MEASURING THE ECONOMIC VALUE OF SPECTRUM

Note on proposed methodologies

2 August 2018

CONTENTS

1 INTRODUCTION

ComReg wishes to estimate the contribution that spectrum makes to the Irish economy. Spectrum is used in a wide variety of sectors and evolving wireless technologies mean that it is now integral to many production processes and commercial practices. This means that measuring the economic contribution of spectrum, as a distinct input used in many sectors, is complex.

The purpose of this note is to identify potential methods that could be used to estimate the economic contribution of spectrum, and to describe the approaches that Frontier proposes to use to estimate the contribution of spectrum to the Irish economy.

The note is structured as follows.

- Section 2 summarises six different options that can be used to estimate the contribution of spectrum to the Irish economy.
- Section 3 describes in more detail the two complementary approaches that Frontier proposes to use to measure the contribution of spectrum to the Irish economy.

2 DIFFERENT APPROACHES TO ASSESSING THE ECONOMIC CONTRIBUTION SPECTRUM MAKES TO THE IRISH ECONOMY

We describe below a number of different approaches that could be used to estimate the impact of spectrum, before recommending two complementary approaches.

- Section 2.1 considers the methodological challenges in measuring the economic value of spectrum;
- Section 2.2 summarises six approaches to estimate contribution of spectrum to the Irish economy; and,
- Section 2.3 assesses the six approaches and recommends a proposed approach.

2.1 Methodological challenges in measuring the impact of spectrum

Measuring the impact that spectrum has on an economy is complex. This is because:

- Spectrum is used in a number of goods and services which are themselves, in turn, inputs in a complex supply chain downstream, meaning the value of spectrum is felt in a wide set of markets.
- Spectrum is only one of a number of inputs in the goods and services that use it.
- The use of spectrum may have wider “spillover” economic impacts, such as productivity improvements or social benefits which should all be captured when estimating its overall contribution.
- In many cases spectrum is allocated for public use (and not for commercial purposes) where the contribution to GVA can be more difficult to measure.

Spectrum is used in a number of goods and services which are themselves inputs in a complex supply chain downstream

Spectrum is a direct input in a number of sectors. These include mobile services (including mobile support / equipment, mobile retail), fixed wireless, broadcasting, aviation, radio technology and low powered devices for IoT.

However, it is indirectly used in a much wider set of economic activities which reach into all aspects of the economy. Therefore, when assessing the impact that spectrum has on the economy it would be preferable to assess the impact across all sectors where spectrum is used as an input. For example, content providers derive economic value from distributing content using spectrum; spectrum is also used widely in logistics and business communications and can thus drive productivity in these sectors too. As another example, without spectrum, a number of services provided in the "gig economy" would not be possible, whilst "traditional" firms would also not have been able to adopt modern distribution processes and practices that rely on wireless communications.

Spectrum is only one of a number of inputs in the goods and services that use it

As set out above, spectrum is but one input used in the supply of goods and services. Arguably, therefore, the economic output associated with goods and services that use spectrum should not all be attributable to spectrum. This is because other inputs such as components, research and development, and intellectual property rights will all contribute to the economic value of the good or service.

A counterfactual analysis, in theory, would identify the economic value which was solely attributable to spectrum by comparing economic outputs today to a counterfactual where spectrum was unavailable. We therefore discuss in section 2 the pros and cons of different approaches that could be used to estimate the value of spectrum compared to a counterfactual of no spectrum.

The use of spectrum may have wider "spillover" economic impacts, such as productivity improvements or social benefits

Spectrum could be described as a General Purpose Technology. Such services can have "spillover effects" such as economy wide productivity improvements. This means that the availability of spectrum improves the growth potential of an economy, compared to a counterfactual which excludes the use of spectrum.

The channels through which technologies that use spectrum can lead to economy-wide productivity gains could include:

- Lower barriers to market entry and expansion. Producers are able to access consumers more easily and vice versa.
- New business processes. In many fields, wireless technologies have led to new processes. These could be in logistics and navigation, for example, where existing process have been improved.
- Innovation more generally. Technologies which use wireless technology may generate innovation which would not be possible absent the use of spectrum.

In combination, these effects could increase the productive potential of the economy. This means the contribution that spectrum makes to these effects should be reflected in the overall estimate of the economic value of spectrum to the economy.

In many cases spectrum is allocated for public use (and not for commercial purposes)

Much of spectrum that is currently managed is used for publicly provided services as distinct from services provided in the commercial economy. For example, spectrum may be used in services provided publicly by the state to transmit data (defence or emergency services are obvious examples), or for use in various forms of imaging and detection (from radar to X-rays). These applications strongly rely on spectrum and have a clear economic value. However, this value can be hard to measure. In contrast, spectrum used as an input in services which are commercially traded can be easier to value because there is typically a clearer consumer demand and price for such services.

2.2 Six approaches to measuring the economic value of spectrum

Given the challenges set out above there are a number of different, but in some ways, complementary approaches to measuring the economic contribution of spectrum.

We set out below six different approaches that can be used to measure the value of spectrum. Each of the approaches has advantages and disadvantages which relate to the issues raised above.

The potential approaches are as follows:

- Approach 1: A "bottom up" approach using company registration data to estimate GVA (and other economic indicators);
- Approach 2: A "top down" approach using National Accounts from the Central Statistics Office (CSO) to measure GVA in the sectors where spectrum is core;
- Approach 3: Estimating consumer surplus associated with products and services that use spectrum;
- Approach 4: Estimating the economic contribution of spectrum compared to a counterfactual of "no spectrum";
- Approach 5: Estimating the opportunity cost associated with spectrum (i.e., the cost of using the next best input and / or the foregone demand if alternative (imperfect) inputs are used); and
- Approach 6: Assessing the impact of spectrum on productivity by analysing and adapting existing estimates of the relationship between use of spectrum and economy wide productivity.

Approach 1: A "bottom up" (using company registration data) to estimate direct economic impact.

This approach identifies the sectors in which spectrum is used as an input and those companies within these sectors that use spectrum. The analysis would then identify the economic value added of these companies.

In addition, it could be possible to use "input-output tables"[1] (published by the CSO) to estimate the wider GVA impact across the upstream supply chain.

[1] Input - Output tables describe what goods (services) are required for the production of a particular good (service). As such, they enable us to identify the suppliers of a core spectrum sector and the amount of output they supplied to that core sector.

Previously, ComReg has used a similar approach to estimate the economic contribution of eight sub-sectors which use radio spectrum as an input. The data for this was taken from company financial records (listed with the Irish Companies Registration Office) and the national accounts.

Figure 1 Pros and cons of Method 1

Pros	Cons
Data which is reliable based on audited data. The GVA multiplier can estimate the economic impact on the wider economy (using multiplier effects).	Does not directly estimate the incremental impact that spectrum has (against a counterfactual where spectrum is not used or not managed). Inevitably it may be difficult to identify all potential firms and sectors where spectrum is a direct input.

Approach 2: A "top down" approach (using national accounts data) to estimate direct economic impact

A macro approach would be similar in nature to the first approach, but would use aggregated national accounts data within each sector. The estimate of the direct impact of the services that use spectrum derived under this approach could then be complemented with an estimate of indirect effects to estimate the wider GVA impact across the upstream supply chain.

In order to assess the level of GVA and of investment in the sectors studied it may be necessary to use surveys or other available data on the GVA:turnover ratio or the investment:turnover ratio.

While this approach would provide high level aggregated results, it has a number of potential drawbacks.

- Data may not be available at the degree of disaggregation necessary to assess the sectors relevant for the study (i.e., it may only be available for telecommunications as a whole, rather than mobile communications).
- Data on GVA:turnover or investment:turnover ratios may not be available in Ireland.

Figure 2 Pros and cons of Approach 2

Pros	Cons
The GVA multiplier can estimate the economic impact on the wider economy.	Does not directly estimate the incremental impact that spectrum has (against a counterfactual where spectrum is not used). Data may not be readily available at a sufficient level of disaggregation.

