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Taking account of service externalities when spectrum is allocated and assigned ☆

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ABSTRACT

Spectrum should be allocated among the various services which use it to maximise the aggregate incremental value (private and external) of those services minus the (non-spectrum) costs of supply. The external value of services such as broadcasting and mobile communications may be significant, yet we know that spectrum assignment by auction, for example, does not take them into account, because the successful bidder cannot monetise the value of the externality. The paper considers how this issue can be addressed. It notes that, if the spectrum assignment in question has no impact on the output of the services competing for it, value generated is unchanged, and the spectrum allocation problem reduces to the minimisation of the aggregate cost of non-spectrum inputs for the relevant services. In the more common case of variable outputs, some means of valuing external effects is needed, and possible approaches to valuation are discussed.

1. Introduction

The startling growth of mobile communications throughout the world has significantly increased the rivalry between sectors and users over access to spectrum. This has placed increasing pressure on spectrum regulators to justify their allocation and assignment decisions. This is one (but not the only) factor behind the increasing use of auctions in spectrum assignment, since auctions introduce a greater element of objectivity into the process. However, when firms bidding in auctions are calculating their willingness to pay, they will take account of the revenues which they receive from their customers, but neglect benefits which accrue to others with whom neither the firms nor their customers have a market relationship.[1]

Thus whereas administrative implementation of spectrum policies can in principle take into account (and in some cases expressly has taken into account[2]) externalities associated with spectrum-using services, the increasing scarcity of spectrum and the widespread use of auctions make it necessary to give thought about how to prevent or correct misallocations arising from failure adequately to incorporate them in the analysis.

☆ The authors were members of a group advising the UK government on matters raised here - see DCMS (2015). This article focuses wholly on the relevant economic issues, and the opinions expressed engage the authors alone, and no other person or organisation with which they are associated.

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[1] On auctions in general, see Noam (1998), Salant (2014) and Cave and Webb (2015).

[2] To give a slightly contrary example, broadcasting policy in the UK (and other countries too) was for many decades explicitly based on the *withholding* of spectrum available for additional television channels, in order to guide viewers to meritorious broadcasters (Peacock, 1986).

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The most prominent example of rivalry in the use of spectrum is the 'battle for the UHF band', which has convulsed spectrum management for the past decade, and led to the progressive refarming of several bands from terrestrial broadcasting to mobile communications. In practice, the re-allocation has largely been accomplished by administrative means, preceded in some countries by the analysis of its broader social effects, which are an important component of the externalities considered in this article. Auctions are generally used only to assign the released spectrum among competing mobile firms. In principle a 'two-sided' auction could determine the division of spectrum between broadcasting and mobile communications, and simultaneously decide which broadcasting firms give up and which mobile communications acquire spectrum. A variant of such an auction (the 'incentive auction') is planned in the United States (FCC, 2014).

However, the issue of external benefits is by no means confined to processes implemented by auction. Where rivalry for spectrum arises between two uses where the product is non-marketed, and perhaps also a public good - for example defence or basic science, the allocation decision will generally rest on the scale of benefits which accrue wholly to non-paying or external beneficiaries.

This issue was raised in the UK Government's Spectrum Strategy (DCMS, 2014), which contained the following paragraphs:

> 2.21. "…Spectrum value may be defined and measured in a number of ways. For example, in terms of final use (e.g. saving life) or cultural potentialities (e.g. social resilience or connectivity) or moral or cultural imperatives (e.g. the state has precedence over its use). In some cases, measures of this kind already exist. ….Pending the development of more precise measures it may be useful in considering social or more intrinsic or hard to measure impacts to employ impact upon well-being measures (e.g. life satisfaction) as the valuation criterion.
> 2.23. Planning the use of spectrum involves ranking the relative public values of various uses. …We will need to find ways to weigh social, economic, financial, technological and political factors against each other…"

The goal of this article is to elucidate some of the economic issues raised by taking account of positive or negative external effects in spectrum allocation decisions. Section 2 describes the problem in economic terms, and illustrates the types of externalities which may arise. Section 3 distinguishes two cases – of 'constant output' and 'variable output' – for which different solutions seem appropriate. Section 4 briefly discusses measurement issues. And Section 5 discusses how in principle spectrum allocation and assignment decisions might be redesigned to take account of externalities.

2. The spectrum management problem – with externalities

Spectrum allocation – deciding which bands should be assigned to which uses - is a typical problem of rationing scarce resources among competing uses in a way which maximises their value. In some cases, a band can be shared among various users, none of whom interferes with another's enjoyment of it. This is traditionally exemplified by use of a 'spectrum commons' by many highly localised users, including for purposes such as WiFi. But most high value bands are assigned to licensees on an exclusive or priority use basis, to avoid interference problems.

