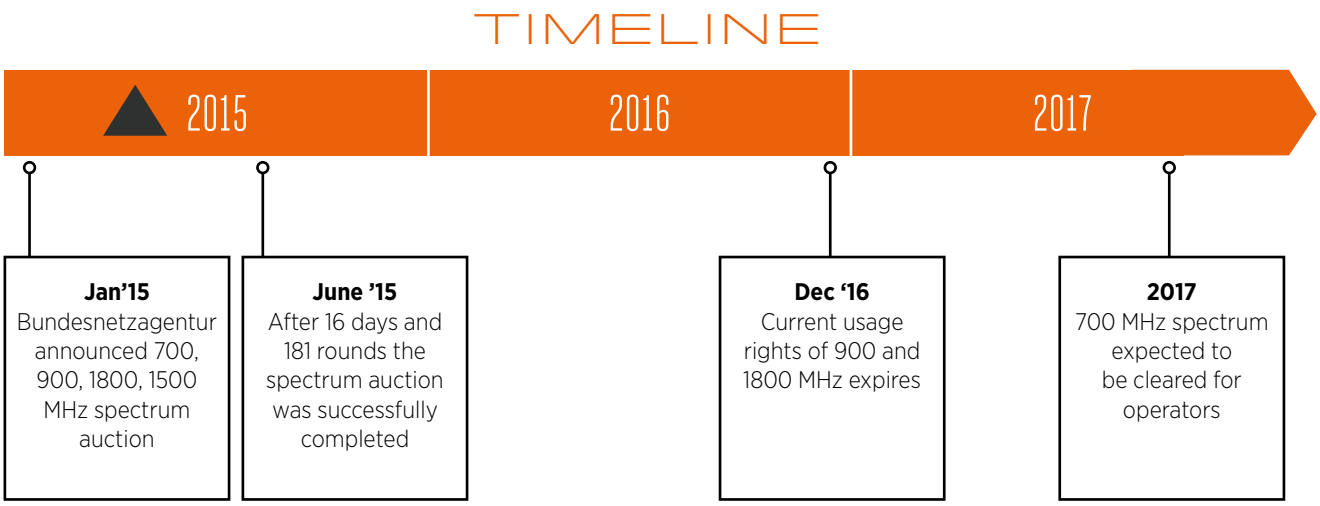
5. UKE = Polish telecoms regulator the Office of Electronic Communications

In contrast, our analysis examined the German Project 16 auction (see figure 9), which began in 2015 and successfully concluded that same year.

- Both operators and regulators were satisfied with the results as the auction was short, all operators were able to obtain spectrum and the price paid was close to the expected value
- The structure of the auction design (spectrum packaging and caps) ensured that all three operators who participated would be able to secure 700 MHz spectrum, to complement their other holdings
- The auction also provided operators with more clarity on their 900 MHz and 1800 MHz holdings, albeit at potentially higher than expected prices for some bands (i.e. 1800 MHz)

Figure 9

Germany 700 MHz, 900 MHz, 1800 MHz and 1500 MHz auction



AUCTION DETAILS

Process: Open ascending simultaneous multiple round auction

Spectrum sold: 6x(2x5) in 700 MHz, 7x(2x5) in 900 MHz, 10x(2x5) in 1800 MHz and 40 MHz unpaired in 1500 MHz

Reserve price: €1.5 billion for all spectrum sold

Winning operators: Telekom Deutschland, Telefónica and Vodafone

Spectrum clearance: 700 MHz spectrum should be cleared by 2017

▲ 700 MHz auction

Source: GSMA

In Europe, taking steps at harmonising EU best practice for awarding spectrum and encouraging their use could resolve such scenarios. In particular:

- Design auctions to ensure the economically and technically efficient allocation of harmonised European spectrum
- Clearly define licence rights and obligations, and set the auction rules and process to promote competition and downstream market efficiency
- Consult the operators and other stakeholders throughout the auction process to ensure potential flaws in the auction design or potential distortions in the outcome of the auction are highlighted in advance
- Aim for the long-term economic value of the spectrum to the economy through technically and economically efficient deployment of mobile networks

Finally, the auction design should meet the market circumstances and to achieve the specific objectives all the while encouraging investment in infrastructure and use of the spectrum to deliver services to consumers and businesses.

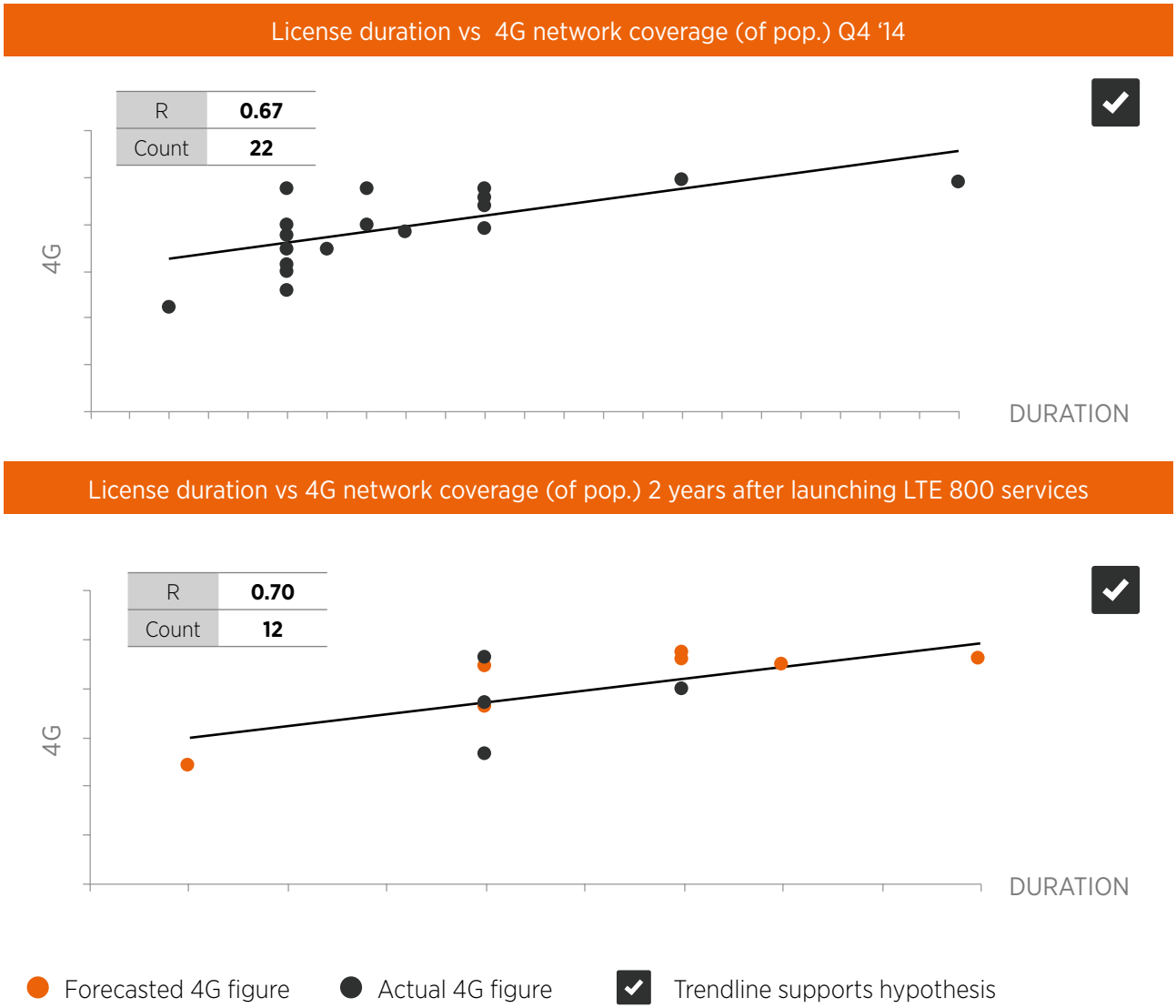
4. Longer licence duration provides greater certainty for network investment