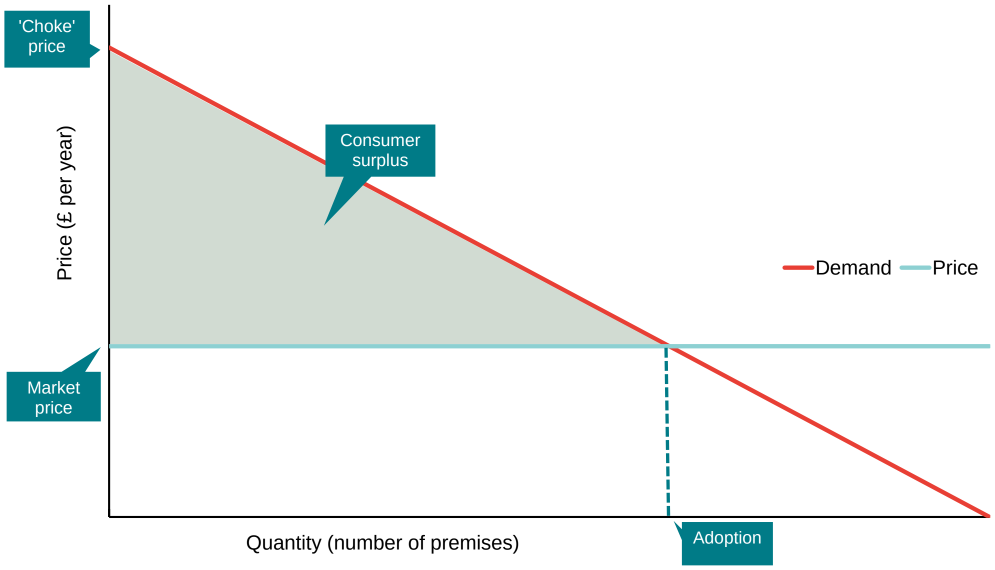
Approach 3: Estimating consumer surplus associated with products and services that use spectrum

A complementary approach to estimating the economic impact of spectrum is to consider the consumer surplus arising from the provision of services that use spectrum.

Consumer surplus could be estimated by using assumptions on the nature of demand. For example, studies which set out the elasticity of demand for mobile services could be used to estimate the consumer demand curves. However, the assessment of consumer surplus is very sensitive to the assumptions made on the nature of demand: such as the shape of the demand curve (whether linear or log-linear), and the "choke price" (i.e. the price at which demand is zero). For these reasons any estimate of consumer surplus would only be a very broad estimate with wide confidence intervals.

Furthermore, estimating consumer surplus would be more difficult to implement in those sectors (such as broadcasting) where revenues are derived from advertising (in a two sided market). This is because in these markets the prices that consumers pay is zero, and therefore estimating the shape of the demand curve is problematic.

Figure 3 Illustration of consumer surplus estimation



Source: Frontier

Figure 4 Pros and cons of Approach 3

Pros	Cons
Considers consumer surplus and therefore offers a more complete estimate of the welfare impact of spectrum.	Estimates of consumer surplus are very sensitive to assumptions on the nature of demand. Willingness-to-pay (WTP) surveys might not always reflect the true valuation of consumers, and might overstate or understate consumer surplus. Does not estimate external welfare benefits to society as a whole (like improved efficiency, network externalities), or the benefits from public use of spectrum (like the use of spectrum in defence, emergency services and aviation). Economic estimates of consumer surplus does not directly relate to national income measures (GDP or GVA).

Approach 4: Estimating the economic contribution of spectrum compared to a counterfactual of "no spectrum"

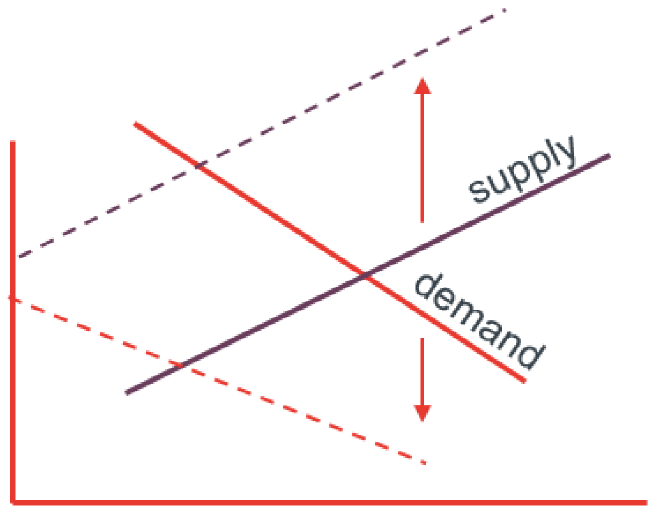
This approach considers economic outputs in a scenario where spectrum is unavailable. It is consistent with estimating the economic contribution of spectrum compared to a counterfactual of "no spectrum" (and so has advantages over approaches 1 and 2).

If spectrum were unavailable then two broad effects might be observed:

- Suppliers might substitute to alternative inputs (wired communications) which can provide similar functionality though at higher cost.
- Consumers might substitute to alternative goods or services, or may stop consuming altogether.

The combination of these two effects will determine the level of economic activity in a counterfactual of no spectrum. This is illustrated in Figure 5 below. The factual output for a specific product or service that uses spectrum is given by the intersection of supply and demand. In the counterfactual of no spectrum the supply curve shifts up (as suppliers shift to alternative (wired) inputs); and the demand curve shifts down (as consumers switch to alternative goods or stop consuming). In the illustrative example, output for the specific good or service declines to zero.

Figure 5 Impact of no spectrum on goods and services that use spectrum



Source: Frontier

Estimating the precise nature of the supply and demand curves for all potential uses of spectrum is, however, complex. It requires a good understanding of the underlying cost function of the supply of goods and the nature of the demand.

An alternative approach would be to apply a qualitative weighting analysis to proxy the impact of the removal of spectrum (in the counterfactual) on demand and supply, and hence output. This is described in Figure 6.

Figure 6 Illustrative approach to categorising economic activity by its reliance on spectrum

Category	Description	Examples	Weight
Core	Spectrum is essential to the service. Without spectrum demand would be close to zero.	Mobile services	100%
Intermediate	Spectrum plays an important role but other inputs are available.	Wireless Communications	50%
Peripheral	Spectrum plays a role but it is a relatively minor role.	Headphones, Bluetooth communications, machine2machine	10%

Source: Frontier

However, in practice, there are a number of practical difficulties in applying this approach including identifying the economic activity which falls within each category; categorising different types of economic activity in the above categories; and determining the appropriate weighting. Ultimately the weighting could be arbitrary.

Figure 7 Pros and cons of Approach 4

Pros	Cons
This approach attempts to measure the contribution of spectrum relative to a counterfactual.	Very difficult to apply in practice. Weighting likely to be arbitrary.

Approach 5: Estimating the cost of using the next best input and/ or the foregone demand if alternative (imperfect) inputs are used

This approach estimates the value or opportunity cost of alternative uses of spectrum. That is, it would assess the cost saved by using spectrum as opposed to the next best alternative input. For example, fixed wireless links could be replaced by fibre links and the cost saved by using spectrum could represent the incremental value of spectrum in this use.

Where an alternative to using spectrum is not practicable (for example in the case of some mobile communications which could not be conducted via a fixed service) this approach could instead estimate foregone demand if that service is not provided. However, it may not be reasonable to assume that the economic activity in the sector would not take place were spectrum unavailable (as consumers may switch to imperfect substitutes).

This approach would use bottom-up cost modelling to understand what producing goods and services (that normally use spectrum) would cost if spectrum was unavailable and alternative inputs had to be used. In this sense it is conceptually similar to the estimate of the cost function in Approach 4, but whereas Approach 4 would use a high level estimate of the cost function, Approach 5 envisages using distinct bottom up cost models in the goods and services that use spectrum.

