Chapter 5
Impact Assessment of CR Policy and Regulation

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Abstract This chapter looks at emerging issues related to carrying out Impact assessment (IA) for identified combinations of techno-economic circumstances and conditions of CR deployment. The aim of such analysis would be to aid the policy discussion and development, by recognising the most attractive and beneficial combinations of regulatory provisions to form the basis for the ultimate CR regulatory framework. Section 5.1 provides an overview of IA and offers perspective on existing IA guidelines in the case of CR policy. Section 5.2 discusses the alignment of regulation and technology, applying an actor-centric approach. It highlights that successful introduction of CR will require alignment between the characteristics of CR and the regulatory regime under which CR will operate. Section 5.3 discusses role of spectrum regulation and argues that more relaxed spectrum regulations would trigger generation of well suited and flexible services, as they could reduce market entry barriers and allow more service providers to access the spectrum resources. Then, Sect. 5.4 describes a study on IA of Dynamic Spectrum Access (DSA). The introduction of DSA has been challenged by several technical, economic and regulatory factors. The authors develop a framework that combines system dynamics modelling (top-down approach) and Bayesian network data analysis (bottom-up approach) for analysing current mobile markets and their future evolutions possibilities. This is followed by Sect. 5.5 that looks at the matter of type conformity assessment for future CR/SDR apparatus, which would be an important consideration for placing equipment on the market. Then Sect. 5.6 analyses reasons of rather sluggish pace of CR innovation, with the aim of suggesting a range of suitable policies to boost further and more fertile developments of CR technology. The chapter is concluded by Sect. 5.7 that offers spectrum

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policy analysis from both positive and normative perspectives. It proposes an "agreement framework", which could be used as reference template against which future policy analysis could be carried out in similar cases, with regard to emerging CR applications and CR technology in general.

5.1 Impact Assessment of CR/SDR Policy: Overview and Guidelines

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5.1.1 Impact Assessments: An Overview

Impact assessment (IA) is the formal analysis of the potential effects of new policies before their adoption. It is used as an aid to policy-making, since IA aims at forecasting the socio-economic impacts of policy proposals in terms of costs, benefits and risks. Therefore, in many countries IA provides a ground work for evidence-based policy-making. It also helps to communicate to stakeholders the evidence upon which legislative or regulatory changes are proposed. Indeed, there has been a wide diffusion of IA to increase the ability of governments to produce high quality regulation (or, as frequently referred to, better regulation). For instance, since 2003, the European Commission has employed an integrated IA system for estimating ex ante the impacts of its policy and regulatory proposals in economic, social and environmental terms [1]. Moreover, research has explored various areas where IA has become relevant and shed light on different rationales for the existence of IA, e.g., improvement of regulatory quality, improvement of market competition as well as of regulatory competition or cooperation, creation of conditions for policy learning, extension of the range of policy options, inclusion of stakeholders' opinions [2].

Notwithstanding increasing use of IA for policy making, IA is a relatively novel tool. Discussions around implementation and use of IA have stimulated an ongoing debate, that has brought to the fore a number of issues, including: different definitions of IA; various views on the relevant role of IA in the policy cycle; gaps between IA rationale(s) and practices; heterogeneous approaches in North America and Europe. Specifically, Torriti ([2], p. 243) noted that "North American authors support a prevalently economic rationale for decision-making, whereas their European colleagues seem more inclined to the view that the problems related with EU policies and regulations cannot be solved solely by adopting cost effective models" (see also [3, 4]).

The rest of this Section is organized as follows. The next subsection will provide a brief description of the European Commission's guidelines for IAs. Then, Sect. 5.1.3 will turn to the CEPT Electronic Communications Committee's guidelines for IAs regarding spectrum matters. Section 5.1.4 will reflect the outcome of discussion in COST-TERRA with regard to IA of CR/SDR regulation.

5.1.2 The European Impact Assessment Guidelines

In 2009, the European Commission adopted a new set of IA guidelines [5], which is offered for Commission staff preparing IAs. However, those guidelines present a number of answers to many relevant questions for any IA exercise. Therefore, this subsection will provide a brief summary of a few high-level questions addressed there. The interested reader is encouraged to refer to the full EC document.

The EC guidelines highlight that IA is "a process that prepares evidence for political decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impacts" ([5], p. 4). In particular, IA is defined as a set of logical steps to be followed in the preparation of policy proposals. Six key analytical steps are identified and further considered:

(1) Identify the problem;
(2) Define the objectives;
(3) Develop main policy options;
(4) Analyze the impacts of the options;
(5) Compare the options;
(6) Outline policy monitoring and evaluation.

Those fundamental steps should consider a few issues which characterize any IA: the nature and scale of the problem at hand; its likely evolution; the stakeholders affected by it and their views; the objectives to be set to address the problem; the main policy options for reaching those objectives; the likely economic, social and environmental impacts of the identified options; the relative effectiveness, efficiency and coherence of different options in solving the problems; last not least, the organization of future monitoring and evaluation.

5.1.3 Impact Assessment for Spectrum Policy

The Electronic Communications Committee (ECC) released *Guidelines for the implementation of impact assessment in relation to spectrum matters* in 2008 [6]. The ECC guidelines took into account existing EC guidelines, and developed them specifically for spectrum policy making. The ECC proposed that IAs will normally involve seven stages:

(1) identify/describe the issue/problem(s);
(2) describe the policy/measure and identify the objectives;
(3) identify and describe the regulatory options;
(4) determine the impacts on all stakeholders, including relevant spectrum incumbents;
(5) determine the impact on competition—if relevant (cf. previous stage);
(6) assess the impacts and choose the best option;
(7) outline policy monitoring and evaluation.

The ECC guidelines examine each stage in detail, thus providing an operational guide for IAs.

The activities to be carried out at each stage are shaped according to a few principles, which include the following ones: (i) IAs provide a framework for weighing up the costs and benefits of the options; (ii) they aim to consider a wide range of options, including not regulating or status quo in regulatory measures; (iii) IAs should take into account the whole value chain and knock-on effects across the relevant spectrum users as well as other sectors, in order to minimize any unintended consequences of decisions; (iv) IAs should be guided by the principle of proportionality and aim to have a low level of uncertainty ([6], pp. 3–4).

The guidelines also address some misapprehensions about IAs. Here, it seems interesting to note, first, that IA is not concerned solely with commercial or monetary considerations, to the exclusion of social or public policy goods; and, second, that IA does not comprise quantitative cost-benefit analysis, to the exclusion of other analytical tools ([6], pp. 4–5).

5.1.4 Impact Assessment for CR Policy

IA was the focus of one of COST-TERRA Working Groups, namely WG4. WG4 worked on carrying out IA for identified combinations of techno-economic sets of CR/SDR deployment rules, with the aim of identifying the most attractive combinations to form the basis for the ultimate CR/SDR regulatory framework with any variations therein. Other COST-TERRA WGs and special interest groups (SIGs) also provided inputs to discussions and constructive feedback on WG4 activities. During COST-TERRA meetings, IA procedures for CR policy were discussed and there was a general agreement on the relevance of EU and ECC guidelines for CR policy. Therefore, COST-TERRA did not elaborate a set of IA guidelines to deal with CR policy.

Nevertheless, the discussion emphasized a few ingredients that IA for CR policy should use in producing effective IAs. In particular, the following ones were suggested:

(i) Definition of problem/issue(s) should consider whether markets or regulatory failures exist, and, if such failures exist, they should be brought to the fore and discussed in IAs;

(ii) A baseline scenario should be included for comparing policy options;
(iii) Qualitative and, as far as possible, quantitative analyses of alternative policy options (incl. sensitivity analyses and risk assessments) should be considered;
(iv) An appropriate time horizon should be selected for IAs;
(v) Objectives considered in IAs should be SMART, that is, Specific, Measurable, Achievable, Realistic, and Time-dependent.

5.2 Aligning the Regulatory Environment with the Technology, an Actor-Centric Approach

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5.2.1 Introduction

Already nearly 15 years ago the concept of CR was proposed by Mitola and Maguire as a promising technology to deliver personalized services to the user through the most efficient radio resource available [7]. Since then the concept of CR has been further explored and the importance of CR for efficient use of the radio spectrum has gained momentum [8, 9]. Significant efforts are put in the development of various aspects of CR. Trials with the commercial use of CR are on-going but are mainly limited to the TV broadcasting bands. There is still no commercial use of CR.