The goal lying behind most spectrum allocation decisions can be conceived as that of maximising the value of the spectrum in use, defined as the sum of the overall benefits created by spectrum-using services, minus the sum of the (non-spectrum) costs of providing those services. This reflects the fact that spectrum, as a scarce input, has an opportunity cost in any use, given by the marginal value foregone in the best alternative use.

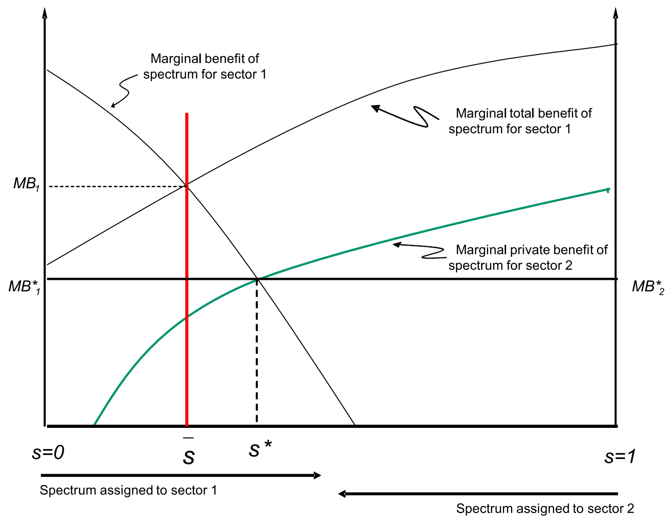

Fig. 1. An efficient allocation of spectrum, with and without externalities.

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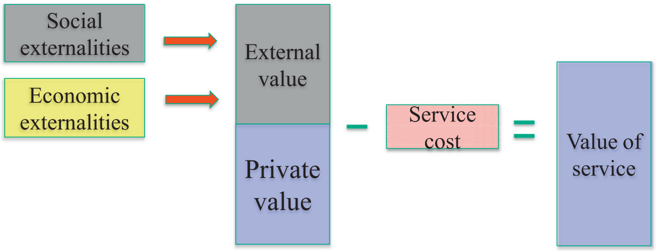

Fig. 2. The value to society of spectrum-using services.

The marginal conditions satisfied by such an outcome are illustrated in Fig. 1. Spectrum in a band is allocated between sector 1, measured from the left hand vertical axis, and sector 2, measured from the right hand vertical axis. The two marginal curves reflecting private value (net of non-spectrum costs) are also shown. Absent externalities, the optimal allocation lies at S^{*}. Now suppose that sector 2 generates a positive externality, causing the marginal total benefit curve to lie above the private benefit curve by the extent of the external benefit. Its intersection with the private benefit curve of sector 1 now falls at $\bar{S}$. The externality shifts the efficient spectrum allocation in favour of sector 2. Note that the externality can be either positive or negative; to simplify the exposition we focus on positive externalities here.

Fig. 1 is framed in terms of equalisation of marginal benefits, in an extreme 'one band - two uses' simplification of the general multi-band, multi-use allocation problem. However, spectrum allocation issues do not generally present themselves as a search for marginal equivalences. Instead they appear as a series of piecemeal choices involving the allocation and assignment of a given increment or decrement of spectrum. The relevant test is which of the alternative allocations best enhances social welfare. Fig. 2 is an alternative representation of the allocation problem in this discrete case.[3] Because it is increasingly common for a variety of bands to be allocated and assigned to the same use, it will usually be necessary to establish the private and external values of an *incremental* allocation in a finite number of alternative uses. These incremental benefits will not be the same as the average benefit of all the spectrum used for the purpose in question. For example, an additional tranche of, say 700 MHz spectrum assigned to a mobile communications firm will generate different external benefits (discussed below) from an assignment in another band, and the scale of those benefits may depend on what other bands are already available as well as on extraneous factors such as the extent of coverage of fixed broadband.

Before continuing, it is useful to note an important qualification. The implicit reasoning has been:

(1) a spectrum-using service has an externality, and failure to take that into account will lead to a market failure;
(2) the market failure should be corrected via an intervention in spectrum allocation.

However, the second proposition does not follow from the first. If the market failure lies in the service market, it is better to resolve it there, because intervening in the input market – by, for example, reducing the price charged for spectrum or increasing the quantity of spectrum allocated to the service with a positive externality - will lead to productive inefficiency: firms producing in those conditions will use too much spectrum and not enough other inputs.[4] To appreciate the operation of this principle, consider a policy of subsidising mobile communications by giving mobile operators free electricity. It might keep mobile prices down and expand consumption, but electricity use would almost inevitably be distorted in an upwards direction.