The licence duration is a key element for the industry's analysis on investment. Longer duration licences - and greater certainty over renewal - allows mobile operators to invest more in developing and upgrading networks, because of the longer payback period.

The analysis conducted further demonstrated that there is a correlation between longer licences and improved 4G population coverage (see figure 10) whether measured at a specific snapshot (in this case Q4 2014) or two years after the launch of 4G services (thus mitigating differences in the duration of 4G deployments).

Figure 10

Hypothesis 2 – overview of trend lines



Source: GSMAi & Arthur D Little

The loss of rights to spectrum currently being used for the supply of services also carries risks to customers in relation to the loss of service. There should be a strong presumption of licence renewal with only exceptional and well specified circumstances under which licences will not be renewed. Therefore, transparent administrative licensing procedures are preferred. In most cases, the existing operators would be expected to re-acquire the licence with the consequence that market based approaches only create unnecessary uncertainty and costs.

This is particularly important as operators plan future network upgrades within current licences – such as 3G in the 900 MHz band and 4G in the 1800 MHz band and, in the future, 5G. Investment will be difficult to justify if the current licence expires in just a few years and there is no certainty over renewal.

For example, an increasing number of countries - including Canada, New Zealand, and the UK - have decided to support a minimum term of 20 years for new mobile licences (and in some cases effectively perpetual licenses), and the European Parliament has proposed 25-year terms. In countries such as the US, the strong presumption of renewal has supported extensive 4G network investment.

5. Excessive spectrum pricing leads to lower 4G connections, penetration and coverage

The level of licence fees (including up-front and annual charges) can significantly impact market outcomes, including the number of players that enter the market and, particularly where annual charges are levied, prices for mobile services. There is a strong economic case to avoid the level of licence fees being determined on the basis of revenue-maximising objectives.

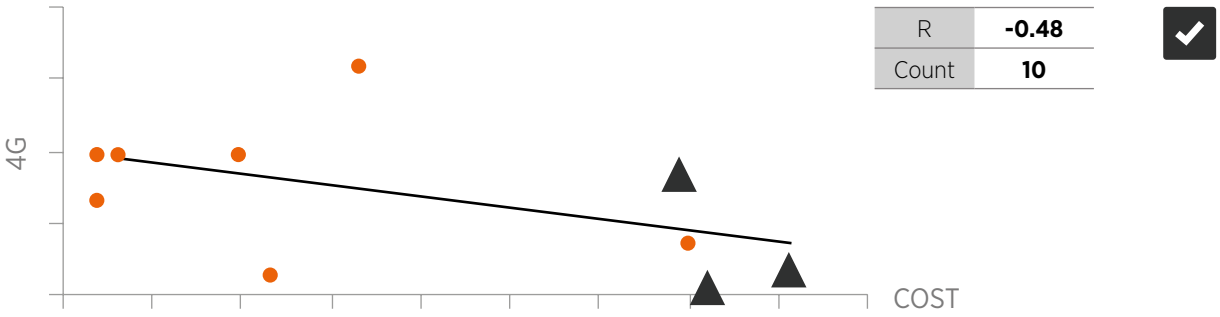
When comparing the price paid for 800 MHz band licences and the number of 4G connections; the level of 4G penetration and the level of 4G coverage, the analysis shows that countries where the cost of 800 MHz licences were lower have higher 4G market penetration and network coverage, 2 years after having launched LTE 800 services (see figure 11).

Excessive spectrum costs for mobile operators therefore risk restricting mobile coverage and service take-up. Spectrum costs can become excessive as a result of restricted supply, high reserve prices, adverse bidding strategies or poorly designed auctions.