One of the main reasons for the lack of practical and commercial use of CR technology is uncertainty about the regulatory model. Although there are possibilities to use CR under the current radio spectrum management regime, the current regulatory model is not conducive for dynamic access of spectrum made possible by cognitive technology. Regulatory provisions are needed to align the regulatory model with the new capabilities of CR technology of flexible and more efficient utilisation of the radio spectrum [10].

The dilemma that governments are facing since the liberalization is that prevailing policy suggests a technology neutral assignment of radio spectrum, while enabling the deployment of a specific technology, i.e., CR technology, is of public interest to achieve more efficient utilisation of the radio spectrum. It appears that in this light, regulation to allow the deployment of a specific type of CR technology in parts of the radio spectrum that would otherwise be underutilised or not used at all is justified [11].

As CR encompasses a very versatile set of technologies, the subsequent challenge governments are facing is the choice among some of the more fundamental features of CR technology, such as the technology used to make a CR aware of its radio environment and the band in which the CR is allowed to operate. Their choices will need to be well informed as their choices play a pivotal role in the business models of the entrepreneurs. The way governments allocate the use of radio spectrum to particular radio communication services on the (inter)national level and assign the rights to use the radio spectrum on the national level is determining the viability of the business case for particular radio communication products and services. In this respect there is the issue of 'the chicken and the egg': certain types of radio spectrum rights assignment facilitate certain types of usage, while certain types of perceived usage will require a particular type of assignment. In other words, entrepreneurs are reluctant to invest in new products and/or services based on CR technology because of the degree of regulatory uncertainty and regulators cannot provide this certainty because it is uncertain if their choices will support a viable business case.

This section proposes a way forward to deal with this dilemma by explaining the relationship between the fundamental choices regulators will have to make and possible business cases for the introduction of new products and/or services based on CR technology. The section starts with an introduction on the regulatory environment and the relationship between the regulatory regime and possible business cases. It will address the changes that will have to be made to allow CR technology and more dynamic forms of spectrum access and the relationship between the regulatory regime and possible business cases. It is followed by a description of the basic technological solutions that are possible for CR and the relationship between the CR capabilities and possible business cases. This exploration is used to assess the impact of a chosen regulatory environment and associated CR technology on possible business cases.

5.2.2 Regulating CR

CR is often associated to unlicensed secondary white space access to spectrum. However, there are more regulatory regimes possible under which the CR application can have access to spectrum [10, 12]. White space access means that CR applications are granted access to white spaces of spectrum as long as the conventional (primary) user is not using it. The white space users operate on a secondary level of usage of the spectrum. Therefore this type of sharing is also referred to as vertical sharing. This secondary usage does not necessary have to be unlicensed. It may be restricted to a closed user group. Restricting access to a closed user group can be arranged through licensing.

Secondly, CR technology can be used to pool spectrum between a number of users or user groups. Spectrum pooling is the situation in which a common "*pool of spectrum*" is shared among multiple users [13]. Access to the pool may be restricted to a (licensed) closed group of users or the pool might be open to all under certain use restrictions.

All users that share a pool of spectrum have the same rights to access the spectrum. Therefore this kind of sharing is also referred to as horizontal sharing.

Table 5.1 Four different regulatory scenarios for implementing DSA

	Horizontal sharing (spectrum pooling)	Vertical sharing (white space access)
Property rights regime (closed user groups)	Spectrum owners dynamically share spectrum	Owners of the spectrum grant specific CR's access to their white spaces
Open access regime (commons)	All users dynamically share spectrum on an equal footing	CR's dynamically access white spaces from incumbent users

This leads to four different scenarios for the implementation of DSA. The different scenarios are summarized in Table 5.1.

Apart from an overall need for more flexibility, the changes that are needed within the regulatory regime will be different within each regulatory regime under which dynamic spectrum access is realised. In the following two subsections these changes as needed to implement dynamic spectrum access are further explored for the different scenarios.

5.2.2.1 Dynamic Spectrum Access in an Open Access Regime

In an open access regime, any user can obtain access to spectrum under certain specified conditions. These conditions will have to be clearly defined to limit the interference level. In the vertical sharing regime, a commons is created by giving devices access to the unused parts of the spectrum of licensed users. This type of sharing is also referred to as Opportunistic Spectrum Access. In this case, the rules for spectrum access will have to guarantee that the interference to the primary user(s) of the band is kept below an acceptable level. The spectrum regulator will need to define an acceptable level to detect and protect incumbent users.

The definition of an appropriate level is not an easy task. If the level is too restrictive the potential gains of Opportunistic Spectrum Access are marginal, while a level that is too permissive may affect the Quality of Service of the primary user. The regulator will have to cooperate with industry to set a realistic level, which is based on the state of the art of technology. The level will have to be re-assessed if the primary user changes its technology. In the case of a true commons in which a frequency band is dynamically shared among all users, there is less need for involvement by the spectrum regulator. The main task of the regulator is in that case to designate a band for such purposes.

The regulator can also support OSA by providing information on the use of the band that will be dynamically shared between primary users and OSA devices.

5.2.2.2 Dynamic Spectrum Access in a Property Rights Regime

A property rights regime is based on the introduction of spectrum usage rights. These property rights go a step further than the licenses of today. They are used to create a market for spectrum in which these rights can be sold, leased and rented. The spectrum regulator will have to define these rights, with as few restrictions as possible. A number of countries have already introduced the possibility of secondary trading. However, in most cases there is an approval mechanism involving the authorities before trading may take place. This kind of barrier induces a delay before a trade can take place and thus makes real-time trading impossible. Hence, this barrier will have to be removed to exploit the full potential of dynamic spectrum access. Trading based on a much shorter time basis may make the market for spectrum more fluid. A central entity (a spectrum broker) could be used to facilitate this spot market.

A spectrum market can only function if information about the actual ownership of the spectrum property rights is readily available to facilitate trading. The regulator is ideally positioned to perform the task to keep a record of the ownership of these rights. Inclusion of monitoring information about actual usage of spectrum can further facilitate trading by giving more insights in the possibilities for trading and secondary usage.

5.2.2.3 Enforcement and Dispute Resolution

To successfully introduce dynamic spectrum access, there must be some assurance for the incumbent users of the spectrum that their usage will not be subject to (harmful) interference. This means that there is a need for a dispute resolution mechanism. To ease the settlement of disputes, it may be necessary to introduce a unique identifier for all CRs that is send alongside with the message with all radio transmissions. This will require that regulators are actively involved in the development and/or standardisation of CR technology [14].

A related point is that regulators will have to be very active in enforcement, especially in the start-up phase of the use of CR technology. This will provide the necessary confidence to existing users of the band that all efforts are taken to prevent CRs from inducing harmful interference and at the same time it will provide useful information to the industry to further develop their product [10].

5.2.2.4 Conclusions

The role of the regulator and the necessary conditions in the various regulatory regimes are outlined in Table 5.2.

5.2.3 The Impact of Regulations on the Business Case

The way in which the regulatory regime allows access to spectrum will greatly influence the business opportunities. This subsection gives an overview of the impact of the regulatory regime on the business opportunities.

Table 5.2 Necessary conditions for DSA in various regulatory regimes

Regulatory regime	Necessary conditions
Open access	Strict protection rules needed to keep the interference to the primary users at an acceptable level
	Rules to promote fair sharing of spectrum resources among OSA devices
	Availability of information on primary use to detect and protect incumbent users
Property rights	Well defined exclusive licenses granted to primary users or brokers
	As few usage restrictions as possible
	No barriers to instant trading
	Electronic information about ownership and actual usage should be available

5.2.3.1 White Space Access

In the white space access regimes the CR devices will always have to respect the needs of the primary user. White space access is only possible as long as there is no need for the spectrum by the primary user and no interference is created to the primary user.

This sets limitations to the business case for unlicensed white space access with an unrestricted number of devices. There will never be a guarantee that a CR device can have access to a white space and there is always the possibility that a CR device has to cease its operation because a primary user wants access to the spectrum. This makes this regulatory regime less suitable for time critical CR applications.

Restriction of access to white spaces to a specific user group provides the possibility for active coordination between the incumbent user and the secondary (cognitive) user about the likelihood of interference, and on guarantees about access to spectrum. Restricted access may also increase the level of trust for the incumbent user and may make them more willing to share their white spaces with a known and trusted CR user.

5.2.3.2 Spectrum Pooling

In case spectrum is pooled between a number of users or user groups, CR technology is used to dynamically share the spectrum resources. Pooling of spectrum in a closed user group between spectrum owners is only a viable option if the various owners are not in direct competition with each other. This is for instance the case if spectrum is used for company internal purposes, such as fixed links or private mobile radio. It is also possible to pool spectrum between various owners which have a completely different service, e.g., between a terrestrial service and a satellite service. Coordination between various owners will be easier if there already is a relationship whereby spectrum is shared at present. This will increase the level of trust and will make it easier to come to an agreement.