In other words, operating on spectrum allocation in these circumstances only makes sense when 'first best' intervention in the service market is impracticable. This might arise if a direct subsidy to the firm generating the externality is inappropriate, because, for example, such a direct subsidy to a broadcaster might call that broadcaster's independence into question, or if a country's fiscal situation ruled out subsidies.

What type of externalities might arise in this context? Fig. 2 embodies a distinction between 'social' and 'economic' externalities. This is not an absolute distinction, in the sense that some effects of spectrum-using services (such as a reduction in labour market discrimination arising from greater tolerance in society nurtured by broadcasting services) might have both an economic and a social dimension. But it may be useful as a broad classification. We illustrate it by reference to externalities provided by the two services of broadcasting and mobile broadband, noting that the convergence of broadcasting and telecommunications is making any classification increasingly complex.

In its 2007 analysis of the so-called digital dividend review (DDR), the UK communications regulator Ofcom addressed the question of whether the 800 MHz spectrum should continue to be allocated to broadcasting, or be switched to mobile communications. The regulator took into account private value (probably to be elicited by an auction process) associated with both uses, and, in the case of broadcasting only, social externalities (referred to by Ofcom as 'Broader Social Value').[5]

[3] It also introduces a distinction between two forms of externalities which we outline below.

[4] This maxim, which can be crudely expressed as: 'don't mess with input prices (when the problem is in the service market)', has an analogy with a fundamental proposition of the theory of commodity taxation (Diamond & Mirrlees, 1971).

[5] Note the ancient economic principle of the 'second best' suggests that correcting one market failure in a context where others are present carries the

The latter included (Ofcom, 2007, annex 7, page 19):

(1) access and inclusion;
(2) quality of life;
(3) educated citizens;
(4) informed democracy;
(5) cultural understanding;
(6) belonging to a community.

Ofcom considered whether the different levels of broader social value associated with alternative uses of the spectrum would be likely to result in a different ranking of alternatives with respect to total value, compared to the ranking based on private value, and concluded that this was unlikely to be the case. This conclusion illustrates the important proposition that knowledge of the precise numerical value of the external benefits of the relevant two spectrum-using services in any comparison is not necessary. Normally it is sufficient to know whether the *difference* between the external benefits of the services exceeds (with an opposite sign) the difference in private values.

Mobile communications networks now support the delivery of different voice and data services that are of direct value to consumer and business customers. They may also have an additional and broader impact on the economy via the provision of broadband, which many describe as having the ubiquitous impact of a 'general purpose technology' upon the operation of the economy.

The potential external economic benefits of broadband use are somewhat diffuse in nature and may include, but are not confined to, the following:

- enhanced speed and quality of information flows: sometimes it is suggested that the combination of more information processing and faster communications (provided by a smart phone, for example) are necessary to deliver the benefits, with one alone producing less spectacular results;
- better access to markets: due to lower barriers to entry, an increase in the geographical scope of markets (the 'death of distance'), better job matching, better access to customers via the web etc.;
- new business processes and organisational structures: better stock control, quicker contracting, just-in-time production etc.; and
- more innovation in general, made possible by the availability of new voice and data services; examples can be multiplied – social networks being a particularly significant one.[6]

Of course, spectrum-using services can generate other conventional economic externalities. For example, mobile (and other) communications can obviate the need for face to face meetings and generate environmental and other benefits which are not captured in market prices – relating to carbon or traffic congestion, for example.

3. The basic economics of incorporating externalities

This section argues that two fundamentally different approaches should be taken to the question of how to incorporate externalities in spectrum-using services in allocation and assignment decisions, depending essentially upon the degree to which the levels of output of the spectrum-using services in question vary depending upon the availability of spectrum. In the 'constant output' case, the volumes of competing services are invariant to the spectrum allocation decision in question.[7] (We discuss below how frequently this case is likely to be observed, either exactly or closely.) In the alternative 'variable output' case, the spectrum decision has an impact on the prices and levels of output of the spectrum-using services, creating a need to address the scale of the relevant externality at the margin. This distinction is important because the data requirements of the two cases differ in important ways. The cases we consider are ones in which each service provider has exclusive use of that part of the band which is assigned to it. In other words, we are not complicating things by considering shared use of the same spectrum.

3.1. Case 1: Constant output

In this case, output is constant in the sense of being set independently of the spectrum assigned to produce it. In the case of a marketed output, this generally implies a constant price. Where the output is non-marketed, it implies a decision by the

(*footnote continued*)
risk of making things worse rather than better.

[6] Some of these features are also likely to have a direct impact on private economic values, and in practice care is needed when assessing external benefits to avoid the risk of double counting.

[7] In other words, it can be assumed that both activities will go ahead anyway, on the same scale. The activity which is not allocated the spectrum will either get spectrum in another band, or a non-spectrum technology will be employed.

Table 1
Value to society in assignment 1.