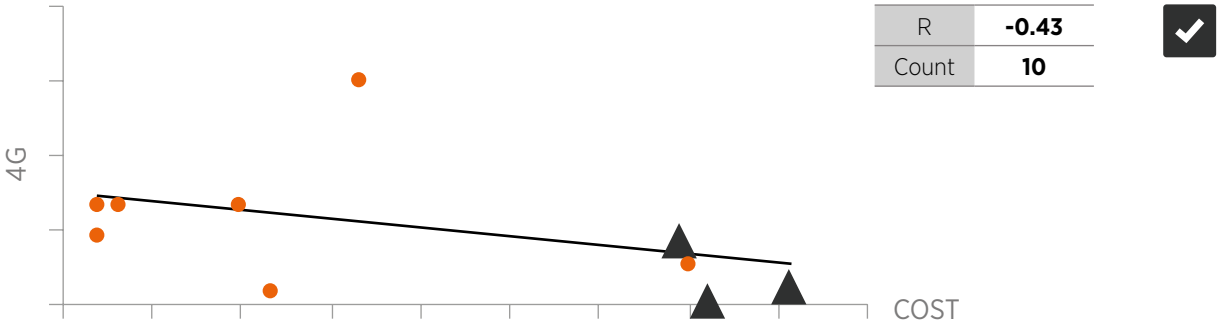
Figure 11

Hypothesis 3 – overview of trend lines

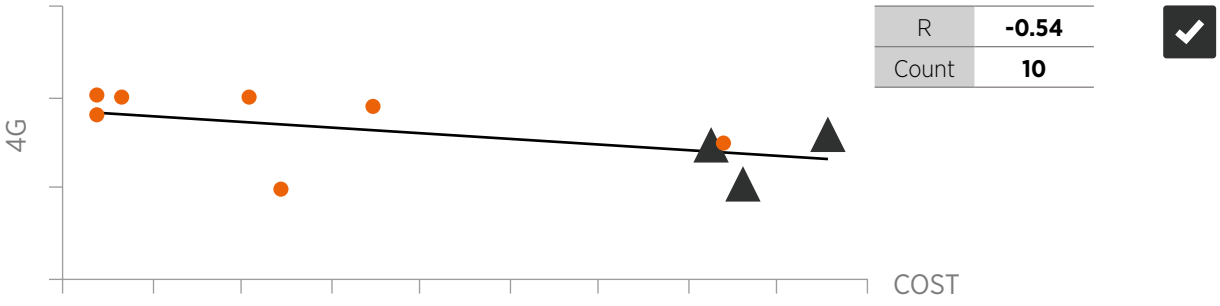
Cost of spectrum (800) vs % of 4G connections 2y > LTE 800 services



Cost of spectrum (800) vs 4G market penetration 2y > LTE 800 services



Cost of spectrum (800) vs 4G network coverage (of pop.) 2y > LTE 800 services



Trendline supports hypothesis

Trendline does not support hypothesis

Forecasted 4G figure

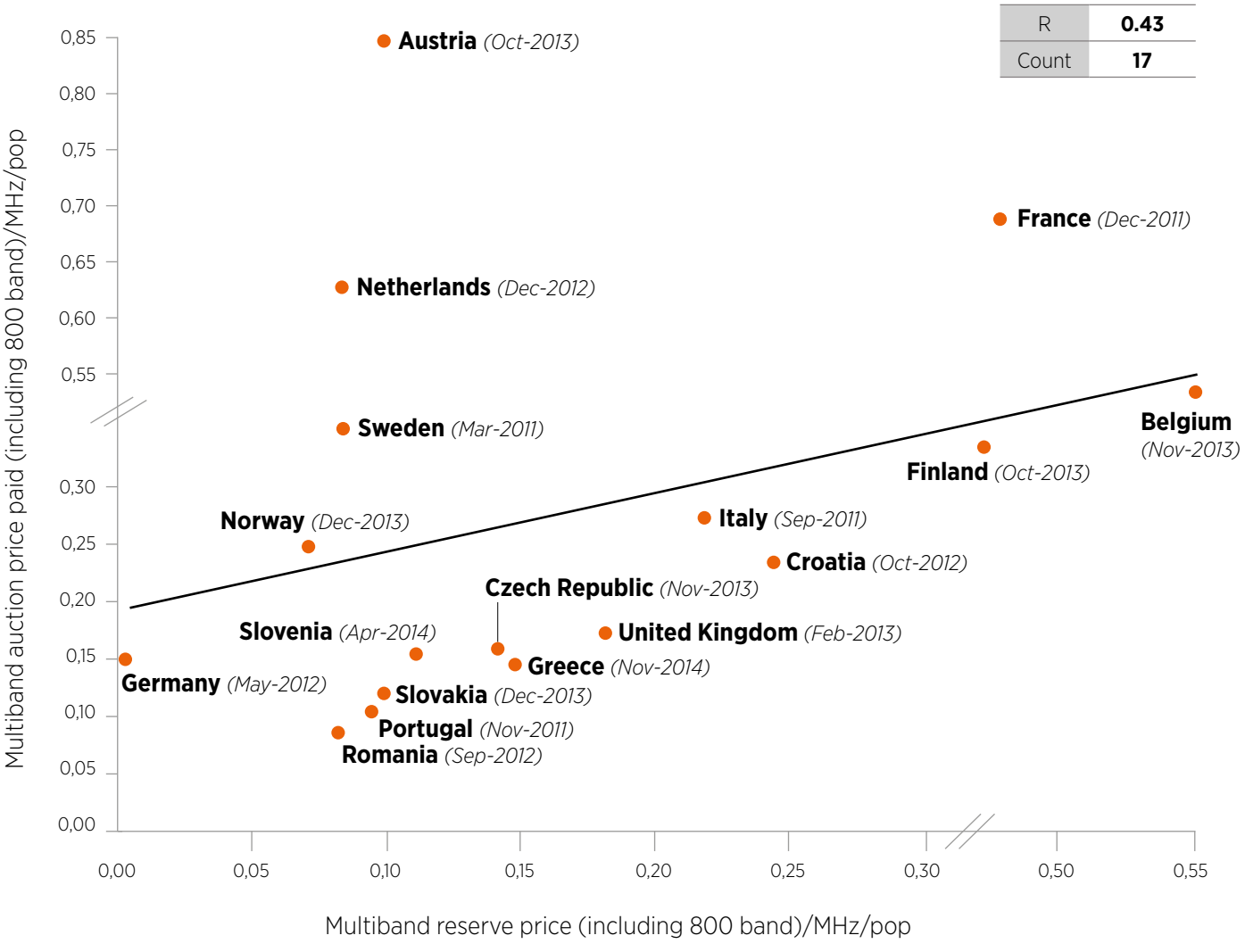
Actual 4G figure

Source: GSMAi & Arthur D Little

The research also investigated possible causes for excessive prices. It finds that auctions with a higher reserve price tend to result in higher prices paid for spectrum (see figure 12.1). This possibly shows that in a relevant number of auctions, there was no competition above the reserve price, or competition raised the price by a fixed amount over reserve. In all these cases, if the reserve price had been lower the final price would also have been lower. The role of reserve prices was therefore to ensure revenues for the treasury, not to charge for scarcity.