In practice, this approach is likely to be very assumption driven. In estimating the incremental costs of alternative inputs, it would be necessary to build a number of engineering models which estimated costs (similar to the model used by ComReg to estimate the benefits of migrating users of 700 MHz spectrum to lower bands). Furthermore, estimating forgone consumer demand relies heavily on assumptions about the hypothetical substitutability of alternative goods.

In certain specific circumstances, this analysis can be a proportionate exercise in relation to the regulatory objectives. For example, in 2015 ComReg published an analysis which examined the costs and benefits of repurposing 700 MHz spectrum from its existing use (principally Digital Terrestrial TV services) to mobile services. This analysis required an understanding of the impact that a reduction in the supply of spectrum had on operators' network costs, given a complex set of constraints (growing in-door and out-door mobile demand, for instance).

However, it is likely that this kind of cost modelling would not be suitable for this analysis for a number of reasons. First this analysis covers a number of different sectors which would multiply the complexity of the analysis. Second, in contrast to the analysis prepared for the 700 MHz project, this analysis would require an understanding of the relationship between supply and demand (whereas in the 700 MHz project demand was assumed to be constant).

Figure 8 Pros and cons of Method 5

Pros	Cons
This approach captures the incremental value of spectrum.	Results are likely to be very sensitive to assumptions. There is unlikely to be data or information available. Requires detailed modelling across a number of sectors.

Approach 6: Assessing the impact of spectrum on productivity by analysing and adapting existing estimates

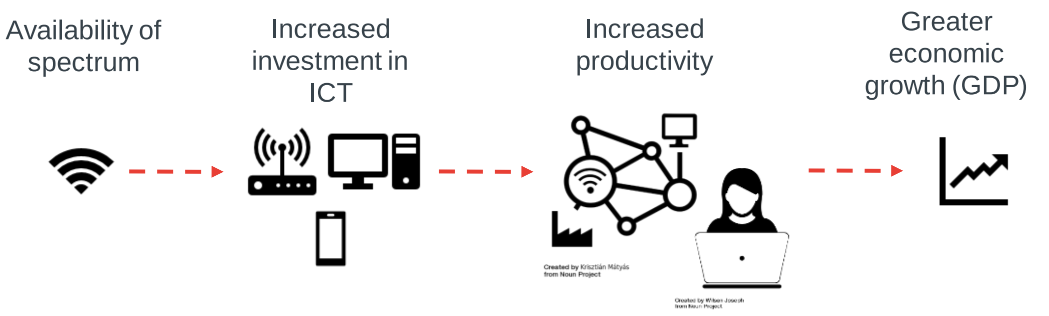
This approach would estimate the effect that spectrum has across the economy, beyond the industries where spectrum is a “core” input.

The availability of spectrum supports the digitalisation of the economy, now a pervasive development across virtually all industries. Related to this, there is a substantial body of empirical evidence showing that, in many cases, increasing investment in and use of Information and Communication Technology (ICT) has been a key driver of productivity growth since the mid-1990s.[2]

Typical estimates suggest that a 10% increase in ICT equipment (the “ICT capital stock”) is linked with a 0.5-0.6 percentage point increase in productivity growth. ICT can have this effect by supporting innovation; facilitating collaboration by lowering communication costs; and allowing firms to adopt more efficient management practices and organisational structures. Alongside this literature, other studies have focussed on the specific impact of wired and wireless communications on economic growth. Of the studies which examine the link between investments in Communications technologies, some studies are specific to either fixed broadband (coverage or take up) or mobile services. However, studies which focus on the quality (i.e. speed) of broadband connections in different areas are rarer given the difficulties in estimating the impact of increments in quality of connection.

This approach would draw on this literature, using existing estimates of the impact of wireless communication, and inferring from the wider literature what proportion of the impact of ICT could be attributed to spectrum.

Figure 9 Stylised representation of links between spectrum and productivity growth



Source: Frontier

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Doing this would require overcoming two key challenges:

- Applying ICT estimates to spectrum. This requires understanding of:
  - Whether the productivity return to wireless ICT investment differs from the return to all ICT investment;
  - What proportion of ICT investment would not take place in the absence of spectrum.
- Applying international estimates to Ireland.

A large proportion of the literature is based on data from other countries (chiefly United States and United Kingdom) or international data from several countries (e.g. OECD, European Union). This approach would consider if and how the return to ICT investment in Ireland differs from other countries.

Figure 10 Pros and cons of Method 7

Pros	Cons
This approach captures the value of spectrum in raising productivity across the entire Irish economy. The approach is consistent with robust empirical evidence showing that ICT can have a positive impact on productivity. This empirical evidence aims to take into account the 'counterfactual' issue – that is, it aims to measure the effect of ICT on top of what would happen otherwise.	Adjustments will be needed in order to apply existing evidence (based on ICT and wireless communications in a number of countries) to the specific scope of this project (impact of spectrum in Ireland). These adjustments can be partly evidence-based but will also involve assumptions.

2.3 Long list assessment

In appraising the different approaches we set out below:

- Proposed criteria to appraise the options;
- A high level assessment of the options against the criteria; and,
- Our preliminary view on the appropriate approach.

2.3.1 Assessment criteria

In choosing which methods to take forward we use a number of criteria. These criteria are in part based on criteria set out in ComReg's terms of reference, augmented by other criteria suggested by Frontier, in order to ensure an accurate representation of the economic value of the radio spectrum in line with available information.

METHODOLOGY ASSESSMENT CRITERIA

ComReg requires that the chosen approach should:

- Rely on readily available Irish economic data.
- Produce reliable and accurate estimates, which are robust and subject to scrutiny.
- Be readily repeatable in subsequent years.

In addition it may be relevant to also consider other criteria. These could include:

- Does the approach assess the impact compared to the counterfactual of no spectrum or does it merely describe the value of goods and services which use spectrum as an input?
- Does it capture all aspects of economic impact, not just GVA but also the indirect and induced effects elsewhere in the supply chain?
- Does the approach take into account non-monetary benefits to consumers?
- Does the approach assess wider spillover effects?
- Does the approach consider wider social impacts or welfare impacts?

2.3.2 Option appraisal

Figure 11 assesses each of the (complementary) approaches against the criteria above. The purpose is not to come to a precise score, since different views on the scores against each category may be equally relevant. However, it does illustrate two factors which are important. First, some Approaches (such as Approach 4 or Approach 5) are less practicable to implement than others. Second, some of the approaches might be complementary.

Figure 11 Option analysis

	Approach 1: A bottom up approach using company registration data to estimate GVA;	Approach 2: A macroeconomic approach using CSO National Accounts	Approach 3: Estimating consumer surplus	Approach 4: Estimating the economic contribution of spectrum compared to a counterfactual of “no spectrum”	Approach 5: Estimating the opportunity cost associated with using spectrum (i.e., the cost of using the next best input and/ or the foregone demand if alternative (imperfect) inputs are used	Approach 6: Assessing the impact of spectrum on productivity by analysing and adapting existing estimates
Available Irish economic data	●	◑	◔	○	◔	◔
Not excessively complex	◑	◕	◔	◕	○	◔
Reliable and accurate estimates	◕	◕	◑	◔	◔	◑
Repeated in subsequent years	◕	◕	◔	◔	◔	◑
Assess the impact compared to the counterfactual	◔	◔	◑	●	◕	◕
Includes indirect supply chain	◕	◕	○	◕	○	◕
Non-monetary benefits to consumers	○	○	●	○	○	◔
Spill over effects	○	○	○	○	○	◕

Source: Frontier

2.3.3 Preliminary view on the appropriate framework

Given the initial analysis contained above, we have suggested using two complementary approaches. This has the effect of maximising the extent to which the criteria set out above are met in our analysis.