Assignment 1	Mobile 700 MHz	Broadcasting 10 GHz	Total
A. Service cost	100	120	220
B. Private use benefit	400	200	600
C. External benefit	200	500	700
Value to society (net) (−A+B+C)	500	580	1080

producer or commissioner of the output to keep its level constant. The significance of this is that in both marketed and non-marketed cases the spectrum decision has no effect on the levels of output, and hence no effect on either private use value or on the valuation of the externality. With both private and external values given for each activity, the desirability of any change in spectrum use hinges entirely upon the degree to which allocation of the band in question reduces the aggregate (non-spectrum) cost of the services.[8]

This is not a startling result, but it is worth illustrating it with a hypothetical arithmetical example which can also be extended subsequently to consider variable output cases. The example we choose is a highly stylised version of conflict in the allocation of the 700 MHz spectrum between the demands of broadcasting and mobile services.[9] It should be noted that, although the competing services are named, no attempt has been made to make the cost and benefit numbers associated with the different bands realistic.

The example is founded on the 'discrete choice' approach to spectrum allocation and assignment set out in Fig. 2 above, in which a decision is being made to allocate a given band to one of two (or a small number) of services. This can be distinguished from a formulation of the spectrum allocation problem as one designed to achieve a global optimum covering all bands and all possible uses; in other words the multi-band generalisation of Fig. 1 above. In our view the discrete choice approach better reflects the current approach to spectrum management.

We start by considering the scenario in which there is a suitable alternative to 700 MHz spectrum for both mobile and broadcasting services. Then we discuss how the analysis is affected if either:

a. There is no suitable alternative spectrum for broadcasting; or
b. The broadcasting service is not financially viable using the alternative band.

Finally, we discuss the circumstances in which an auction-based system can be expected to result in an efficient outcome.

In the first scenario, we suppose that (incremental) mobile services can be provided using either the 700 MHz or 2.3 GHz bands. Similarly, broadcasting services can be provided terrestrially using the 700 MHz or by satellite using 10 GHz bands. For simplicity, we assume that both the 2.3 GHz and 10 GHz bands are otherwise unused. This implies that there are two alternative assignments as follows:

- Assignment 1: mobile services use the 700 MHz band and broadcasting the 10 GHz band
- Assignment 2: broadcasting services use the 700 MHz band and mobile the 2.3 GHz band

For the purpose of this scenario, we initially assume that:

- Both services are financially viable without subsidy in both assignments.
- Output of both services is unaffected by the assignment of spectrum, so our focus in on the efficient production of a constant level of output.

Each service generates benefits to users and external benefits to non-users, and results in a cost of supply. The value to society from each service is given by the sum of the private use benefit (consumer surplus) and the external benefit to non-users, less the cost of supplying the service.[10] Tables 1 and 2 show the assumed service cost, private benefit, external benefit, and (the algebraic sum of the above) the net value to society for each service in assignments 1 and 2. As can be seen:

- The service costs for both services are lower with 700 MHz spectrum than with next best alternative band.
- As output is constant, the private benefit from each service is the same in both assignments, and is higher for mobile than for broadcasting.

[8] Note that we are dealing here with an appraisal of the net of an incremental or piecemeal change in spectrum allocation – ie seeking to identify a potential Pareto improvement. There is no requirement that either the prior or the end state be optimal.

[9] This example is also discussed used in DCMS (2015) and Cave and Webb (2015), chapter 11.

[10] The results would not be affected if producer surplus were included as well.

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Table 2
Value to society in assignment 2.

Assignment 2	Mobile 2.3 GHz	Broadcasting 700 MHz	Total
A. Service cost	200	80	280
B. Private use benefit	400	200	600
C. External benefit	200	500	700
Value to society (net) (−A+B+C)	400	620	1020

- As output is constant, the external benefit from each service is the same in both assignments, and is higher for broadcasting than mobile.

Under these assumptions the broadcasting service generates more value to society if it uses 700 MHz spectrum than would the mobile service by virtue of the fact that it creates very significant external benefits. It would, however, be efficient to assign the 700 MHz band to mobile and the 10 GHz band to broadcasting, since the aggregate value to society from both services is higher in assignment 1 (i.e. 1080) than in assignment 2 (i.e. 1020). The reason for this is that assignment 1 results in a reduction in the aggregate cost of the broadcasting and mobile services of 60 (i.e. 280–220) compared to assignment 2, whilst the aggregate user and external benefits are the same in both assignments.

This illustrates the important conclusion that alternative spectrum assignments should be assessed in terms of the 'opportunity cost' of the band in question measured by the increase in costs which would be incurred if a second best band were used instead. As it can be seen, the opportunity cost of the 700 MHz band is higher for mobile than for broadcasting by an amount that reflects the difference in cost savings. Opportunity costs are decisive because there no change in private or external benefit associated with the given output levels.