Figure 12.1

Reserve price of all bands sold vs actual price paid



Source: Press releases, Arthur D. Little

Note: reserve prices refer to the reserve prices for the total amount of spectrum that was sold

Figure 12.2

Reserve price of all bands sold vs number of bidding rounds

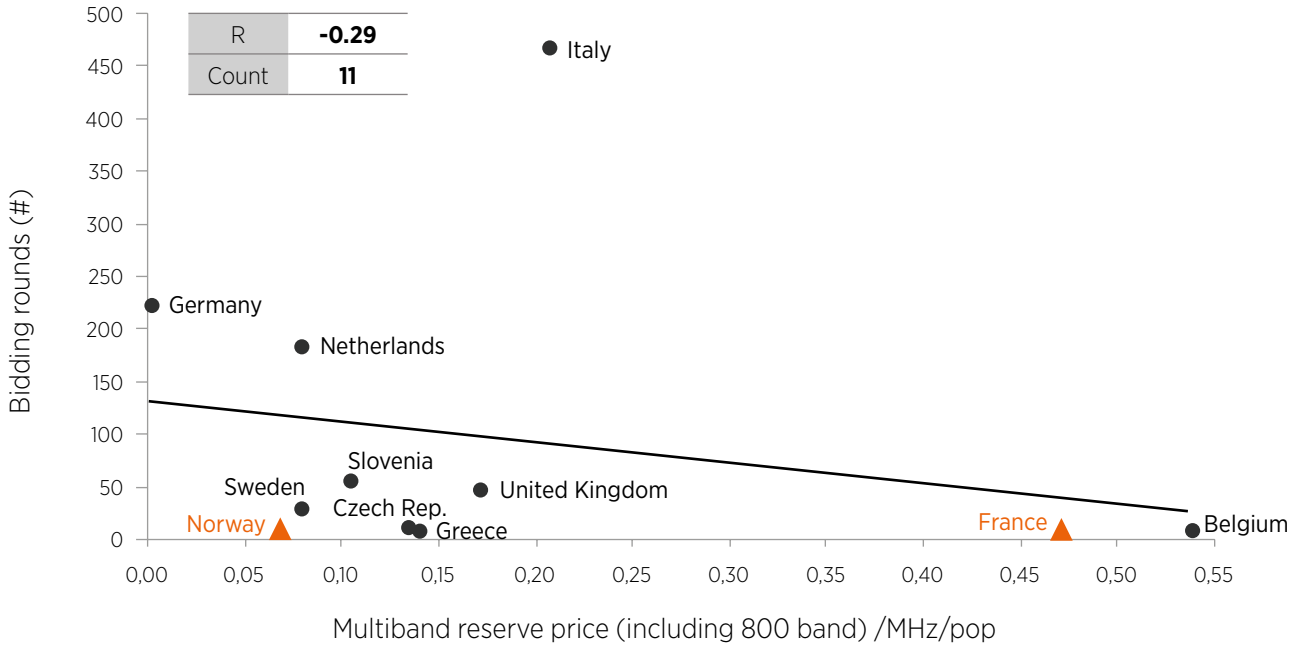
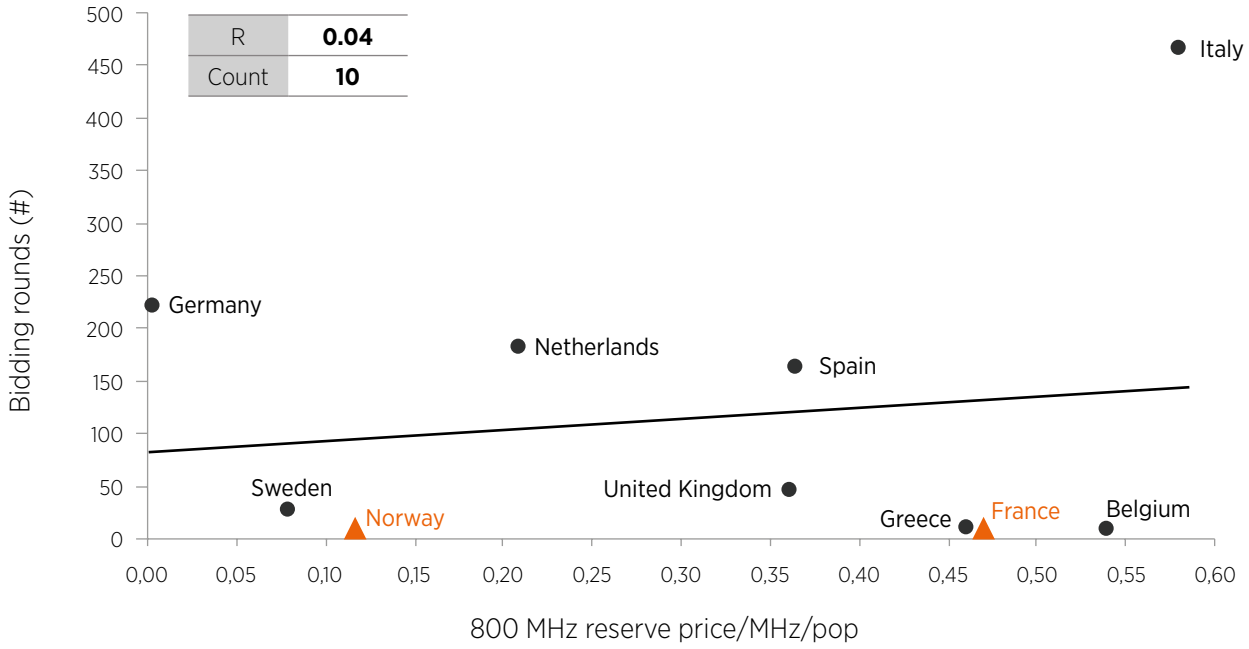


Figure 12.3

Reserve price of 800 MHz bands sold vs number of bidding rounds



▲ Sealed bid (1 round) auction

Source: Press releases, Arthur D. Little

In the first 3G auctions in Europe, 10-15 years ago, high reserve prices resulted in licences being left unsold, for example in Belgium, Greece, and the Czech Republic. Non-EU countries were also affected – for example Singapore and Israel, and the problem recurred again in Australia and India in 2013.