- To estimate the direct economic output in the sectors where spectrum is used as an input we will propose to examine both **Approach 1 and Approach 2**. Note that the methodology for measuring direct impacts may vary depending on the sector under consideration (in some cases it may be preferable to use CSO data (a "top down approach"), in other cases it may be preferable to use CRO data (a "bottom up approach").
- Separately we will review the literature on the contribution of spectrum to economic growth and productivity (using techniques as described in **Approach 6**). Based on this, we will provide an assessment of the contribution that spectrum has made to the wider Irish economy.

3 DETAILED APPROACH

3.1 Introduction

Given the discussion set out in section 2.3, we propose to adopt two complementary approaches to measuring the economic contribution that spectrum has on the Irish economy.

The first methodology ("Methodology 1") measures the direct economic activities in those sectors where spectrum is core. However, the results of this approach should be treated with care. This is because.

1. It will understate the contribution of spectrum in those sectors where spectrum is not core but still an input into the supply process. This is because the additional value added through the use of the radio spectrum in those sectors is not included. As noted above, measuring the contribution of the radio spectrum for sectors that are not considered core is difficult because it requires large amounts of reliable information and is subject to a large margin of error. Such discrepancies could affect the estimate of the contribution of the non-core sectors and result in an unreliable estimate of the total contribution of the spectrum.
2. It might overstate the contribution that spectrum makes in the sectors identified as relying on spectrum as a core input. This is because it is explicitly not a counterfactual analysis (i.e. it does not measure the incremental economic activity related to spectrum relative to a counterfactual of no spectrum).

The first impact naturally leads to a conservative estimate of the economic contribution of the radio spectrum to the economy. The second impact is relevant where the economic impact of the spectrum as one input among competing alternatives is being assessed. While this would be a concern in a counterfactual analysis, it is not so in this case, as we are merely estimating the contribution of spectrum to a broader economic aggregate (i.e. GDP, GNI), i.e. the contribution of selected sectors to the economy as measured by the national statistics agency.

The second methodology ("Methodology 2") measures the contribution that spectrum makes to the wider economy (including economic spill over effects on wider economy wide productivity).

These are described in more detail below.

3.2 Methodology 1: Measure the economic impact (measured by GVA and other economic metrics) of suppliers of goods and services where spectrum is "core"

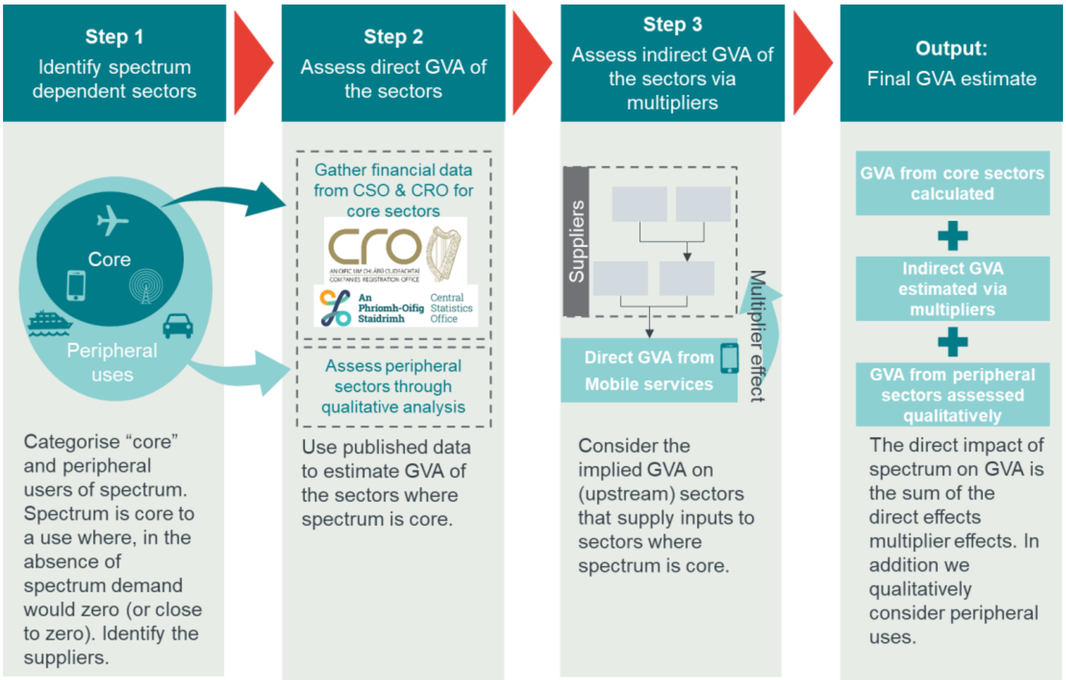
Our proposed approach estimates the contribution that spectrum makes to the Irish economy by identifying the economic value added in sectors where spectrum is core to the supply of goods or services. Added value in this context refers to Gross

Value Added (GVA), which is based on earnings accruing to capital and labour at companies that produce the relevant goods and services.

This approach involves the following three steps.

- Step 1: Identify sectors where spectrum is "core" to the supply or demand of the good or service.
- Step 2: Estimate the direct economic activity (value added) associated with the sectors identified in the financial years 2013-2016.
- Step 3: Estimate the indirect supply impact of the economic activity associated with step 2.

Exhibit 1. Illustration of methodology to measure the direct impact



Source: Frontier

3.2.1 Step 1: Identify sectors where spectrum is "core" to the supply or demand of the good or service

The analysis identifies sectors where spectrum is "core" to the supply or demand of the good or service. These are economic activities where, in the absence of spectrum, economic output would be zero or close to zero. Inevitably there is a degree of judgement in identifying the sectors where spectrum is considered to be "core".

The sectors that we have identified are as follows.

Operation of mobile services

Mobile services clearly rely on spectrum to support mobile communication services. Mobile network operators provide mobile services (such as calls and data) which are entirely dependent on the use of spectrum. Spectrum in a number of bands is used by mobile network operators to provide services. The three mobile network operators[3] jointly contribute a majority of sector turnover, and in addition a number of MVNOs (Mobile Virtual Network Operator) rely on spectrum.

Manufacture, sale and distribution of mobile devices

The manufacturing of mobile equipment includes the manufacture of mobile devices and mobile network equipment. In the absence of spectrum to support mobile services it is likely that demand for mobile devices would significantly diminish. Much of the distribution and sales activity of consumer mobile devices is carried out by manufacturers and mobile service operators. As such, much of the GVA associated with this activity will be included in the segment discussed above.

However, there are also a number of independent wholesalers and retailers which we aim to include. Note that to a small extent, these companies also sell devices that are not directly relevant for this analysis, e.g. laptops which partially use spectrum (for example to support wireless connectivity via Wi-Fi or Bluetooth. However, in this sense spectrum may not be “core” to the supply of the good. There are also likely to be a number of small retailers who we have not included.

Radio broadcasting

Radio broadcasting describes the provision of a live stream of voice and music based programming. Traditionally, radio stations were only available via terrestrial broadcasting which relied on spectrum. Now services are supplied using wired communications (via the internet or cable TV).

Wireless television broadcasting

TV broadcasting relies on spectrum in a number of ways. This principally relates to the transmission of TV broadcasting via terrestrial TV networks; satellite TV networks or streaming via mobile networks. Similar to radio, at one time terrestrial broadcasting was the only way for users to receive television services. However, they are now also received via wired cable networks or the internet.

Satellite communications services

Satellite services provide connectivity via networks which use a combination of ground based stations which downlink / uplink to a network of satellites which orbit the earth. Satellite data services provide specialist services to businesses, broadband in very rural areas, data to aircraft and maritime, to support broadcasting, and in some cases international telecommunications services.