CR technology can also be used to pool spectrum between unlicensed applications. Knowledge of the radio environment is in this case used to realise a fair distribution of access to spectrum between the devices.

Table 5.3 Impact of the regulatory regimes for spectrum access on the business case for CR applications

	Horizontal sharing (spectrum pooling)	Vertical sharing (white space access)
Open access (commons)	Fair distribution of spectrum access	No guarantees for spectrum access, i.e., less suitable for time critical applications
Closed user group (licensed)	Increased level of trust More certainty about access to spectrum	
	CR user groups not in direct competition with each other	Possibility for active coordination. More guarantees for spectrum access

5.2.3.3 Conclusions

The regulatory regime has a huge impact on the Business Case for CR. Each regulatory regime will facilitate a different kind of CR applications and/or service offerings. A mixture of these regimes will be necessary to unlock the full potential of CR technology in increased spectrum efficiency. The impact on the business case of the regulatory regime under which the CR application will operate is summarised in Table 5.3.

Especially the use of CR technology in a closed user group can help to bring this technology further for two reasons. First, restricting access to a controlled group may increase the level of trust between the users who share the spectrum. Second, restricted (licensed) access can provide certainty about access to spectrum over a longer period of time needed to recover the investments to be made in CR technology.

5.2.4 The Impact of CR Capabilities on the Business Case

The fundamental difference between a CR and a conventional radio is that a CR uses information of the radio environment to select and deploy the most appropriate communications profile, such as frequency band, access technique and modulation method. There are various techniques possible to obtain information about the radio environment.

The regulator will have to make fundamental choices about the radio environment in which the CR will operate and on the way in which the CR collects information of the radio environment. Each of them will have different implications for potential CR applications and the magnitude of the required investments.

5.2.4.1 The Radio Environment

CR technology is proposed to improve utilisation by using spectrum that is allocated but actually not used at a given time and location. The question is whether there is enough capacity in these unused spaces that can be made available to support the underlying business case for CR technology and if the business case is solid enough to recoup the necessary investments in this new technology.

The ease of making unused spectrum available for cognitive use depends on the characteristics of the incumbent user. It is easier to find a white space if conventional user(s) and usage is relatively static than when conventional users are mobile and/or their usage fluctuates.

Moreover, the fact that large parts of the spectrum are not utilised does not imply that an attractive business case for the remaining unused parts exists. The fact that in rural areas GSM spectrum is underutilised does not necessarily mean that there is a viable business case for these unused GSM frequency channels, at least not for mobile communications. The business case for the exploitation of these white spaces will have to be distinctively different from the business case of the conventional user.

5.2.4.2 Sensing

In its basic form a CR senses the radio environment to acquire information on the local usage. The CR device relies thereby on its own judgment of the local use of the spectrum to transmit over sections of the spectrum that are considered free. No matter how good the sensing technology is, a system that only relies on its own judgment to obtain information about spectrum usage might come in a situation where it inadvertently is not able to detect usage of a radio channel. This means that with a CR based on sensing alone, there is always the possibility of interference to the conventional users of the band. To limit this risk, restrictions on the output power of the CR devices will have to be set. As a consequence, the CR can only be used for applications which use low power in relation to the incumbent usage.

Sensing can be used without the need for coordination with the "outside world". Hence, sensing can be used for stand-alone applications, whereby there is no need for investments in the roll-out of associated infrastructure.

The probability of finding a white space that can be utilised depends on the activities of the incumbent user(s), the range of frequencies which is sensed and the number of active white space devices. Sensing will have to take place over a sufficiently large frequency range to support the capacity needed by the CR application. Sensing becomes more challenging, and more expensive, when a wider range of frequencies and/or a wider range of conventional user applications are to be taken into account. At the current state of technology and field experience on sensing, a case-by-case approach will be required which takes into consideration the existing spectrum usage. Hence, for new CR regulations to be meaningfully applied, i.e., before making available a band for white space devices, an assessment should be made of the amount of white spaces that can be made available against the capacity needed for the introduction of the application that uses these white spaces.

Sensing can be made more reliable by cooperation between the sensing devices [15]. Cooperation can improve the probability of detection and reduces the detection time and thus increase the overall agility of the system. Drawbacks are the need for a common signalling channel between the devices and the additional overhead needed to exchange sensing information over this channel.

Especially the need for a signalling channel makes this coordinated approach complex. The cognitive devices become part of a network. This makes this coordinated approach especially feasible in applications where the CR device is already part of a (local) network, e.g., in-house networks. Coordination is a less attractive option for stand-alone CR applications.

5.2.4.3 Database

A second option is to get information about the local use of the spectrum from a database. Such a database should contain the relevant information on the frequencies that can be used at a certain location as well as the applicable restrictions. The database will have to be kept up-to-date, which makes this option especially suitable in cases where spectrum usage of the conventional user(s) does not change frequently, e.g., in a broadcasting band or a band for fixed satellite communications.

The restrictions for the CR application imposed by the use of a database are twofold. First of all, the CR device needs to be aware of its geographical location. This information can be programmed in the device during the installation of the CR device for fixed applications. Mobile CR devices will need a means to acquire that information, for instance by incorporating radio navigation in the terminal. However, the use of radio navigation will be difficult for indoor applications.

Secondly, the CR device will need to have access to this database on a regular basis. Access to the database is easier to arrange if the CR device is already part of a network than for stand-alone CR applications. The rate at which the CR devices have to obtain updated information on the local radio environment depends on the rate at which the information on the incumbent user may change and on the degree of mobility of the CR device.

5.2.4.4 Cognitive Pilot Channel

Coordination between CR devices can be realised through a so-called Cognitive Pilot Channel (CPC). A CPC is a dedicated carrier providing information about the availability of spectrum and possibly usage restrictions to the CR devices in a certain area. The CPC can be used to (1) give general—local—information on the availability of white spaces in relation to the service to be protected, or (2) to coordinate the use of the spectrum resources by the CR devices competing for spectrum access or (3) a combination of both [16].

The first option requires that the CPC broadcasts information on channels that are available and possibly the associated use restrictions, unless these restrictions are already known beforehand by the CR device. The second option is more complex because there is also a need for the network to know which channels are actually used by the CR devices and therefore there is a need for a feedback channel.

Implementation of a CPC will require a radio-infrastructure to support the CPC. The CPC can be provided by a dedicated, autonomous network, but this will require substantial investments. The necessary investments can be lowered if the CPC uses a logical channel within an existing network, e.g., within a mobile network. Standardisation activities in this field are on-going (see Sect. 1.3).

Because a CPC can provide real-time information, a CPC is highly suitable in cases where spectrum usage of the user(s) with which the band has to be shared is more dynamic. In this case, the network will need to have up-to-date information of the spectrum usage of all user(s) at all times.

5.2.4.5 Conclusions

The means a CR uses to acquire information on the radio environment has a significant impact on the business case for CR applications. An outline of the main conclusions of the impact of the CR technology on the CR applications, and thereby on restrictions for a viable business case, are given in Table 5.4.

An apparent difference between sensing on the one hand and a database or Cognitive Pilot Channel on the other hand, is that the latter two will require investments in infrastructure. This means that sensing can be used for stand-alone applications, whilst the other options are better suited for the delivery of services with an associated infrastructure roll-out, i.e., sensing can be used in a business case based on the sales of equipment whereas the database and CPC are better suited for a service provider driven business case based on the sales of a service. In that case there will be a direct relationship between the service provider and the customer. This relationship is necessary to recoup the investments in infrastructure.

Of course, it is always possible to use a combination of techniques. Especially a combination of database access and sensing seems promising. The database can be used to protect existing services with which the band is shared and sensing can be used to assess whether the opportunity is really available or already in use by another CR device.

Another possibility is the use of a local CPC (or so-called beacon) to reduce some of the drawbacks of sensing, especially the complexity and associated costs of sensing devices. A relatively complex master device can be used to process the sensing results of a range of locally connected devices. The master device decides based on this information on what channel the connected devices may operate and sends this information to these devices over a local beacon. This solution can only be used if these devices form a local network. The relatively expensive master device acts as an intelligent central node for the relatively cheap connected devices.