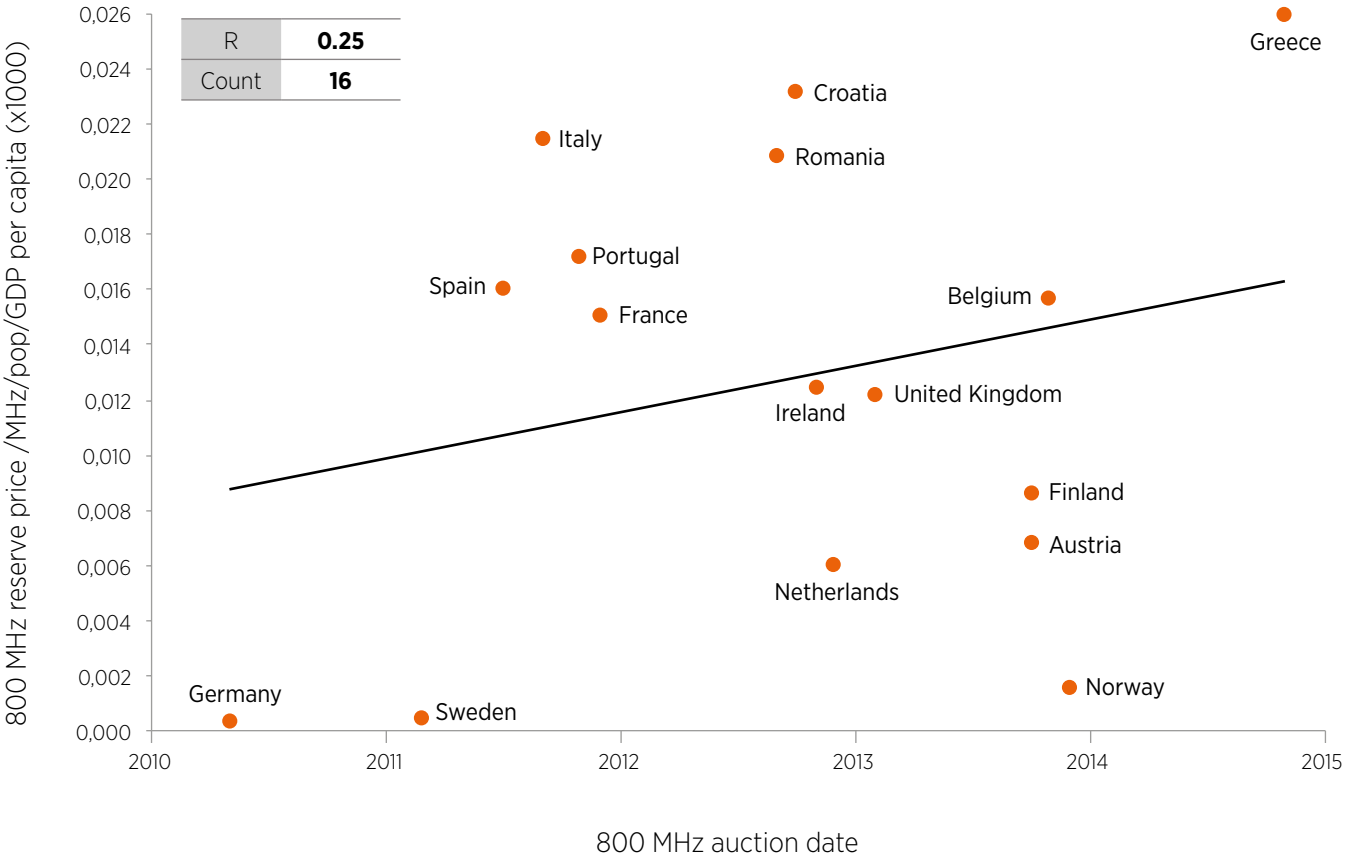
Reserve prices should be set conservatively rather than to try to match the expected market price. Best practice is that reserve prices are set at a moderate level - to discourage frivolous bidding and ensure mobile bidders value the spectrum more than alternative users (the opportunity cost). A well-designed auction can then achieve the task of price discovery.

When Member States set artificially high reserve prices, they risk increasing spectrum costs excessively, reducing service coverage and take-up, and leading to inefficient outcomes.

The research further found that rather than designing auction rules that allow the auction process to determine the opportunity cost of spectrum, regulators in some Member States took as a reference benchmarks from auctions in other markets, under potentially very different circumstances. This "ratcheted up" reserve prices over time (reserve prices for 800 MHz licences are shown below in figure 13).