If there were such differences, they would have to be inserted in rows E and F in Table 3, which shows the incremental value to society (compared with the relevant alternative for each service) of assigning the 700 MHz band to mobile or broadcasting. But in Table 3, output levels are constant, so both private benefit and external benefit are constant, leaving the incremental value to society to be determined solely by opportunity cost.

3.2. Case 2: Variable output

It is hardly rocket science to show that if output levels of spectrum-using services are changing, then the cost-benefit calculation of any change in spectrum allocation will hinge upon the resulting change in external benefits, as well as on the resulting change in private values.

However, the above arithmetical example – slightly amended - provides a concrete illustration of why this necessarily follows. We first extend the above example to show the effects of the possibility of varying output levels. We do this first by supposing that that there is no suitable alternative spectrum for the broadcasting service, so that it would not be provided under assignment 1. In this scenario, assigning the 700 MHz band to mobile eliminates the broadcasting option entirely, reducing its costs and benefits to zero.

Against this counterfactual, the *incremental* costs and benefit of assigning the 700 MHz band to broadcasting are as shown in the right hand column of Table 4. Broadcasting offers the higher overall incremental value from the 700 MHz spectrum, which should accordingly be allocated to it.

Returning to the initial example, we consider another scenario in which the source of the variation in output (of broadcasting again) is that broadcasting service revenues are not sufficient to cover the higher service costs incurred using 10 GHz spectrum. If this is not addressed in some way, broadcasting services using 10 GHz spectrum would not be financially viable and hence would not be provided – thus breaching the constant output condition.

As noted above, this market failure is probably best remedied by providing an appropriate subsidy to increase broadcasting revenues so as to ensure that use of the 10 GHz spectrum is financially viable. This would allow spectrum efficiency to be maximised, with the 700 MHz band assigned to mobile, and the 10 GHz band to broadcasting.

Table 3
Incremental value of 700 MHz band to each service.

***Incremental* value of 700 MHz spectrum**	Mobile 2.3 GHz	Broadcasting 10 GHz
D. Service cost	100	40
E. Private benefit	0	0
F. External benefit	0	0
Value to society (net) (D+E+F)	100	40

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Table 4
Incremental value of 700 MHz band to each service.

***Incremental* value of 700 MHz spectrum**	Mobile 700 MHz	Broadcasting 700 MHz
A. Service cost	100	−80
B. Private benefit	0	200
C. External benefit	0	500
Value to society (net) (A+B+C)	100	620

If such a subsidy were not available, then the second best outcome is to assign the 700 MHz band to broadcasting. In effect, spectrum efficiency is distorted in order to subsidise broadcasting services. If the benefits from broadcasting on 700 MHz can be partially replicated by other means, then there is a trade off which must be assessed between the incremental cost to society to using the 700 MHz 'inefficiently' and the loss of benefit from the full 700 MHz broadcasting service. This calculation inescapably requires knowledge of the external benefit of broadcasting.

Finally we ask who would win an auction of the 700 MHz band between the two sides. Table 3 shows that mobile operators stand to gain more than broadcasters from getting access to the 700 MHz band, as against the assumed alternative for each. Their willingness to pay would exceed that of broadcasters, and so they would win in a standard second price auction.

The auction might be inefficient if there were an increase in the external benefit provided by broadcasters when the service was offered at 700 MHz as against the relevant alternative of 10 MHz, while there was no equivalent difference in external benefits provided by mobile operators. Here we are departing from the constant output assumption, so it is no surprise that an auction based wholly on competing private values may yield an inefficient outcome.

3.3. Conclusion

This arithmetical example shows that there is a complex 'translation' process involved in deriving inferences concerning spectrum assignment from the costs and valuation of spectrum-using services. Essentially this is because both cost and demand factors are involved in the allocation of spectrum. The relative importance of the two aspects depends upon (a) the availability of alternative ways of delivering the spectrum-using service, (b) the degree to which alternative ways of delivering the service produce the same benefits for customers and external benefits, and (c) the ability of policy makers or regulators to intervene, when a market failure arises in service markets, in those markets (which is the first best approach) rather than in input markets (which is second best).

But the analysis shows that, if competing services have alternative means of delivery which produce the same outputs, with the same external benefits, and if at least one of those means is commercially viable for each output, then a competitive auction will generate an efficient outcome.

A focus on the cost side of the equation is illustrated by Ofcom's cost benefit analysis of changing the use of the 700 MHz band in the UK to mobile services. This effectively held constant the output of broadcasting and other services competing for the band with mobile communications. It then showed that the costs of repackaging these services into spectrum in the 470–694 MHz band or elsewhere was less than the sum of reduction in costs of expanding mobile services and the benefits in better building penetration and rural coverage by mobiles associated with use of the 700 MHz band as compared with the relevant alternatives (Ofcom 2014). Thus with the change in outputs confined to fairly limited changes in quality of services, most of the calculation revolved around costs. However, it will not always be possible to confine the allocation problem in this way.