Table 5.4 The impact of the CR technology on the business case for CR applications

	Implication to potential CR applications	Remarks
Sensing	Low power in relation to the primary user Sensing over a relatively small band sets limits to the data transfer capacity available Wide band sensing increases the capacity available, but is more complex and expensive Can be used for stand-alone applications	There remains a potential for interference to the conventional user
Database	Can be used for applications which need a higher power CR device needs to be aware of its location Application needs a connection to the database on a regular basis	Only useful in bands with relatively static conventional users Costs of database service will have to be recovered
Cognitive pilot channel	Can be used for applications which need a higher power CR device is part of a network	Can also be used for more dynamic conventional use Large scale deployment more expensive than a database

5.2.5 Aligning the Regulation and Technology, an Actor-Centric Approach

Although there are possibilities to use CR under the current radio spectrum management regime, regulatory provisions are needed to align the regulatory model with the new capabilities of CR technology of flexible and more efficient utilization of the radio spectrum [10].[1]

In this subsection it is proposed to use an actor-centric approach to deal with this issue of alignment. After all, CR is a technology to share spectrum among various users. The various users of the spectrum, the industry that has to develop the equipment and the government that has to provide the necessary regulations will have to coordinate to come to a successful exploitation of CR. The actors involved in this coordination will all have their own objectives and incentives.

This subsection will offer an explanation of methodology to analyze the alignment between a new technology and the regulatory environment within which it will be introduced. Evidence for the relevance of this approach may be found in the historic discourse provided in Sect. 1.1 of the first chapter, which analysed the coordination of radio spectrum use in the past and the development of radio spectrum regulations resulting from those coordination efforts. This approach will be then applied in Chap. 7 to carry out the analysis of the so far best known intended use of CR technology: white space access in the TV bands and, based on that analysis, proposing some forward looking recommendations.

[1] This subsection also reflects on [12, 13].

5.2.5.1 Two Levels of Alignment

Various contributions have been made on the need to adapt the regulatory framework to the new capabilities of CR [10, 17]. While alignment between new technologies, such as CR, and the associated regulations is an important prerequisite, it is not enough to assure a successful introduction of this new technology. There are numerous examples on the introduction of new technologies were the necessary alignment between the technology and the regulations was in place but the market for the provisioning of products and services based on this new technology did not mature.

Our analysis of the underlying causes is that firms will only decide to invest in new products and/or services if they can expect a future return. These investment decisions are driven by three major considerations: (1) the prospective demand and willingness to pay for new products and/or services; (2) the magnitude of the investments required; and (3) the degree of risk or uncertainty involved.

The profile of the business case, in terms of depth of investment and the recovery period required, will influence the ability to obtain the necessary (external) funding. As such the business case is especially challenging for service provisioning that requires a huge, upfront investment, e.g., an infrastructure roll-out to provide mobile telephony. In these cases the right to exploit the radio spectrum or any other infrastructure over a significant period of time and on an exclusive basis will contribute to the willingness of firms to invest as it reduces the uncertainty, which may make the business case more viable [11].

Although the regulator can't do much about technological and market uncertainties as such, the regulator plays a crucial role. The regulator should create a regulatory environment in which these uncertainties are lowered to an acceptable level for commercial applications to emerge. This environment should, among other things give clear directions on the expectations of CR technology [18].

However, in setting up institutional arrangements, governments will steer technology and possible business cases in a certain direction. It was shown [19] that the specificities of the entry and authority rules will favor certain types of usage over other types of use.[2] This is also true the other way around; certain types of perceived usage will require particular entry and authority rules.

Hence, decisions made by governments on the market design and associated regulations will have an influence on the viability of possible business cases. For example, decisions made in spectrum policy on the amount of spectrum allocated, whether the spectrum is made available on a license exempt basis or not, the number of licenses issued, the roll-out and other obligations attached to the licenses and the award mechanism for the licenses (e.g., an auction or a beauty contest) will all influence the required investments and the possibilities to exploit a certain business case. This is quite well demonstrated by mobile communications

[2] Ostrom made this observation in the investigation of common pool resources. The problems associated to infrastructures are quite similar [16]. The latter source argues that infrastructures

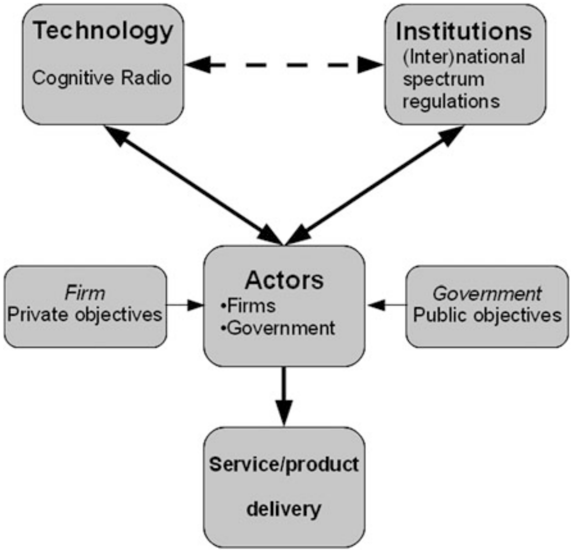

Fig. 5.1 Two levels of alignment

(GSM) which could flourish under a strict licensing regime and Wi-Fi that could develop under a license exempt regime.

Governments will need to be very well informed to make the right decision in order to let the intended business case flourish. Lessons learned from the past seem to suggest that a too "pushy" approach from governments may be counterproductive and retard or stall technological development [20]. Governments will need to take decisions that are not only in line with their own goal(s), but also make it possible for entrepreneurs to realize their goals. After all, it is through the actions of the firms, individually and collectively, that the governmental goals will be realized. This is illustrated in Fig. 5.1.

The government and the entrepreneurial firm have different objectives. In a somewhat simplistic view of the world, since the liberalization governments have, above all, an objective of economic efficient use of spectrum.

This is accompanied by societal objectives, such as universal service delivery, and in some cases also by industry policy. Governments rely on a market design and associated regulations to serve this mixture of economic and societal objectives. In the case of mobile communications, radio spectrum policy is used to create a market for mobile telephony. Specific auction rules may be used to allow new entrants and to influence the number of players on the market. Specific obligations are attached to the licenses to serve societal objectives, e.g., a coverage obligation.

(Footnote 2 continued)
(including energy, communication, transport, and postal services) can be perceived as common pool resources providing essential services to society.

Firms, on the other hand, have a completely different objective. They want to invest in (new) technology to develop products and services with the aim to maximize profit. The government and the firm are highly interdependent in the realization of their objectives. The institutional arrangements that are set up will have to provide certainty to entrepreneurial firms to invest in new technology and the exploitation thereof. If, as a result of profit maximization considerations, firms decide not to use the system as intended, the government fails in realizing its governance objectives.

Use of the new technology in such a way that both the government and the entrepreneurs can realize their goals is what we call a "sweet spot". A "sweet spot" is only possible if the use of certain technology and the associated institutional arrangements are aligned in such a way that both the intended business opportunity and the public objectives can be realized. The finding of "sweet spot" for CR technologies shall be further discussed in Chap. 7 of this book.

5.3 Inter-Operator Spectrum Sharing: From Techno-Economic Enablers to Real Market Show Stoppers

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During study on the inter-operator spectrum sharing scenarios in HSPA networks [21], key modifications to the market and business models were identified, which were seen required by the spectrum sharing scenario implementation in future networks [22]. Due to the fact, that the spectrum usage in the current markets is subject to various constraints coming from regulatory, standardisation bodies, as well as hardware limitations point of view, various market players and their positions within described spectrum sharing scenarios were considered in order provide full picture of this complex environment. Spectrum resources were considered as goods being required for the mobile network subscriber value delivery. Therefore, spectrum valuation aspects as well as the end user requirements and expectations were incorporated in the discussion.

Aim of the study was to evaluate, whether the spectrum sharing extended by appropriate novel resource allocation techniques, might be able to generate new services for mobile subscribers, at the same time enabling new revenue streams for mobile network operators. Considering various aspects of the end user value perception, possibility of cost and complexity of the services delivery has been also addressed. Described inter-operator spectrum sharing was found to be an opportunity being able to open new markets and generate new mobile services. Based on system level simulation results [21] and using game theory to model cooperation among spectrum users, it was observed that there is a sharing gain achieved in terms of the total sum rate of the cell goodputs of both Mobile

Network Operators (MNO) participating in the game. Nevertheless, in the referred solution, which was based on the spectrum valuations being modelled by the cell specific buffer states, it was further observed that a load imbalance between sharing participants is the key aspect of the analysis. When the network load imbalance was high enough, the less loaded network was not able to gain from the participation in the sharing. This meant that any risk-free network operator might not be attracted by such cooperation mechanism. For that reason, it was found that appropriate motivation for potential players has to be formulated in order to stimulate their willingness to participate in such sharing mechanism. In order to find solution for the identified concern, we can think of the mechanism, where the sharing MNO is modifying his utility function in order to improve the sharing outcome (e.g., from proportional fair to throughput maximisation).