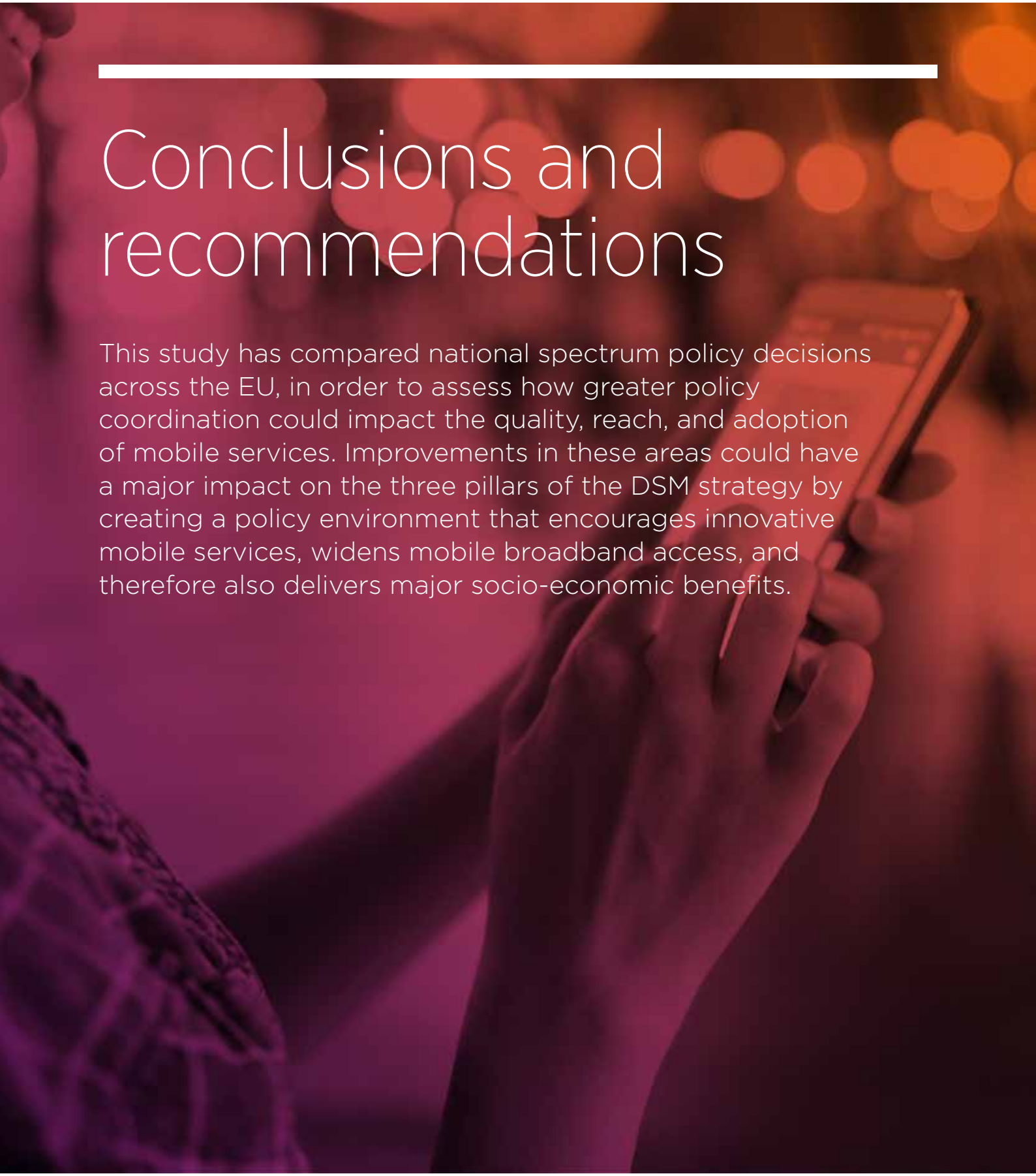
Figure 13

GDP normalised reserve price of 800 MHz bands sold vs auction award date



Source: Press releases, Arthur D. Little[6]

6. Reserve prices refer to the reserve prices for the total amount of spectrum that was actually sold (i.e. does not include unsold spectrum)



Conclusions and recommendations

This study has compared national spectrum policy decisions across the EU, in order to assess how greater policy coordination could impact the quality, reach, and adoption of mobile services. Improvements in these areas could have a major impact on the three pillars of the DSM strategy by creating a policy environment that encourages innovative mobile services, widens mobile broadband access, and therefore also delivers major socio-economic benefits.

Based on the findings, the GSMA recommends that the European Commission consider measures to encourage coordination as part of the Digital Single Market strategy in the following areas:

Managing spectrum prices:

- High spectrum prices risk constraining mobile coverage and take-up of mobile broadband services: It is therefore reasonable to conclude that the Telecom Framework Review should consider harmonising measures, which prevent excessively high spectrum prices, and thus impeding infrastructure and service rollouts

Auction design:

- There is a consistent pattern of regulators 'ratcheting up' reserve prices for a band following auctions in other markets
- Countries with higher reserve prices tend to have a higher actual price paid for spectrum: Taken alongside the finding that higher prices lead to worse mobile broadband services, the Commission should consider investigating harmonising methods for preventing high spectrum reserves (and reserve ratcheting)
- Poor auction design has led to failed auctions in the EU which has resulted in valuable spectrum going to waste and delays to the evolution of mobile broadband services: By encouraging Europe to harmonise around auction best practice – including prequalification, clearly defined licence rights, obligations, auction rules and transparency of processes - these problems could be overcome allowing government to ensure spectrum is effectively assigned and efficiently used

The duration of licences:

- There is a trend towards better 4G coverage with longer spectrum licences: As such, efforts to reduce the use of short licences could improve access to mobile broadband in the EU

Timing of spectrum availability:

- Countries which auction mobile bands and launch services earlier have higher levels of 4G take-up (i.e. connections), market penetration and coverage: It is therefore advised that Member States are encouraged to make new mobile bands available as early as is reasonably possible
- A lack of harmonisation in key mobile bands creates international coordination challenges: This can result in delayed, or impaired, LTE services in border areas so efforts should be made to encourage the use of harmonised bands EU-wide
- Some EU countries are slow to clear new mobile bands which in turn can impact mobile broadband coverage and take-up: Harmonising best practice surrounding spectrum clearing could help alleviate this problem
- A lack of compatible mobile devices can slow down mobile broadband adoption: Efforts to harmonise when spectrum is made available in the EU will give device manufacturers more confidence that there is a wide addressable market making them more likely to develop customised devices for Europe

Methodology

During this study, Arthur D. Little was asked to assess the impact of the lack of harmonised spectrum policy within the EU on socio-economic benefits for member state citizens, focussing on eight aspects or parameters: Timing of availability of cleared spectrum, licensing procedure, the reserve price, discrimination against existing operators / spectrum reserves for new entrant, licence duration, approach to licence renewal, coverage obligation and annual fees.

The analysis was completed by gathering data from a range of sources, including GSMAi databases and Arthur D. Little databases, Telegeography, PolicyTracker, National Telecoms Regulators, EU Rail, Fierce Wireless and Eurostat. These sources were further complimented by direct interviews with mobile operators (from the GSMA membership) and some vendors.

Main methodological steps, for key elements of the analysis are outlined below.

1 PRICE BENCHMARKS

The average price per GB for 10 European countries was taken from the 2nd edition of the Arthur D. Little Voice and MBB Services Tariff Plans Benchmarking. For 10 European countries only 4G data plans offered were examined by Operators active in that country, including the Price per month and GB included in that plan. Those were put into 4 different categories (based on package sizes in GB) and the average Price per GB of each category in each country was calculated.

2 SPECTRUM COSTS

The actual cost of spectrum was calculated based on research into actual prices paid, normalising for both population and GDP per Capita. We distinguished between prices achieved for specific bands (i.e. 800 MHz) and general prices (across all bands). The total amount of spectrum sold was calculated as the sum of all MHz sold and no difference was made between paired and unpaired spectrum. The exchange rate was applied at the time of the auction to convert the local currency into Euro for those countries, which reported auction results in local currencies.