Aviation

Aviation relies on spectrum for specialist communication, safety, data broadband links and navigation. Arguably the demand for aviation would be considerably lower in the absence of spectrum since the quality of the service would be significantly impaired. Therefore we will include the major aviation related providers which are based in Ireland. However, arguably this understates the GVA of aviation

[3] Three and Telefonica Ireland (O2) were separate companies prior to their merger in 2016.

services in Ireland which use spectrum, as any international airline which flies into Ireland also relies on the management of spectrum in Ireland.

Fixed wireless

Fixed wireless technologies are used to connect fixed locations (e.g. buildings) via a wireless link. They are often used in the provision of internet and other services to areas of low population density, where the construction of fixed telecommunications infrastructure would not be economical. If spectrum was unavailable, these wireless services could not be provided and fixed services could only serve as a substitute to a limited extent.

Professional Mobile Radio (PMR)

Professional mobile services are specialised mobile communication services that are often used by police forces and fire brigades, as well as certain commercial sectors. They are reliant on spectrum to the same extent as regular mobile services.

PMSE

Programme Making and Special Events (PMSE) refers to equipment and services used to support broadcasting, news gathering, theatrical productions etc. Much of this equipment is wireless, and is often used for the creation of content for radio and television broadcasting. As such, a significant portion of GVA associated with the manufacture and sale of these devices and services is dependent on spectrum.

Mobile content creation and advertising

A part of the GVA associated with mobile content creation is captured by mobile Operating System developers that operate the app stores (e.g. Apple Store). These companies also develop a large number of default mobile apps. Unfortunately, identifying the GVA associated with apps and app stores that pertain to Ireland from the financial statements of these global companies is not feasible. There are also a large number of SMEs that develop apps and sell them through the established app stores. These companies are too small and numerous to include in this analysis however. As a result, mobile content creation will not be included in this analysis.

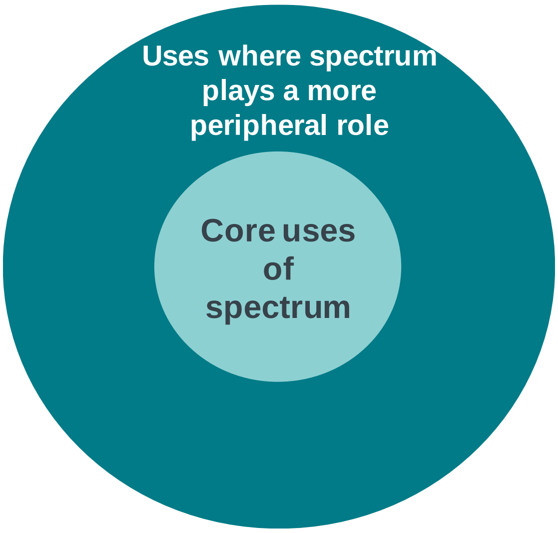
Many mobile services and applications rely on advertising revenues. Arguably a significant proportion of mobile advertising revenues are incremental, in that in the absence of mobile services advertising investment would not be displaced to alternative outlets. However, we will not estimate the value added of mobile advertising in this analysis. These activities are carried out by large advertising firms, and it is not feasible to separately identify the GVA associated specifically with mobile advertising from the financial statements of these firms.

Sectors where spectrum is not core

While spectrum is essential to a “core” set of goods and services (which can be identified readily), its use now pervades almost all aspects of economic life. For example, there are a wide range of services which, "partially" rely on spectrum (even if spectrum is not core to the good or service). These could include:

- Goods and services which use spectrum as an input, but where the wireless element is not core. These could include the multitude of wireless devices which are embedded in many manufactured consumer devices. For example laptops, car security, home security, baby monitors, Bluetooth, Near Field Communications (NFC), RFID (Radio Frequency Identification – such as tap and pay bank cards).
- Business goods and services (i.e. where spectrum is used in "intermediate" products). These could include different forms of M2M connectivity, for example to support logistics.

Exhibit 2. Core and peripheral uses of spectrum



Source: Frontier

If spectrum was not managed or unavailable it is difficult to think of a single area of economic activity that would not be altered. Furthermore, the utility that end users of goods and services derive from spectrum related features on goods and services is difficult to observe or otherwise empirically measure. Therefore our analysis of the direct effects of spectrum focuses on those uses where spectrum is a core input (i.e. where without it demand would be close to zero). However, in doing so, it is important to be mindful that there is considerable economic value generated in a wide range of goods and services where spectrum is a more peripheral input.

Measuring the economic value of spectrum in sectors where its use is more "peripheral" is much more complex. In the absence of spectrum, suppliers can switch to alternative inputs, and users could switch to alternative products. Measuring the cumulative impact on output given these effects would be difficult. Therefore, this analysis will not capture the value that spectrum has in those sectors where it is used more peripherally. In this way the estimate of the direct value will under-estimate the value of spectrum.

In practice we recognise that there is a degree of judgement involved in assessing whether the use of spectrum in a given sector is core or where spectrum is more peripheral. Even in those sectors where spectrum is “core” it is unlikely to be the case that output would be zero in the absence of spectrum. In this way, the estimate of the direct value will over-estimate the value of spectrum in those sectors. However, this potential overestimate only applies to the nine sectors outlined above. The overall estimate is still likely to be a conservative estimate of the value of radio spectrum given wireless technologies` widespread use in industries that are not considered by this analysis.

Identifying the suppliers present in each sector, and mapping the sectors that use spectrum to NACE Rev2 codes

Some of the core uses of spectrum we have identified map easily and exactly to the NACE[4] codes, such as operation of mobile services or satellite services. Others can be mapped to NACE codes but only at a less disaggregated level. For example, there is no NACE code that is specific to the manufacture of wireless communication equipment, and so instead the less disaggregated NACE code for manufacture of (all) communication equipment must be used as an alternative.

Finally, there are some core uses that are either difficult to map to NACE codes or, if mapped, would only represent a tiny proportion of a more aggregated NACE code. For these core uses, such as low power devices or PMR, we do not attempt to estimate the value of spectrum using NACE codes.

We summarise the sectors where spectrum is used as a core input, together with the relevant NACE codes, below.

[4] The NACE code is the common basis for statistical classifications of economic activities within the E.C.. It is set out in the Annex to Council Regulation (EEC) No. 3037/90 of 9 October 1990 on the statistical classification of economic activities in the E.C. (Nomenclature statistique des activités économiques)

Figure 12 NACE Rev2 codes of core uses of spectrum

Core use	Closest NACE Rev2 Class		Matches core use exactly? i.e. does the whole NACE code rely on spectrum?
Operation of mobile services	Wireless telecommunications services	61.20	Yes
Manufacture of mobile equipment/devices	Manufacture of communication equipment	26.30	No
Sale and distribution of mobile devices	Wholesale of electronic and telecommunications equipment and parts	46.52	No
	Retail sale of telecommunications equipment in specialised stores	47.42	No
Mobile content creation	Software publishing	58.20	No
Mobile advertising	Advertising	73.10	No
Radio broadcasting	Radio broadcasting	60.10	Yes
Wireless television broadcasting	Television programming and broadcasting services	60.20	No
Satellite services	Satellite telecommunications services	61.30	Yes
Aviation	Air transport	51.00	Yes
Fixed wireless	None		
PMSE	None		
PMR	None		

Source: EC

To then identify the relevant suppliers in each of the sectors we will:

- Include those firms previously used in ComReg's analysis.
- Do a further review (with assistance from ComReg) of firms who identify their activities as a NACE code which is related to spectrum (for example 61.20 wireless telecommunications).
- Consider whether there are a range of ancillary economic activities which do not rely on spectrum directly but which support spectrum related activities. These could be supply of mobile applications and content, and or supply of mobile advertising.
- We will use NACE codes to extract data on the core sectors from national accounts where available.