Based on the telecom market analysis, it was not difficult to notice, that fruitful deployment of the cellular network depends on the availability of the spectrum resources, which are scarce resource and can be allocated only by the national regulatory agency. Due to limited availability of this medium, in most cases the allocation is based on the long-term auctioning process, which aims to maximise the revenue from the spectrum and allocate it to the network operator, who values particular spectrum band the most. For all the reasoning mentioned earlier, the auctioned spectrum bands in many markets have generated bids, which were much higher than expected by national regulators. Simple conclusion is that in order to be able to provide mobile services, one has to consider high investment to obtain the spectrum resources.

It comes at no surprise that after successful acquisition of spectrum band, every mobile network operator tries to cover the market as wide as possible (in terms of the amount of the subscribers) in order to compensate expenses from the spectrum resources acquisition, by possibly largest revenue flow. What it means, is that MNOs are not focusing on too granular user definitions and are targeting their offer at high population of users. In such case, it is not very likely that the offer will cover very specific end-user requirements.

From the economical point of view, the most optimal offer creation process shall be constructed from as little building blocks as possible. At the same time, this process should allow to cover the market as wide as possible. In other words, for the Operational Expenses (OPEX) reduction, company would be interested in maintaining as little product lines as possible and at the same time, for the revenue maximisation purposes, the company's goal would be to generate as many product variants as possible, in order to satisfy possibly widest range of customers.

In relation to the cellular networks and mobile services, this can be translated into an offer, which is constructed from limited number of basic services (limitation of costs of services provisioning and maintenance), being able to attract certain population of subscribers. Due to the granularity of the service offer, it is likely to happen, that it will not be possible to offer sufficiently large number of various subscription plans and respective mobile services to certain, well defined group of end users having specific demands, or not willing to pay for the subscription which is not suited for their needs and expectations.

Trying to analyse this problem from the standpoint of the new market entrant, it is felt that this situation might give the opportunity for new mobile services creation, but cannot attract the current MNOs due to relatively low (in reference to their expectations) revenues forecast. What is the most important observation, is that in contrary to the MNOs, the presented case might be highly attractive for new market players (e.g., virtual operators, mobile service providers, etc.), who's cost structure is much less complicated and which is not being affected by high investments in the spectrum and infrastructure. The enabler for this to happen is the modification of the spectrum access regulations for bands that are not yet allocated, as well as for the re-use of spectrum resources, which is already in the possession of the MNOs (e.g., short-term auctioning, leasing, etc.).

Looking back at the referred simulation results [21], the observation on the sharing gains as a function of the load imbalance has to be highlighted, i.e., the higher packet load imbalance was considered between operators, and the higher sum rate throughput gains were observed. That brought us to the conclusion, that the most optimal spectrum utilisation (irrespective of the radio access technology consideration) shall be met in case of services generating highly uncorrelated (in terms of the generated data traffic) packet load over particular areas in case of shared spectrum or full network sharing.

Thinking of the relaxed spectrum regulations, which would allow dynamic (i.e., variable in time) and flexible (i.e., variable amount) spectrum allocation grants, well suited and flexible services would emerge on the market being provided by new market entrants, as there would be much lower entry barrier, i.e., no need for long-term spectrum band acquisition. For the current market players owning already acquired spectrum bands, it open new revenue generation possibilities, at the same time, allowing them to decide on the competitiveness of the emerging offer being delivered via their radio access network. The proposed model differs from the Mobile Virtual Network Operator (MVNO) business case, which allows new market players not owning spectrum bands, but does not allow spectrum allocation flexibility and its dynamics—only medium to long-term contracts are considered.

From the current market stage, novel spectrum sharing techniques are expected to arise on the market, gaining from the opportunistic spectrum availability. Frequency, time and space specific network capabilities boosts coming from spectrum sharing will materialise only in case of the matching UE needs, as well as available scheduling grants. From the business point of view, authors are of the opinion that the current market of mobile services is too generous. With the users expecting flat rate subscription, network operator agrees to offer cell's peak rate (of course with no guarantees). Spectrum sharing will make the cell's peak rate even higher, but it is not guaranteed that the revenue will increase for the operator(s).

The missing element is the definition of the Service Level Agreement (SLA) being signed between market players who are providing radio access and the mobile services. SLA specifies the radio access bearer as well as the services, including definition of the bearer throughput, its availability and quality of service, which should be specified independent from the network provider and RAT being used.

Moreover, SLA might cover the traffic volume being guaranteed for the service provider, possibly being time and geographical location specific. Depending on the volume of the SLA and its parameters, the consideration of the service provider requirements in certain radio access network might be high, requiring appropriate network planning and dimensioning actions, or capacity extensions.

In conclusion, it is suggested that more relaxed spectrum regulations, which would allow more service providers to access the spectrum resources, would trigger generation of well suited and flexible services to emerge on the market, as the consequence of much lower entry barrier.

5.4 Introduction of DSA: The Role of Industry Openness and Spectrum Policy

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5.4.1 Introduction

Dynamic Spectrum Access (DSA) aims to improve the spectrum efficiency by accessing dynamically the spectrum resources. Despite large efforts in R&D, these technologies have not been successfully introduced into the mobile market. Several technical, economic and regulatory challenges have been identified for this slow deployment. In practice, a dynamic management of the spectrum involves most of the telecommunication layers and players; and not only end user terminals as Mitola originally suggested. This involves a wide restructuring of the mobile industry. In addition, under an unclear evolution, several standards for DSA are currently under development, such as those related to IEEE and ETSI organizations.

This section aims to analyze how industry openness and spectrum policy affect the introduction of such technologies taking while taking into consideration their main challenges. Industry openness refers to entry and exit barriers of the industry, and spectrum policy refers to the number of spectrum holders and the type of licensing. We consider the deployment of DSA technologies in two opposing scenarios: end-user centric devices and mobile operator centric devices.

5.4.2 Methodology

This section combines top-down and bottom-up approaches. The bottom-up approach is used for analyzing the current data on market structure through Bayesian network analysis. The top-down approach analyzes the future impact of DSA technologies on different markets through System Dynamic modeling.

System Dynamics analyzes different organizational systems as a whole with the objective to understand their dynamic behavior, and the relations between different factors. We support the main assumptions of this model with country data analysis, using a Bayesian network. While System Dynamic modeling describes the relation of different variables within time, our Bayesian network describes the conditional probabilities between variables in one point of time. Thus, in this section we use a Bayesian analysis as an input for modeling the dynamic behavior of the whole system characterized by feedback loops between variables within time.

5.4.3 Bayesian Analysis of Mobile Market Structure

This analysis utilizes a diverse collection of variables to define the level of openness of the mobile industry. Variables that can potentially describe the level of investment and return of the industry that act as entry barriers are: mobile average revenue per user (ARPU), cellular investment per capita, investment as percentage of revenue (investment/ARPU). Variables that describe entry barriers related to customers are: churn rate (monthly %), mobile price (average price of one minute in USD), mobile penetration (%), prepaid ratio (% from total subscription). Other variables that explain entry barriers related to operators are: termination rate (in USD) and network operator—service operator separation (yes or no).

Regarding spectrum policy, we utilize variables that are related with the spectrum licensing and policies. The most relevant variables describing spectrum policy are: technology neutrality policy (yes or no, according to law), technology neutrality of the market (yes or no, according to the market), spectrum concentration index (HHI[3]), market share concentration index (HHI), spectrum reselling rights (yes or no, the possibility of trading spectrum) and the number of mobile network operators (MNOs). Since spectrum is a heterogeneous resource, we use another variable to analyze the impact of the concentration in lower frequency bands (below 2.0 GHz); which are usually considered as more valuable for mobile operators.

A Bayesian network[4] describes the conditional dependencies between variables and therefore it shows which variables are more adequate to describe the industry openness and the spectrum policy. Pearson correlation detailed graphically by the color and numbers in the arcs (Fig. 5.2b). Blue indicates a positive correlation and red indicates a negative correlation. Arrows depict the dependence between variables. Figure 5.2b describes the causal relation between variables related to the spectrum policy from 24

[3] HHI stands for Herfindahl—Hirschman Index.

[4] The utilized Bayesian network was implemented with the help of BayesiaLab 5.1 software, which includes machine learning algorithm functionality.