Similar approaches were taken to the calculation of reserve spectrum costs, referring to quoted reserve figures; consultation documents and auction tender invitation letters, as well as other sources.

3 CORRELATIONS

The correlation of parameters were assessed based the Pearson Product-Moment Correlation Coefficient for any two sets of values.

4 COVERAGE CHALLENGES

The defined index was based on the geographic scale and topographical nature of each country considered to subjectively compare the relative degree of challenge in covering the country.

For further details on the methodology, please consult Annex I

Annex 1

DETAILED METHODOLOGY

Metric	Definition	Source
4G connections (%) Q4 2014	• 4G unique SIM cards (or phone numbers, where SIM cards are not used) at the end of Q4-2014 that have been registered on the mobile network	GSMAi database
4G market penetration (%) Q4 2014	• 4G connections at the end of Q4-2014, expressed as a percentage share of the total market population	GSMAi database
4G network coverage (%) Q4 2014	• 4G mobile coverage at the end of Q4-2014, expressed as a percentage of the total market population	GSMAi database
4G connections (%) 2y > Launch LTE 800	• 4G unique SIM cards (or phone numbers, where SIM cards are not used) that have been registered on the mobile network, 2 years after the launch of LTE services on the 800 MHz band	GSMAi database
4G market penetration (%) 2y > Launch LTE 800	• 4G connections, expressed as a percentage share of the total market population, 2 years after the launch of LTE services on the 800 MHz band	GSMAi database
4G network coverage (%) 2y > Launch LTE 800	• 4G mobile coverage, expressed as a percentage of the total market population, 2 years after the launch of LTE services on the 800 MHz band	GSMAi database
800 MHz auction date	• Date on which the results of the 800 MHz spectrum auction were announced	ADL spectrum tracker
Multiband auction date (including 800 band)	• Date on which the results of all the bands that were auctioned at the same time as the 800 MHz band spectrum auction were announced	ADL spectrum tracker
First LTE service launched (all bands)	• Date on which the first LTE service was launched on any band	GSMAi database
First LTE service launched (all bands)	• Date on which the first LTE service was launched specifically on 800 MHz	GSMAi database
Correlation coefficient (R)	• The equation for the correlation coefficient is: *Where x and y are the sample means AVERAGE(array1) and AVERAGE(array2).*	(Calculated)

Metric	Definition	Source
Average price per GB	• Average price paid for a gigabyte of data by end-users per country • Calculated as: Sum of per gigabyte prices of all operators / # of observations	ADL Tariff Plans Benchmarking
Cost of spectrum (800 MHz) €/MHz/Pop	• Total cost of 800 MHz spectrum sold, normalized for amount of MHz sold and population size of the country • Calculated as: Total price paid for 800 MHz/Sum of 800 MHz sold/Population	ADL spectrum tracker
Cost of spectrum (all bands) €/MHz/Pop	• Total cost of all spectrum sold at the time of the 800 MHz auction, including 800 MHz, normalized for amount of MHz sold and population size • Calculated as: Total price paid for all spectrum/Sum of all MHz sold/Population	ADL spectrum tracker
Cost of spectrum (800 MHz OR all bands) €/MHz/Pop/GDP	• Total cost of all spectrum sold as calculated in (3) and (4) normalised for GDP levels • Calculated as: Total price paid for spectrum/Sum of MHz sold/Population size/GDP per capita	ADL spectrum tracker
Reserve price (800) €/MHz/pop	• Reserve price set for 800 MHz spectrum, normalized for amount of MHz sold and population size • Calculated as: Reserve price (800) / Sum of MHz (800) sold / Population	ADL spectrum tracker
Reserve price (all bands) €/MHz/pop	• Reserve price set in an spectrum auction, including 800 MHz, normalized for amount of MHz sold and population size • Calculated as: Reserve price (all bands) / Sum of MHz sold / Population	ADL spectrum tracker
Reserve price (800 MHz OR all bands) €/MHz/pop	• Reserve price of all spectrum sold as calculated in (table 6) and (table 7) normalised for GDP levels • Calculated as: Reserve price/Sum of MHz sold/ Population size/GDP per capita	ADL spectrum tracker

Cost of spectrum (800 MHz) €/MHz/Pop

- For all EU 28 countries + Norway we have looked up and incorporated in the ADL Spectrum Tracker:
  - Per country, the total price in Euro[7] that was paid by all Operators together for all 800 MHz spectrum sold (if communicated)
  - Per country, the total amount[8] of 800 MHz spectrum that was sold in the auction
  - Total population per country at the time of the 800 MHz auction (from GSMAi database)
- We then calculated the cost of 800 MHz spectrum as: Total price paid for 800 MHz / Amount of 800 MHz spectrum sold / Population at the time of the auction

Cost of spectrum (all bands) €/MHz/Pop

- For all EU 28 countries + Norway we have looked up and incorporated in the Spectrum Tracker:
  - Per country, the total price in Euro[7] that was paid by all Operators together for all the spectrum in all the bands sold at the same time as the 800 MHz band (including the 800 MHz band) (if communicated)
  - Per country, the total amount[8] of spectrum in all bands that was sold in the multiband auction
  - Total population per country at the time of the multiband auction (from GSMAi database)
- We then calculated the cost of all spectrum as: Total price paid for all bands / Amount of spectrum sold / Population at the time of the auction

Cost of spectrum (800 MHz / all bands) €/MHz/Pop/GDP

- In order to normalise the cost of spectrum for the relative wealth of each country we adjusted it with GDP per capita of that country
- We extracted the GDP per capita for all EU 28 countries + Norway from the GSMAi database at the time of the auction (Historical values)
- We then divided the cost of spectrum calculated in (table 3) and in (table 4) by GDP per capita

7. We applied the exchange rate at the time of the auction to convert the local currency into Euro for those countries which reported auction results in local currencies
8. The total amount of spectrum sold was calculated as the sum of all MHz sold and no difference was made between paired and unpaired spectrum

Table 3

Actual price/MHz/Pop (800 MHz)