4. Discussion of the occurrence of the two cases

How do spectrum allocation decisions split between 'constant output' and variable output' cases, and precisely how 'fixed' must outputs be to justify a cost-based only approach?

We start by asking if there are any fully 'constant output' cases. At first sight, the requirement looks exceptionally stringent. Clearly outputs of spectrum-using services of all sorts are changing all the time, but here we are focussing solely on changes in output directly associated with spectrum re-allocations.

Four types of spectrum re-allocation are distinguished below, differentiated by whether the spectrum-using service is a marketed service produced by a commercial firm or a (usually) non-marketed service produced by a public body:

Commercial marketed service to commercial marketed service

Many such re-allocations owe their origins precisely to increasing demand for one service, leading to the need for further spectrum, while the need for spectrum in another grows more slowly, either because of stagnant demand for the service, or because of greater technical efficiency of spectrum use.

The constant output approach is particularly relevant to small ('marginal) reallocations of spectrum, or when there are

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alternative inputs than a particular band that could be used by the services. This does not preclude the possibility of applying the 'constant output' approach in other circumstances, for example where a proper comparison of outputs 'with and without' the allocation indicates that any change in service is outputs is likely to be limited.[11]

Non-marketed public sector use to non-marketed public sector use.

Such cases arise where there is competition for a band between two public sector users. Usually, it is for spectrum desired for a specific service required under a specific programme, rather than for a service for which the demand is growing unpredictably. Examples might be spectrum required to accompany a new weapons system, or required to support a new signalling system for a high speed railway.

Compared with the commercial sector, the public sector's current endowment of spectrum is in many jurisdictions relatively generous, as a result of the relative ease with which it was able to acquire it in the past.[12] Thus in the case of public to public sector reallocations the prospect of an activity being 'crowded out' is small; instead the task will be to fit the desired services into available spectrum slots at the minimum opportunity cost. In other words the 'constant output' condition is quite likely to be fulfilled. Where, as in the UK, public sector bodies are charged for their spectrum use on the basis of opportunity cost prices, these might in principle support the efficient allocative outcome. Or it could be done on a command and control basis.

But not all such conflicts will be resolved in this relatively simple way. Where outputs are variable, a valuation of external benefits would be required (to be set alongside the private use valuation which is also required in the case of non-marketed services).

Non-marketed public sector use to marketed commercial service

Numerous examples can be given of spectrum transfers in this direction, often involving transfers from defence use to mobile communications. The United States furnishes an interesting example. In 2004, the US Congress passed the Commercial Spectrum Enhancement Act which created a Spectrum Relocation Fund, into which some auction proceeds were placed, to cover the costs incurred by US Federal Government entities which relocated to new frequency assignments or alternative technologies. The basic idea is that if expected auction revenues exceed expected transfer costs, the transfer should take place. In principle, it is possible to use the expected transfer cost as the 'reserve price' in the auction. If that price is not attained, the sale does not take place.

The first auction of this kind to occur was of the 1710–1755 MHz band, which was used by 12 Federal Agencies, including the Department of Defence. The sale was accomplished, and a portion of the auction proceeds was used to cover spectrum relocation costs. It subsequently transpired that these costs exceeded estimates by about 50%. However, these larger costs were still exceeded by auction revenues, by more than four times.

This could be interpreted (somewhat freely) as a case where: output of the defence service was maintained at the previous level, which we take as appropriate; the private use value of the spectrum in mobile communications, captured in the auction price, exceeded the incremental cost of relocating the defence use; the incremental external benefits of mobile communications use are potentially relevant, since output goes up there, but they would have to be implausibly negative and large to render the re-allocation inefficient.

Marketed commercial service to non-marketed public sector user

Such cases are too rare to generalise from.

It follows form the above that there is subset of cases, where the constant output assumption appears to work, but they may be confined to a minority, possibly concentrated on public to public re-allocations. In other words, the problem of measuring external benefits is not an exceptional one. The next section describes how this task might be accomplished.

5. Measurement issues

This section contains a brief discussion of measurement issues. It is not one of this article's goals to make detailed measurement proposals, Nonetheless, since measurement is undoubtedly a large elephant in the room, it is important to have some understanding of the problems and possibilities.

The first question is: what are we trying to measure? The basic equation in Fig. 2 is:

Total value = Private use value + External value

In circumstances where private value is disclosed by a market process - normally a spectrum auction[13] - the focus is on external value. Yet externalities arise when persons or firms are impacted otherwise than via a market transaction by spectrum-using service. In other words, in the case of an externality the market for the impact is by definition missing.