3.2.2 Step 2: Estimate the direct economic activity associated with the sectors

We will estimate the direct economic activity associated with the sectors identified in Step 1 (GVA, employment). This could be based on analysis of company data (Approach 1). Alternatively it could be based on analysis of national accounts where this data exists at a sufficiently disaggregated level (Approach 2). For each sector we will make a judgement on whether using national accounts or company level data is the most appropriate approach to measure GVA using the criteria set out in section 2.3.

As set out previously, neither approach will provide precise estimates of the economic activity related to supply of goods and services where spectrum is core. A national accounts measure may overestimate the activities that are not in fact related to spectrum within a given sector (for example if economic activity is wrongly recorded as being related to a specific sector). In contrast, using company data may underestimate the contribution of spectrum to modified Gross National Income[5] (GNI) as it does not account for:

- Small businesses whose information does not appear in the Companies Registration Office`s database; and
- Companies for which spectrum is not a fundamental input, but would still not exist in a world without spectrum, such as companies that make billing software which is used by mobile network operators (i.e. the ‘indirect effect’).[6]

Measuring GVA

Gross value added (GVA) is defined as output (at basic prices) minus intermediate consumption (at purchaser prices). It can be used to measure output in a given sector. We propose to use the “income approach” to measuring GVA in a given sector.

[5] Modified GNI (or GNI*) is defined as GNI less the effects of the profits of re-domiciled companies and the depreciation of intellectual property products and aircraft leasing companies.

[6] We will account for these effects via the multiplier approach in section 3.2.3.

MEASURING GVA

GVA can be calculated through either the income or production approach.

Income approach

GVA at basic prices = Gross operating surplus + compensation of employees + compensation of those self-employed

GVA at market prices = Contribution to GDP = Gross operating surplus + compensation of employees + compensation of those self-employed (mixed income) + taxes on products – subsidies on products

Gross operating surplus is effectively equal to the sum of gross trading profits and income earned through the ownership of buildings (rental income).

Compensation of employees is the sum of all employment incomes, pensions, National Insurance contributions, bonuses and benefits.

Mixed income accounts for the income of those self-employed, which consists of both salary and profit.

Production approach

GVA at basic prices= Output – intermediate consumption

GVA at market prices = Contribution to GDP = Output – intermediate consumption + taxes on products – subsidies on products

Output comes in two forms:

- Market output, which represents goods and services that are sold at a positive price such as by corporations, and which can be measured as total sales plus changes in inventory.
- Non-market output, which represents goods and services that have no meaningful selling price, such as those given by governments or non-profit institutions, and whose value is approximated by summing labour costs, intermediate costs and depreciation of assets.

Intermediate consumption is defined as all goods and services used or transformed in the production process, such as raw materials, fuel, rent and advertising, but excludes staff wages and capital investment.

In practice, the analysis will use company data from companies' annual accounts, obtained from the CRO. To be consistent with the income approach of measuring GVA at market prices and with the methodology used by national statistics agencies[7], we sum

- operating profit (EBIT)
- depreciation, amortisation and impairment; and,
- production taxes minus subsidies

[7] https://www.imf.org/external/pubs/ft/qna/pdf/2017/QNAManual2017.pdf

- total staff costs (including national insurance contributions, pensions etc.).
- taxes minus subsidies on products.

Net taxes and subsidies on products are usually not available in companies' financial statements and are therefore estimated using information provided by the CSO.

3.2.3 Step 3: Estimate the indirect supply impact of the economic activity associated with step 2

We will use a "multiplier approach" to assess how activity in sectors where spectrum is directly used affects activity in related upstream markets. Multiplier analysis is widely used for this purpose. However, there are a number of disadvantages which should be borne in mind when interpreting the results.

While multiplier analysis can be suggestive of the indirect upstream impacts as a result of economic activity in a downstream market, it can lack transparency and be difficult to calculate robustly for very granular subsectors of the economy. Therefore, while we propose to include it within our analysis our focus would be on estimating the direct impact.

Furthermore, we note that the most recent multipliers available from the CSO are from 2011, which may further affect the accuracy of these results.

WHAT IS THE MULTIPLIER EFFECT, AND WHY IS IT IMPORTANT?

The **total economic impact** of additional economic activity in one sector comprises two effects: the **direct effect** and the **multiplier effect**.

The **direct effect** is an increase in output in the economy as a result of a change in final demand in a sector – additional activity in a sector such as increased use of mobile devices will lead to an increase in output in the economy, for example.

The **multiplier effect** measures the indirect impact that incremental economic activity in a sector generates. There are two types of effects:

- Indirect Effect: the additional expenditure in the sector's supply chain, following the incremental activity within the sector. Those in the upward supply chain will purchase more goods and services– leading to an additional increase in output in the supply chain.
- Induced Effect: the income effect of hiring more workers to meet an increase in final demand. As these workers gain greater income, there will be additional household expenditure on goods and services that would not occur if not for the initial increase in activity in the sector. Frontier does not propose to measure the induced effect for this study.

In Ireland, the CSO publishes input-output tables and estimates associated output multipliers from which it may be possible to measure the indirect effect that incremental activity in one sector can have the wider economy. Input - output tables describe what goods (services) are required for the production of a particular good (service). As such, they enable us to identify the suppliers of a core spectrum sector and the amount of output they supplied to that core sector, as well as the GVA associated with that output.

3.3 Methodology 2: Estimate the contribution that spectrum makes to economic productivity from across the economy

A different but complementary approach is to estimate the contribution that investments in spectrum make to economy-wide productivity.

A rich literature developed over the last 15 years has generated relevant evidence showing that:

- Investment in Information and Communication Technology (ICT) leads to productivity gains that exceed those from investing in other types of capital.[8]
- Greater connectivity (most importantly for this study, diffusion of mobile broadband and wireless connectivity) is linked with faster economic growth.

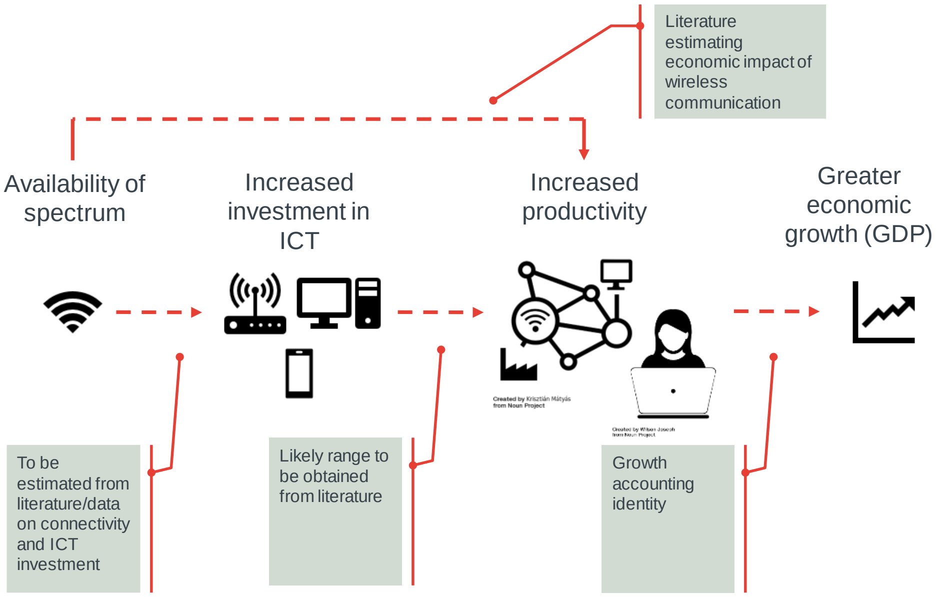
This evidence base could contribute to new estimates of the impact of spectrum as follows:

1. Gathering from the literature a range of estimates of the effect of ICT capital on productivity;
2. Estimating the contribution that spectrum has on ICT capital stock in the different sectors in Ireland; and,
3. Combining evidence under 1) and 2) to estimate the impact that spectrum has on economic growth.