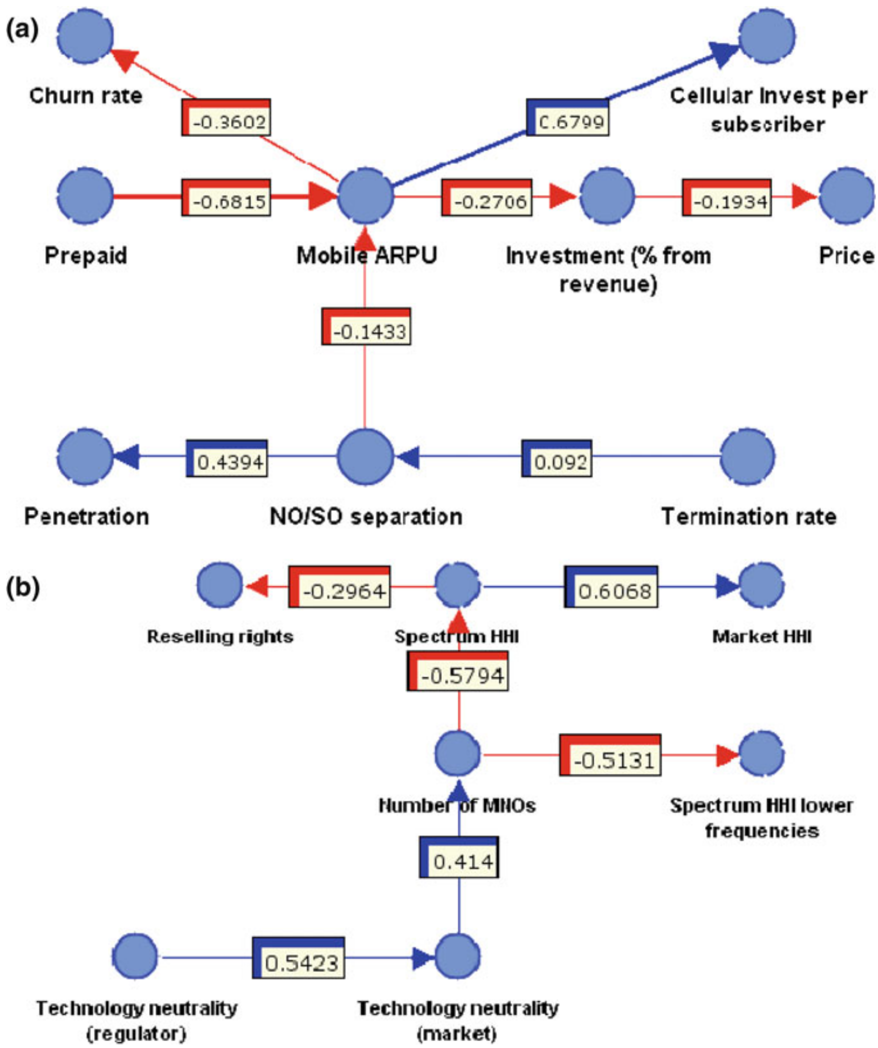


Fig. 5.2 Industry openness (**a**) and spectrum policy (**b**) variables and their causalities explained by a Bayesian network. Numbers in arcs indicate Pearson correlation

selected countries[5] [23–25] and Fig. 5.2a explains the same relation for the industry openness from 37 selected countries.[6] These models use a confidence level of 95 %.

[5] Australia, Austria, Belgium, Brazil, Canada, China, Chile, Czech Republic, Denmark, Finland, France, Germany, India, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

[6] Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Korea

From Fig. 5.2b, we can conclude that spectrum policy is best described by the market share HHI rather than the initial spectrum allocation or other regulatory decisions (spectrum decentralization index ≈ market HHI). From Fig. 5.2b we can conclude that the level of industry openness can be best described by the price level and the cellular investment per capita, which best explain the level of entry and exit barriers (industry openness ≈ 1/(price index* cellular investment per capita).

5.4.4 System Approach for Understanding the Introduction of DSA Technologies

In the following subsection we use a system dynamics to analyze the introduction of DSA technologies, using two approaches: competition with high network externalities and competition with predator–prey substitution.

The network externality competition model [26] describes a struggle between two homogeneous networks to dominate the market without space for competitors. In this case, the network effect is higher when the success of competing technologies depends on compatibility issues, such as the spectrum availability for sharing, compatible services and service providers, critical mass of terminals in the market, etc. The predator–prey substitution model describes competition based on the substitution effect using the Lotka-Volterra predator–prey equations [27]. This model describes a substitution model, in which a new technology competes against an older technology of a saturated market.

We base our assumptions on the previous work. Regarding spectrum policy, it is suggested that a centralized allocation of spectrum does not incentivize transactions in a secondary market since it does not provide room for improvements in the original allocation, while a market driven decentralized allocation incentivizes further improvements through a secondary spectrum market [28]. Regarding industry openness, it is observed that the unbundling favored by regulators to incentivize competition can have a negative impact on the investments due to an increase in the intensity of price competition [29]. Thus industry openness can be described by price to quality ratio.

Figure 5.3a depicts a system dynamic diagram for a network effect competition model. This model assumes that when an industry is open, low prices disincentivise the investment for centralized technologies favoring the usage for new technologies, such as end-user centric devices [30]. In addition, end user centric devices need a decentralized spectrum policy and a high level of standard cooperation. Thus, the inability to agree on standards or the existence of closed systems has a negative impact for reaching critical mass [31].

(Footnote 6 continued)
(South), Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

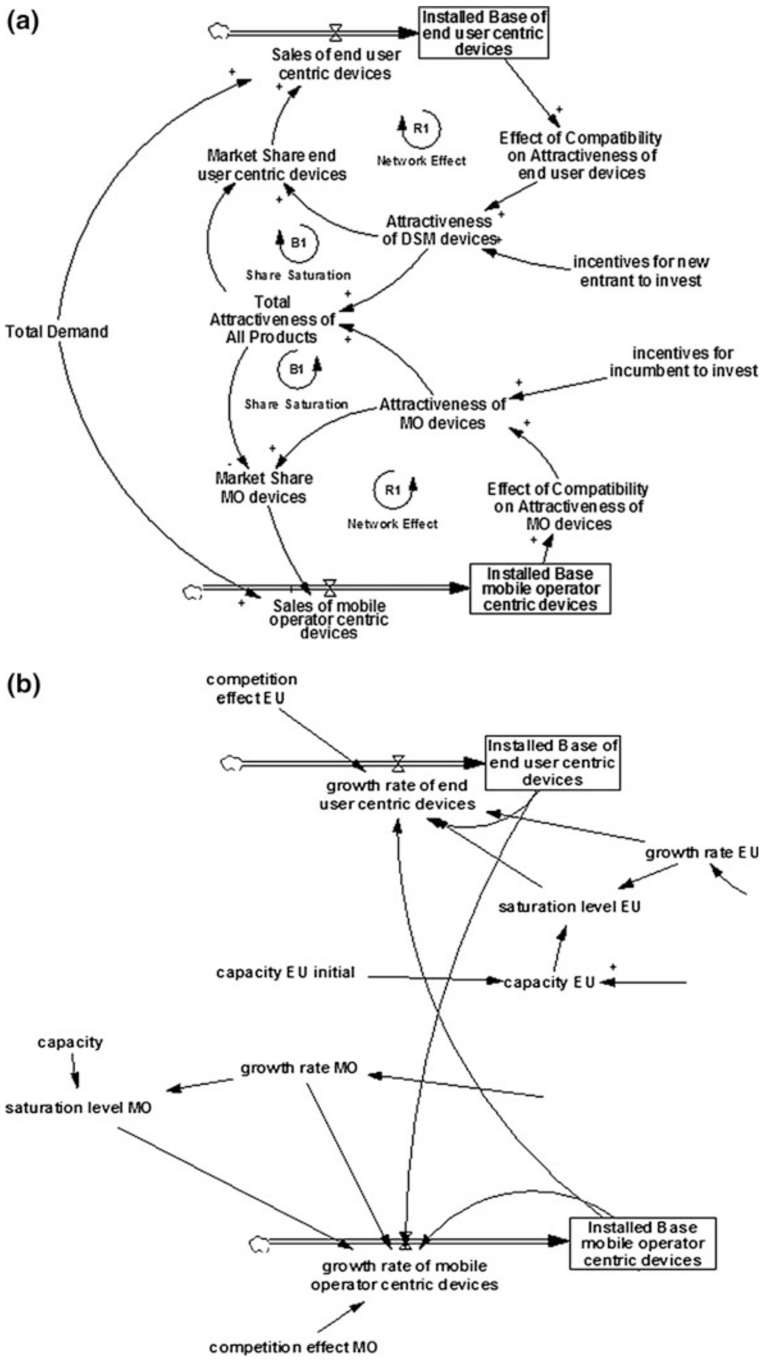


Fig. 5.3 System approach to describe the introduction of DSA technologies considering the network effect (**a**) and the predator–prey competition model (**b**)

The predator–prey competition model (Fig. 5.3b) considers the end user centric devices as predator and mobile operator centric devices as prey. It is suggested that the rate of technology adoption is directly proportional to the expected profitability and a decreasing function of the size of the investment [32].