[11] In applying the reasoning of the constant output case, the relevant comparison is between the outputs of the two services 'with and without' reallocation of the band, rather than 'before and after' the reallocation. This is to ensure that one takes proper account for changes in output that would occur without any reallocation, and which may affect both the private and external value of the services.

[12] This difference in endowments is reflected in the direction of flows of refarmed spectrum in recent years, which have been broadly from public to commercial sectors – see below.

[13] There is some debate about the degree to which bids in spectrum auctions capture and compare the private value of spectrum-using services, in cases where bidders use different business models to derive revenue. For example, it has been argued that mobile operators are better able to monetise the value of the services that they provide than firms which provide other (non-mobile services) on a less commercial basis.

On the other hand, if data on private use value are also unavailable (as is the case for non-marketed services such as defence), efficient spectrum management implicitly requires the making of judgements on total value.

In relation primarily to social externalities (one category of external value) we consider two possible approaches to gaining whatever valuation is required without market data. This discussion draws on Fujiwara et al. (2015).

The first is stated preference, which sits squarely within the economic tradition of demand studies relying upon utility maximisation, with the key difference that preferences are not revealed by behaviour in the market place but elicited in response to hypothetical questions.[14] Stated preference is a well-established technique. It is known to have certain problems,[15] but ways have been found to overcome them, at least partially.

As an illustration of one form of stated preference (chosen for its relevance to the problem under discussion, rather than necessarily for its reliability) we cite a study falling into the category of stated preference known as contingent valuation, carried out in relation to the services of the BBC, a UK public service broadcaster (Measuring the Value of the BBC, 2004, p. 19) that was (and is) funded by a mandatory licence fee payable by anyone watching broadcast television. Respondents were asked what price they would be willing to pay as a monthly subscription to the BBC, and in particular to distinguish:

- their consumer value, expressing the private value of the service to the individual respondent – which was £18.35 per month;
- their total value, including the value of the service to society as a whole – which was £20.70 per month.

The implication of the responses was the external value of the service is £2.35 per month. The validity of such an inquiry depends on respondents having a common understanding of what the question is trying to elicit. There may also be a tendency to give the questioner an answer which is seen to be acceptable or expected, rather than one which is true.

Another variant of stated preference is choice modelling – also known as conjoint analysis. Under this approach, the respondent is asked to choose between alternative service offerings, which differ in a number of attributes. The attributes can include a hypothetical monetary price. Analysis of the choices made can reveal the marginal rate of substitution across, or the part-utilities of, different attributes. If one of the attributes is a monetary price which the end user must pay, a monetary value of all the other attributes can be inferred.[16]

An advantage of choice modelling (and of stated preference more generally) is that researchers can introduce and seek valuations of whatever attributes they choose – subject of course to the requirement that the alternatives are intelligible to the respondents.

In the case of external effects, this is a quite demanding condition. For example, the characteristics of broader social value listed in the above-noted 'digital dividend' study by Ofcom include 'educated citizens' and 'belonging to a community.' It is clearly difficult to capture these qualities by means of (even loosely) quantifiable attributes which could be inserted, together with other attributes, in different options among which respondents would choose. It would also be necessary to be clear about which aspects of the externality were to be captured. The hypothesis is that one viewer's consumption of a television service benefits other members of society, responding to the relevant question. This might arise from the respondents' altruism, or it may reflect the way in which they benefit from the viewer's altered behaviour. The effects may also be reciprocated, because everyone may benefit from other viewers' changed behaviour or attitudes. Disentangling these effects into private and external ones presents considerable difficulties.

An alternative approach not grounded in conventional demand theory is social wellbeing valuation.[17] This relies upon self-reporting on a specified scale (say, 1 to 10) of the wellbeing of a large number of individuals. Respondents also complete a questionnaire which records their individual circumstances, or in some cases changes in their individual circumstances, in some detail.

Econometric analysis can then identify a relationship between their consumption of spectrum-using services and their wellbeing. If one of the variables known about individuals is their receipt of a monetary windfall (for example, a lottery winning), the wellbeing of a change in circumstances can be translated into monetary units, as above with choice modelling.

For example, as the use of 4G mobile technologies spreads across a country, it might be possible to establish the relationship between the use of that service and wellbeing. Because the respondent reports a single score, this approach seems to capture all the effects on the consumer.

The above discussion is applicable to social externalities. As far as conventional economic externalities are concerned, Section 2 noted the possible wider market effects of ICT, including fixed and mobile voice communications and fixed and mobile broadband.

A popular way of examining both private use and external benefits of mobile communications is via international cross-sectional studies of the incremental impact on gross domestic product (GDP) of, say, a 10% increment in the diffusion of a

[14] For a survey see Bateman et al. (2002).