Figure 13 below describes these channels and the sources that might be used to estimate the impact of each channel. Along with publications on 1) and 2) – the first two links in the figure below, we will also review literature on the impact of wireless communications on productivity (link at the top of figure below). This would provide evidence on the impact of relatively small improvements in wireless communications (e.g. 3G coverage), and would provide a useful cross-check for the estimates generated through the ICT channel.

[8] The availability of spectrum enables greater investment in ICT equipment, which then leads to a greater amount of ICT equipment being installed in Irish firms – a greater "ICT capital stock". The available estimates of the impact of ICT on productivity measure the effect of an increase in the capital stock (as opposed to an increase in investment). For this reason, in the remainder of this section we generally refer to the ICT capital stock or to ICT equipment rather than to investment.

Figure 13 Channels to impact on productivity growth and relevant sources



Source: Frontier

Applying this framework will in practice mean adapting the available estimates from academic literature, and making assumptions that will be set out transparently and discussed with ComReg. This is illustrated in Figure 14 and discussed in further detail in Section 3.3.2 below.

Figure 14 Matching evidence base to the aim of this project

Question	Estimates available in evidence base	Analysis	Assumptions
How much greater is the ICT capital stock in Ireland, as a result of spectrum availability?	N/A	Triangulate from different sources, including: - Total existing ICT capital stock; - Investment in fixed and mobile telecommunications infrastructure; and - ICT capital stock in core spectrum sectors.	N/A
What **is** the effect of **spectrum-related ICT** capital on productivity **in Ireland**?	What **has been** the effect of **ICT** capital on productivity **in a range of countries**?	Analyse how existing estimates of the effect vary over time, by country, by sector. Apply most appropriate range to Ireland.	The effect of spectrum-related ICT is the same as the effect of non-spectrum-related ICT . Assumptions on if and how the impact of ICT changes over time.

Measuring productivity

This section of our note focusses on productivity defined as "Total Factor Productivity" (TFP): the output produced in an economy per total amount of inputs used in production (capital and labour). If the input amounts are computed appropriately, TFP measures how efficient the economy is at combining those inputs. Differences in TFP across countries have been shown to explain a substantial proportion of differences in total economic activity (modified GNI).[9]

TFP is distinct from measures of "single factor" productivity, such as labour productivity (e.g. GVA per worker).[10] Investment in ICT increases the stock of capital in the economy and therefore allows each worker to produce more in each hour worked. However, ICT can also lead to growth in TFP: adding sensors, computers, smartphones and other devices to production does not only allow workers to collect data, perform analysis and communicate more efficiently. The addition of ICT is also linked with re-organisation of production. As communication becomes cheaper and instantaneous, firms can organise production in ways that would not have been possible before – for example, exercising more choice about when to delegate responsibility to local teams, or to increase the responsibility of central teams.

Focussing on TFP minimises the risk of double-counting benefits of spectrum when adopting this approach along with alternatives, such as the "direct contribution" approach set out in this note.

3.3.1 Gathering evidence

The first two components of this approach would consist of a review of the relevant literature. We are already familiar with much of this evidence base, which includes a range of different sources:

- Peer-reviewed academic journals[11];
- Studies published by public institutions in the UK and internationally[12];
- Research undertaken by organisations within the communications sector and industry analysts (including Frontier)[13]; and,
- Studies published by international organisations[14].

We will restrict our search to studies published in the last 15 years that provide robust quantitative impact estimates. These will be mainly from studies comparing

[9] Hall, R.E. and Jones, C.I. (1999), "Why do some countries produce so much more output per worker than others", The Quarterly Journal of Economics 114(1), 83-116 is a key study on this issue.

[10] OECD (2001), "Measuring Productivity – OECD Manual", OECD Publishing, Paris.

[11] E.g. Prieger, J.E. (2013): "The broadband digital divide and the economic benefits of mobile broadband for rural areas", Telecommunications Policy, Volume 37, Issues 6-7, July-August 2013, Pages 483-502.

[12] E.g. Analysys Mason (2014): "The economic impacts of mobile broadband on the Australian economy, from 2006 to 2013", Prepared for the Australian Communications and Media Authority

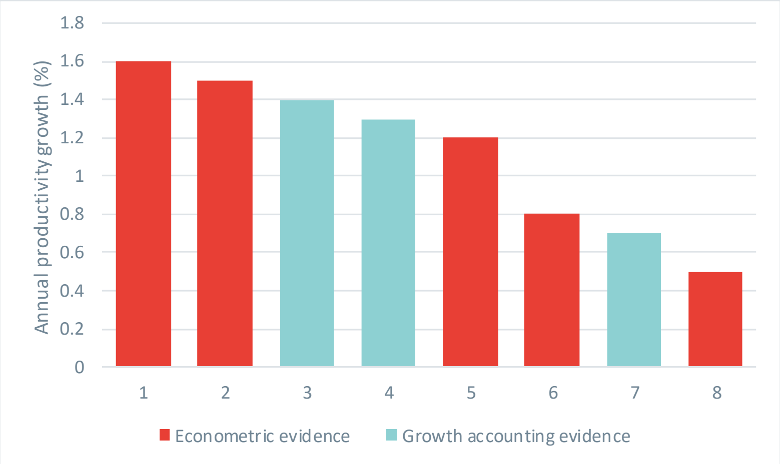
[13] E.g.: Edquist, H, Goodridge, PR, Haskel, J, Li, X and Lindquist, E. (2017): "How important are mobile broadband networks for global economic development?", sponsored by Ericsson Research.

[14] E.g. Minges, M. (2016): "Exploring the Relationship Between Broadband and Economic Growth", World Development Report 2016, Background Paper, Digital Dividends

firms, sectors or countries where ICTs are used more intensively with others. To be judged as “robust”, these estimates should attempt to go beyond simply showing that ICT use is correlated with greater productivity growth Specifically, the study should attempt to control for other possible differences between intensive ICT users and others (e.g. it may be that sectors that started using ICT more intensively in the early 2000s were already more productive than other sectors). However, we will also consider studies that take a “growth accounting” approach. This approach decomposes overall national economic growth (e.g. a 3% annual increase in GDP) into its components, estimating the contribution of different inputs, such as quality-adjusted labour and various types of capital (including specifically ICT capital) as well as different industries.[15]

This evidence will provide a range of estimates. We will screen out estimates that are unlikely to be applicable to this study (for example, estimates of the effect of ICT on developing countries) and outliers. We will then check whether there are patterns that explain differences across estimates – for example, whether a specific estimation method is systematically linked with higher estimates. Figure 15 below provides an example of the outputs we would aim to generate to summarise the evidence gathered.

Figure 15 Example representation of evidence



In the figure, each bar is an estimate of the impact of a 10% increase in ICT capital stock on annual productivity growth. Note that one study may generate several estimates, where the empirical work tested how the impact of ICT varies, or tested the sensitivity of the estimates to different specifications and assumptions.

3.3.2 Adapting the evidence

To use the estimates described above to assess the economic impact of spectrum on the Irish economy, we will need to make two types of adjustments to the evidence base.

- **Adjustments needed to use estimates of the impact of ICT capital stock on productivity**. Estimates of the economic impact of ICT will have typically been generated using a broad measure of ICT capital (i.e. not limited to

[15] For example, Spiezia (2012), ‘ICT Investment and Productivity’.

spectrum related ICT investment). To use these estimates, we will adjust to reflect how *spectrum* increases the ICT capital stock.

- **Adjustments needed to apply international evidence to Ireland**. Much of the evidence base will consist of studies comparing different firms within a country. Where this is not Ireland, we will need to understand to what extent the effect of ICT on the productivity of, say, firms in the United States is a realistic estimate of the effect of ICT on the productivity of Irish firms.