From this perspective, a high level of standard cooperation increases the expected profitability and decrease the level of investments. Therefore, we assume that standard cooperation positively affects the adoption of new end user devices (saturation level) as well as the incentives for investments.

5.4.5 Results of Simulations

The results of simulation of Fig. 5.4a show how the introduction of end-user centric devices can be successful under a minimum required HHI and openness of industry. If these factors do not reach the required level, the industry locks into a centralized management of spectrum, based on current mobile operator centric devices, see Fig. 5.4b–d.

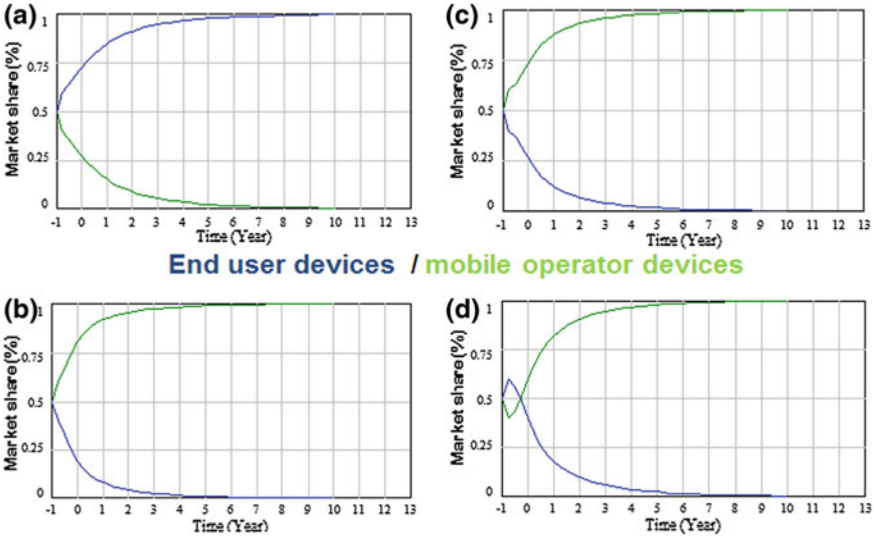
Figure 5.5 shows the results of the simulation using the predator–prey competition model.

The results show that in this competition model, end user devices have a slower diffusion than in the competition model with strong network effect, but have higher chance of success, because of its predator behavior. Figure 5.5a indicates that end user device diffusion is slightly faster when spectrum is decentralized and industry is open. Figure 5.5d additionally suggests that when spectrum is decentralized, the introduction of end user devices opens the industry. If the spectrum is centralized, the industry continues with the domination of mobile-operator centric device, even though a predator–prey competition model allows certain level of coexistence with end-user centric devices.

5.4.5.1 Conclusions

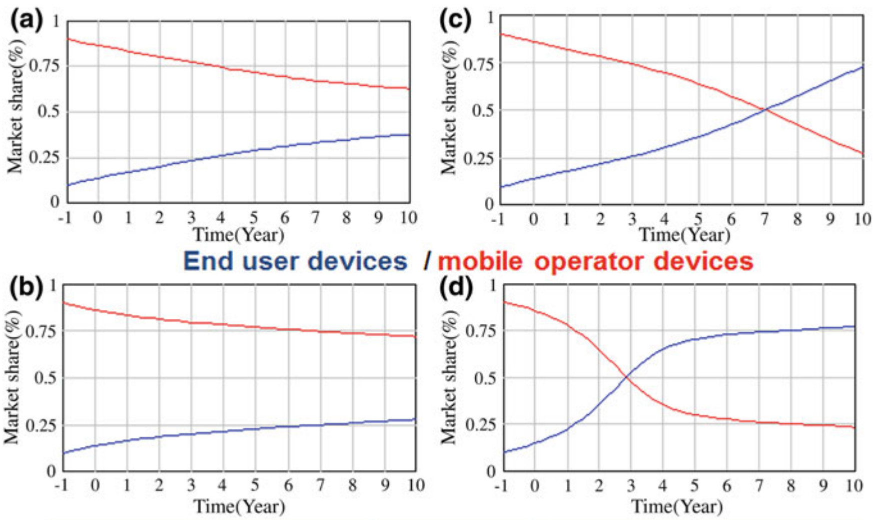
This section explored the introduction of DSA technologies by analyzing different mobile markets in a combined approach consisting of Bayesian network data analysis and System Dynamic modeling.

The two different competition models analyzed in this section show significantly different results. Under the presence of high network externalities, end-user centric devices will dominate only under an open industry and decentralized spectrum policy. Under a predator–prey model, a decentralized spectrum policy should be enough to drive an end user device scenario. Using the concepts of modular and integral design [31], a modular standard would show a predator–prey behavior. This means that a modular design should augment the substitution process while decreasing the network externalities.



	A	B	C	D
HHI	0.2 (decentralized)	0.6 (centralized)	0.2 (decentralized)	0.6 (centralized)
Industry openness	0.6 (open)	0.4 (closed)	0.4 (closed)	0.6 (open)

Fig. 5.4 Results for system simulation of competition with network effect



	A	B	C	D
HHI	0.6 (centralized)	0.6 (centralized)	0.2 (decentralized)	0.2 (decentralized)
Industry openness	0.9 (open)	0.3 (closed)	0.9 (open)	0.3 (closed)

Fig. 5.5 Results for system simulation of competition with substitution effect

Table 5.5 Strategies for industry players in different DSA scenarios

Regulation favors	Incumbent operator	New entrant or challenger operator	Spectrum holder (other than mobile operator)
End-user centric devices	Take active role in DSA offering new services	Early adoption of DSA Focus on innovation	Sell spectrum in the market. Consider becoming a new player
Mobile operator centric devices	Utilize DSA to decrease costs and increase efficiency	Cooperation with incumbent operators. Offer compatible services	Share spectrum with operators

Finally, this section gives valuable insights to regulators to understand the current type of policy in practice in their countries and the future consequences of their decisions. It also gives a global overview to different stakeholders on how to deal with DSA technologies as ICT evolves, see Table 5.5.

Regulators should analyze if their current regulation in terms of industry openness and spectrum decentralization is suitable to enable future innovation in a DSA scenario. At the same time, regulators should study the most appropriate mechanism to allow spectrum sharing and trading in their regulations. Incumbent operators should check their current level of cooperation and prepare strategies for spectrum sharing. In this way, they can take the most appropriate decision when investing in these technologies. Other spectrum holders should think on new business opportunities to actively drive spectrum sharing rather than taking passive role. New entrants and challenger operators should try to build a competitive advantage through early adoption of DSA technologies.

5.5 European Market Access and Compliance Regulation for CR/SDR[7]

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5.5.1 Introduction

So far the debate on the regulatory dimension of the deployment of CR/SDR systems focused mainly on issues related to spectrum access regulation. But prior to any transmission these systems would have to be lawfully placed on the market.

[7] The views expressed here are solely those of the author in his private capacity, and do not necessarily reflect the views of OFCOM.

Hence the pertinence to analyse the hypothetical impact of present-day regulation on market access and compliance of CR/SDR.[8] One of the purposes of this contribution is to raise the awareness to the fact that the requirements—both essential and administrative—flowing from market access and compliance regulation should be taken into consideration early in any undertaking aiming ultimately at the deployment of CR/SDR systems.

The present contribution will centre on the regulatory framework for market access and compliance of radiocommunication equipment implemented in EU/EEA/EFTA countries[9] (hereafter "Europe"). The R&TTE Directive[10] is the regulatory centrepiece of this framework for placing on the market, free movement,[11] and putting into service of radio equipment and telecommunications terminal equipment in Europe.[12]

The R&TTE Directive puts into effect the core objective of free movement of goods in the Single Market.[13] As a consequence, if a radiocommunication apparatus is compliant with the provisions of the R&TTE Directive it can be lawfully placed on the market in EU/EEA/EFTA countries even if this equipment cannot be operated in any of those countries.[14] In other words, placing on the market must be permitted despite the existence of interdictions and restrictions on putting into operation in some or all of the EU/EEA/EFTA countries. One notable curiousness of this regime is thus that an end-user in an EU Member State cannot infer the possibility to use a radiocommunication equipment simply from the fact that it is lawfully sold in that country.[15] Accordingly, the R&TTE Directive foresees that additional mandatory information has to be provided on or with the equipment by

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[8] The European Telecommunication Conformity Assessment and Market Surveillance Committee (TCAM) has for long recognised that CR/SDR will have an impact on market access and conformance regulation. It launched initiatives analysing this possible impact and contemplates adapting said regulation to the new realities which CR/SDR could bring about.