	Actual price paid (€m)	MHz sold	Population	Actual price/MHz/Pop
Austria	359	60	8,510,787	0.70
Belgium	360	60	11,124,448	0.54
Croatia	40	40	4,298,568	0.23
Denmark	100	60	5,597,760	0.30
Estonia 1	1	20	1,287,251	0.04
Estonia 2	1.6	20	1,286,381	0.06
Estonia 3	5.1	20	1,284,641	0.20
Finland	108	60	5,434,910	0.33
France	2,640	60	63,759,344	0.69
Germany	3,600	60	83,017,404	0.72
Greece	309	60	11,127,119	0.46
Italy	2,962	60	60,768,135	0.81
Latvia	4.7	60	2,048,016	0.04
Lithuania	2.3	60	3,014,772	0.01
Spain	1,300	60	46,574,223	0.47
Sweden	197	60	9,432,298	0.35

Source: GSMAi & Arthur D Little

Table 4

Actual price/MHz/Pop (All bands, including 800 MHz)

	Actual price paid (€m)	MHz sold	Population	Actual price/MHz/Pop
Austria	2,015	280	8,510,787	0.85
Belgium	360	60	11,124,448	0.54
Croatia	40	40	4,298,568	0.23
Czech Republic	332	198	10,721,333	0.16
Denmark	100	60	5,597,760	0.30
Estonia 1	1	20	1,287,251	0.04
Estonia 2	1.6	20	1,286,381	0.06
Estonia 3	5.1	20	1,284,641	0.20
Finland	108.1	60	5,434,910	0.33
France	2,640	60	63,759,344	0.69
Germany	4,384	359.2	83,017,404	0.15
Greece	381	240	11,127,119	0.14
Hungary	418	135	9,927,729	0.31
Ireland	855	280	4,588,711	0.67
Italy	3,945	240	60,768,135	0.27
Latvia	4.7	60	2,048,016	0.04
Lithuania	2.3	60	3,014,772	0.01
Netherlands	3,802	359.6	16,736,624	0.63
Norway	212.5	170	5,067,298	0.25
Portugal	372	300	10,600,717	0.12
Romania	682	375	21,740,702	0.08
Slovakia	163.8	290.8	5,452,189	0.10
Slovenia	149	470	2,075,592	0.15
Spain	1,600	210	46,574,223	0.16
Sweden	197	60	9,432,298	0.35
United Kingdom	2,722	250	63,047,978	0.17

Source: GSMAi & Arthur D Little

Reserve price (800) €/MHz/pop

- For all EU 28 countries + Norway we have looked up and incorporated in the ADL Spectrum Tracker:
  - Per country, the Reserve price in Euro[9] that was set by Regulators for all 800 MHz spectrum sold (if communicated; unsold spectrum not taken into account)
  - Per country, the total amount[10] of 800 MHz spectrum that was sold in the auction
  - Total population per country at the time of the 800 MHz auction (from GSMAi database)
- We then calculated the reserve price of 800 MHz spectrum as: Reserve price for 800 MHz sold / Amount of 800 MHz spectrum sold / Population at the time of the auction

Reserve price (all bands) €/MHz/pop

- For all EU 28 countries + Norway we have looked up and incorporated in the Spectrum Tracker:
  - Per country, the Reserve price in Euro[9] that was set by Regulators for all the spectrum in all the bands sold at the same time as the 800 MHz band (including the 800 MHz band) (if communicated)
  - Per country, the total amount[10] of spectrum in all bands that was sold in the multiband auction
  - Total population per country at the time of the multiband auction (from GSMAi database)
- We then calculated the reserve price of all spectrum as: Reserve price for all bands sold / Amount of spectrum sold / Population at the time of the auction.

Reserve price (800 MHz OR all bands) €/MHz/pop

- In order to normalise the Reserve prices for the relative wealth of each country we adjusted it with GDP per capita of that country
- We extracted the GDP per capita for all EU 28 countries + Norway from the GSMAi database at the time of the auction (Historical values)
- We then divided the Reserve prices calculated in (table 3) and in (table 4) by GDP per capita

9. We applied the exchange rate at the time of the auction to convert the local currency into Euro for those countries which reported reserve prices in local currencies
10. The total amount of spectrum sold was calculated as the sum of all MHz sold and no difference was made between paired and unpaired spectrum

Table 6

Reserve Price/MHz/Pop (800 MHz)

	Actual price paid (€m)	MHz sold	Population	Actual price/MHz/Pop
Austria	128	60	8,510,787	0.251
Belgium	360	60	11,124,448	0.539
Croatia	40	40	4,298,568	0.233
Finland	100	60	5,434,910	0.307
France	1,800	60	63,759,344	0.471
Germany	15	60	83,017,404	0.003
Greece	309	60	11,127,119	0.463
Ireland	120	60	4,588,711	0.436
Italy	2,120	60	60,768,135	0.580
Netherlands	210	60	16,736,624	0.209
Norway	35.7	60	5,067,298	0.117
Poland	297	50	38,221,064	0.155
Portugal	180	60	10,600,717	0.283
Romania	175	60	21,740,702	0.134
Spain	1,020	60	46,574,223	0.365
Sweden	48	60	9,432,298	0.08
United Kingdom	1,370	60	63,047,978	0.362

Source: GSMAi & Arthur D Little

Table 7

Reserve Price/MHz/Pop (Multiband, including 800 MHz)

	Actual price paid (€m)	MHz sold	Population	Actual price/MHz/Pop
Austria	226	280	8,510,787	0.095
Belgium	360	60	11,124,448	0.539
Croatia	40	40	4,298,568	0.233
Czech Republic	286	198	10,721,333	0.135
Finland	100	60	5,434,910	0.307
France	1,800	60	63,759,344	0.471
Germany	89.8	359.2	83,017,404	0.003
Greece	376	240	11,127,119	0.141
Italy	3,030	240	60,768,135	0.208
Netherlands	480	359.6	16,736,624	0.080
Norway	58.3	170	5,067,298	0.068
Poland	380	190	38,221,064	0.052
Portugal	299	300	10,600,717	0.095
Romania	638	375	21,740,702	0.078
Slovakia	143	290.8	5,452,189	0.090
Slovenia	103.2	470	2,075,592	0.106
Sweden	48	60	9,432,298	0.08
United Kingdom	2,722	250	63,047,978	0.173

Source: GSMAi & Arthur D Little

GSMA HEAD OFFICE
Floor 2
The Walbrook Building
25 Walbrook
London EC4N 8AF
United Kingdom
Tel: +44 (0)20 7356 0600
Fax: +44 (0)20 7356 0601