[15] These include notably hypothetical bias – the tendency for respondents to express levels of willingness to pay for hypothetical purchase which exceed levels which they reveal in actual payments. More fundamentally, it is necessary that any respondent in a stated preference study has an adequate understanding of the service being valued.

[16] An interesting recent example of inferring the *private* value associated with a regulatory measure which changes the attributes of a (potentially spectrum-using) service is a study performed by WIK for BEREC on the value of net neutrality to consumers in the EU. See WIK (2015).

[17] Note that this was expressly raised as a possible approach in the UK's 2014 Spectrum Strategy (DCMS 2014) – see Section 1 above.

Table 5
Estimates of the effect on GDP of increased broadband penetration.

Authors	Countries	Effect on growth of 10% additional broadband penetration
Czernich et al. (2011)	OECD, 1996–2007	0.9–1.5%
Katz and Avila (2010)	24 Latin American and Caribbean countries	0.2%
Gruber and Koutroumpis (2010)	EU15, 2003–2006	0.26–0.38%
OECD (2011)	EU countries, 1980–2009	1.1%

communications service such as fixed voice. The results of some recent studies of the effects of broadband is shown in Table 5. These increases exceed, in some cases by an order of magnitude, the additional contribution to GDP made by mobile communications, as recorded in the sectoral national accounts.

Several points can be made in relation to economic externalities associated with mobile communications:

- the data reported either arose before the comparatively recent spread of mobile broadband, or relate largely to countries with fairly ubiquitous fixed networks and relatively high diffusion rates of fixed broadband. What impact mobile broadband has had, whether in the presence or the absence of a fixed network, has subject to less study;
- the estimates vary considerably – by a five-fold factor or more – across the studies, even in relation to more developed countries;

This may be an area which would repay further study, to resolve such questions. Indeed, for the reasons given above any substantial investment made in investigating external social effects would be wasted unless progress were made on the measurement of other types of externality.

In summary, implementing a programme of estimating the full value of spectrum-using services, outside the special case of constant output, faces considerable obstacles. It remains to be seen how these might be overcome.[18]

6. Making progress with incorporating externalities

Based on the analysis and judgements above, it is possible to identify several (increasingly uncomfortable) ways in which spectrum allocation and assignment decisions can take account of externalities in spectrum-using services.[19]

1. It has been argued that, where the outputs of the services competing for spectrum are constant, the alternatives under consideration differ only with regard to the non-spectrum related supply costs, with the result that estimation of external benefits is not required to make efficient choices. This may be particularly likely to arise where the rivals for use of a band are non-marketed public sector spectrum-using services, on the basis that the degree of spectrum scarcity in the public sector may be less than that observed in the private sector, or where the change on service output levels is small, and/or where there is reason to believe that incremental external effects are diminishing.[20]
2. Where the circumstances in which spectrum-using services are such that private use values are discoverable, and the difference in external values of two spectrum-using services is not known exactly but is known to be less than the difference in private use values, the spectrum regulator could reach a decision between alternatives on this basis. This case may arise when outputs are considered to be 'approximately' constant.
3. Where both services are non-marketed (and therefore almost certainly public sector, AND output levels vary in response to the allocation, it is necessary to take account in the decision of both private value and external value. (It might be claimed that spectrum managers have in the past made such calculations implicitly.)
4. Where external benefits are valued, and where a spectrum auction is to be used to value private use benefits, the auction can be amended to take external benefit into account by means of so-called bidding credits. Thus suppose a bidder was expected to generate €X million of beneficial externalities over the lifetime of a licence. In determining the winner, its bids would be treated as if they were €X million higher than in fact they were, but if it were the winner it would only have to pay the amount it bid. The same form of adjustment (including a bidding debit in the case of a negative externality, no adjustment in the case of no incremental external effect) would apply to all bids.[21]

As there is no disguising the fact that the measurement of external effects represents a serious challenge which has not

[18] An approach to addressing these issues is set out in DCMS (2015).

[19] In practice, there implementation of these options will need to reflect the relevant legal and regulatory framework for spectrum management. Consideration of this is outside the scope of this paper, given our focus on the economic aspects of the issue.

[20] For example, it might be demonstrable that the broader social benefits of the first ten mass audience television channels is larger than the channels numbered 1000 to 1010.

[21] Where bidding credits have been used in the past, they have been based on the characteristics of the service provider (a credit for small firms, for example) rather than on the characteristics of the service provided.

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yet been fully faced, let alone overcome, we rely in the short term upon cases 1, 2, and 3 above to make progress in this area, rather than 4. In the medium term the measurement issues have to be addressed, probably by trial and error, and a focus is desirable upon those external effects which seem most likely to be capable of reversing spectrum private value rankings.

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