Availability of spectrum and investment in ICT

We will look for existing evidence on the relationship between availability of spectrum and ICT capital stock but we consider that this is unlikely to be available. Therefore, we will generate a range of parameters based on available data. Reviewing the available data will be (along with the literature review described above) the first step in implementing this approach. We expect to focus on the following indicators:

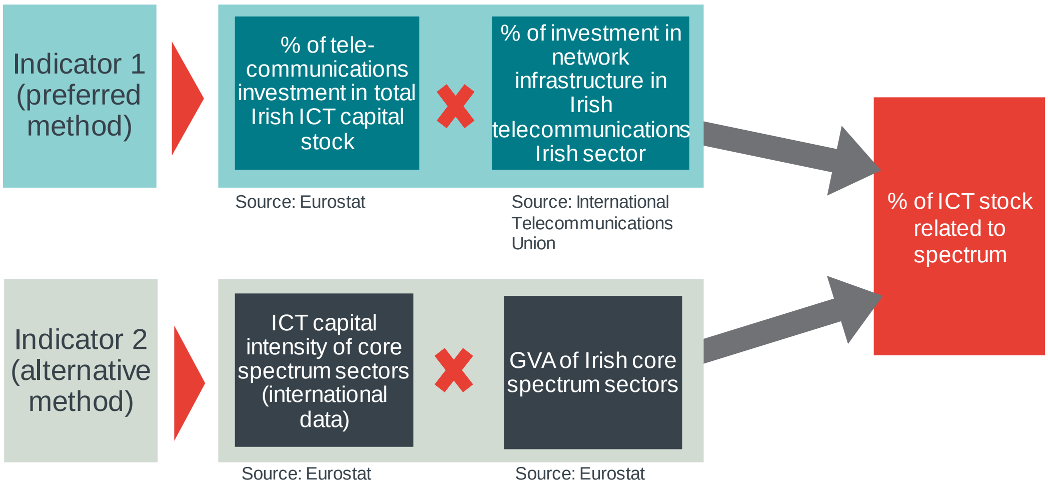
- Indicator 1: Estimates of the proportion of ICT capital in Ireland that is spent on mobile devices and wireless equipment;
- Indicator 2: Estimates of ICT capital in sectors where spectrum is considered “core”, as a proportion of total ICT capital stock in Ireland.[16]

For both indicators, limitations in the data available will mean we will need to rely in part on proxies. The proposed approach is summarised in Figure 16 overleaf.

For indicator 1, Eurostat, the European Union’s Statistics Agency project provides the share of total ICT capital stock made in the Irish economy that relates to communication equipment, up to 2014, but does not separate out mobile communications. The International Telecommunications Union (ITU) provides the share of total investment in network infrastructure made in the telecommunications sector in Ireland that relates to mobile telecommunications. We would use this share to apportion the total Irish telecommunications capital stock into its mobile and fixed components (multiplying the ITU share by the Eurostat share), and apply this share to the Eurostat data to obtain an estimate of share of total ICT capital stock related to mobile communications.

[16] Indicator 2 can be computed using data from the EU KLEMS project, combined with data from the CSO and CRO on investment in core spectrum sectors.

Figure 16 Estimating the proportion of mobile-related ICT capital stock



For indicator 2, we will also use data from Eurostat. However, data on the ICT capital stock in core spectrum sectors ("core spectrum ICT stock") in Ireland are not available. Therefore, we will use international data to construct an estimate of the core spectrum ICT stock :

- Compute the ICT capital intensity of core spectrum sectors in other comparable countries outside of Ireland (measured as the ratio between the ICT net stock in the sector and the sector's Gross Value Added)[17] CSO time series data on the stock of computer hardware and office machinery in the ICT sector (NACE Rev 2 code J);[18]
- Estimate the core spectrum ICT stock in Ireland by multiplying the ratio computed above by the GVA of the Irish core spectrum sectors.

This approach assumes that the ICT capital intensity (ICT net stock per unit of GVA produced) is constant between Ireland and the appropriate comparator countries.

Applying international evidence to Ireland

To apply estimates produced across a number of geographies to the specific Irish case we would take into account:

- The availability of spectrum and wired connectivity (considering take-up of mobile broadband and the timing of spectrum release);
- The conditions needed to translate ICT use into productivity gains and the ability of the Irish economy to "absorb" ICT and generate these productivity gains, compared to other advanced economies.

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[17] The value of ICT net stock is the sum of the written-down values of all the fixed assets still in use. Source: https://stats.oecd.org/glossary/detail.asp?ID=1752

[18] Data on capital stocks over time would need significant elaboration to yield a proxy for investment.

Evidence on returns to ICT investment shows that organisational flexibility, labour and product market flexibility and the availability of high-skilled workers, among others, are key factors needed to gain from ICT use.[19] This is because adopting ICT effectively requires re-organising production to make the most of new technology. Moreover, ICT makes high-skilled workers more productive, by improving their access to information and enabling collaboration. The following indices measure these national characteristics and have been used in economic analysis:

- OECD indices of the strictness of product market and employment protection regulation;[20]
- Relevant elements of the World Economic Forum's Global Competitiveness Index: its components related to Goods Market Efficiency, Labour Market Efficiency, Higher Education and Training.

We will compare Ireland with other advanced economies along these dimensions, where suitable data exist. Estimates of ICT impact from countries that outperform (are outperformed by) Ireland will be adjusted down (up) to reflect the fact that the impact in Ireland would likely be smaller (larger).

3.3.3 Results

The results of this analysis will provide an estimate of the impact of spectrum related ICT in Ireland on total factor productivity. That is to say it will estimate the proportion of economic output in Ireland that can be explained by investments in spectrum related ICT. Given the assumptions that will have to be made in the analysis, it will be provided in a range, and caveats will be noted to aid interpretation. However, it will provide a "fuller" estimate of the contribution that management of the spectrum resource makes to the Irish economy than Approach 1.

3.4 Conclusion

We consider that approaches described in this section, in combination, meet the objectives of ComReg in estimating the value of spectrum to the economy in Ireland.

In particular the combination of Approach 1 and 2 will provide estimates that are directly measurable, can be easily repeated in subsequent years on a consistent basis, are intuitive and understandable; and relate to other measures of national accounts (such as GNI).

However, we acknowledge a number of potential limitations which should be borne in mind when interpreting the results. First, the direct value added in sectors where spectrum is considered to be "core" cannot be fully attributable to spectrum. While these sectors could not operate without spectrum as they do today, it is likely that

[19] Van Reenen et al. (2010), 'The Economic Impact of ICT'; Haugh (2013), 'From Bricks to Brains: Increasing the Contribution of Knowledge-Based Capital to Growth in Ireland', OECD Economics Department Working Paper No. 86.

[20] Product regulation: http://www.oecd.org/eco/growth/indicatorsofproductmarketregulationhomepage.htm; Employment protection: http://www.oecd.org/els/emp/oecdindicatorsofemploymentprotection.htm.

at least to a small extent, there would be alternative goods and services available. In this way that economic contribution of spectrum is over stated in these sectors. Second, we may not be able to identify all suppliers in the sectors identified (particularly smaller firms below CRO reporting thresholds) and may thus underestimate the economic contribution of spectrum. Third, this analysis excludes the contribution that spectrum makes in sectors where it is not “core” to the supply. It is not possible to readily estimate the magnitude of these effects (and thereby to determine whether our estimates are likely to be biased upwards or downwards). Instead we note that the estimates should not be interpreted as precise point estimates, but rather an indication of the scale of value of spectrum to the economy in Ireland.

Furthermore our approaches deliberately exclude the consumer welfare associated with the enjoyment of the goods and services that use spectrum. Instead, we will provide a qualitative assessment of these benefits in the final report. In addition it excludes the value of public uses of spectrum.

Approach 6 provides an alternative and complementary approach. This approach expressly estimates the spillover impacts that spectrum makes to economy wide productivity. However, the approach relies on econometric studies which are themselves only partially attributable to the Irish context so care should be taken in interpreting the results.