[9] EU Member States, EEA EFTA countries (Island, Norway and Lichtenstein), and Switzerland (the transposition of R&TTE in this country is expressly foreseen in a mutual reconnaissance agreement with the EU).

[10] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity ("R&TTE Directive").

[11] See the rulings of the European Court of Justice (ECJ) in Joined Cases C-388/00 and C-429/00 Radiosistemi [2002] ECR I-5845, Case C-14/02 ATRAL [2003] ECR I-4431, and Case C-132/08 Lidl Magyarország Kereskedelmi [2009] ECR I-3841.

[12] Accordingly, the approach followed in the United States—whose paradigms differ markedly from those of the European approach—will not be addressed here. For an overview, see Annex 2 to [17].

[13] Considerings (12) and (32) of the R&TTE Directive.

[14] Article 8(1) of the R&TTE Directive.

[15] See Sect. 9. "Possibility to place products on the market in the Community, which cannot be used in the Community" of "Interpretation of the Directive 1999/5/EC" under http://ec.europa.eu/enterprise/sectors/rtte/documents/interpretation_en.htm [Accessed 31 October 2013].

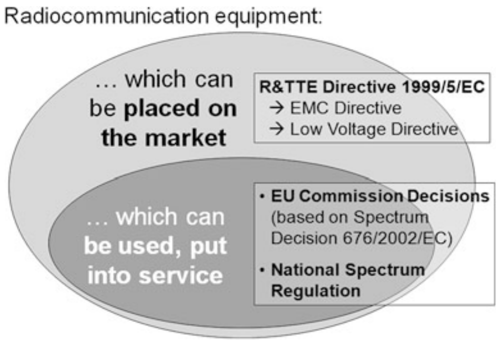

Fig. 5.6 In Europe, a radiocommunication apparatus operating lawfully needs to be lawfully placed on the market.

the manufacturer or importer when differing restrictions on the use of the apparatus apply in some countries or geographic areas[16] (Fig. 5.6).

5.5.2 Selected Aspects of European Market Access and Compliance Regulation

Dwelling on the details of the R&TTE Directive would be of no avail as the Commission has made a proposal for a revision of this Directive [33].[17] The discussion in this section will concentrate on some fundamentals which are likely to remain unchanged[18] and are of relevance for developers of CR/SDR. The intent of this overview is to emphasize that various approaches are open to CR/SDR developers (manufacturers, programmers, or integrators) when going to market in Europe. Several approaches lay at hand of equipment manufacturers in order to induce for their products a presumption of compliance with the technical requirements laid down by the Directive. In theory, there never is only one unique technical solution which has to be used in order to meet the essential requirements set out in the Directive.[19]

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[16] Article 6(3) of the R&TTE Directive.

[17] Formally the proposed directive should repeal the R&TTE directive (see draft Article 50) but in effect it will be a revision of the latter as far as radiocommunication equipments are concerned.

[18] For further particulars readers are referred to European Commission, Guide to the R&TTE Directive 1999/5/EC, available under http://ec.europa.eu/enterprise/sectors/rtte/files/guide2009-04-20_en.pdf [Accessed 31 October 2013].

[19] Considering (27) of the R&TTE Directive: "whereas compliance with such harmonised standards gives rise to a presumption of conformity to the essential requirements; whereas other means of demonstrating conformity to the essential requirements are permitted".

5.5.2.1 Essential Requirements

A radiocommunication equipment may be placed on the European market and put into service only if it is complying with material requirements laid down in the R&TTE Directive. These requirements are mandatory. Essential requirements define the results to be attained, or the hazards to be dealt with, but do not specify or predict the technical solutions for doing so [34].

The R&TTE Directive lays down three essential requirements that are of public interest:

- Protection of health and safety of the user and any other person, based on the protection requirements of the Low Voltage Directive;
- Protection requirements with respect to electromagnetic compatibility contained in the Electromagnetic Compatibility Directive; and
- Effective use of the radio spectrum/orbital resource so as to avoid harmful interference.[20]

The R&TTE Directive also empowers the European Commission to stipulate that some products fulfil additional—or "elective"—essential requirements in addition to the three above-mentioned mandatory ones. By decision the Commission can mandate that certain functions have to provided.[21] Up-to-now the only additional requirements that have been mandated aim at ascertaining access to emergency services by particular types of equipment pursuant to Article 3(3)(e) of the R&TTE Directive.[22]

5.5.2.2 Administrative Requirements

In addition to the requirements pertaining to their qualities, radiocommunication equipment must comply with some formal requirements. To list a few:

- Application of the adequate conformity assessment procedure[23]
- Marks and inscriptions[24]
  - Conformity marking ('CE' Mark)
  - Identification of the notified body, if applicable
  - Class identifier, if applicable
  - Batch and/or serial number
  - Name of the manufacturer or the person responsible for placing apparatus on the market

[20] Respectively Articles 3(1)(a), 3(1)(b), and 3(2) of the R&TTE Directive.

[21] Article 3(3) of the R&TTE Directive.

[22] See relevant Commission decisions under http://ec.europa.eu/enterprise/sectors/rtte/documents/legislation/decisions/ [Accessed 31 October 2013].

[23] Article 10(1) of the R&TTE Directive.

[24] Article 12 of the R&TTE Directive.

- Notifying authorities of the placing on the market of certain types of radiocommunication equipment[25]
- User information[26]
  - Intended use
  - Declaration of conformity
  - Identification of the countries where use of the equipment is permitted, where appropriate
  - Possible restriction to the use of the equipment.

It is worth highlighting that some administrative requirements could be subject to notable changes (which includes abolition) when the Radio Equipment Directive will enter into force. Nevertheless, two of them deserve a succinct development:

(1) **'CE' Mark**

The CE marking symbolises the conformity of the product with the applicable requirements imposed in Europe. It is affixed under the responsibility of the manufacturer, his authorized representative or the person responsible for placing the apparatus on the market in Europe. The CE marking affixed to products is a declaration by the person responsible that (i) the product conforms to all applicable Community provisions, and that (ii) the appropriate conformity assessment procedures have been completed.[27] (Fig. 5.7) European market surveillance authorities must presume the conformity of CE marked products with the applicable requirements and are not allowed to restrict their placing on the market unless they can demonstrate noncompliance on the basis of evidence.

(2) **Conformity assessment procedures**

The manufacturer is responsible for assessing the conformity of his product with the essential requirements of the R&TTE Directive or for having it assessed by a third party (generally, an accredited laboratory). He has to prepare technical documentation providing evidence that the apparatus complies with the essential requirements. This includes evidence that the apparatus complies with the relevant harmonised standards or, if harmonised standards are not used or used only in part, a detailed technical justification. Once the product successfully passes the conformity assessment procedure, the manufacturer does not need obtaining further approvals from any authority. The R&TTE Directive identifies several conformity assessment procedures for radio equipment including a transmitter (see Table 5.6). One procedure (1) in principle does not require the involvement of an accredited laboratory, whereas in the two other ones the laboratory's assessment can include either (2) its opinion on compliance with the essential requirements based on the technical documentation drawn by the manufacturer, or (3) its assessment of the

25 Article 6(4) of the R&TTE Directive.

26 Article 6(3) of the R&TTE Directive.

27 Article 12 of the R&TTE Directive.

Fig. 5.7 The CE marking must be affixed visibly, legibly and indelibly to the product and have a height of at least 5 mm

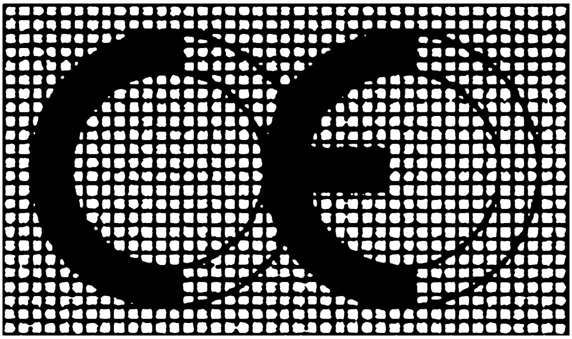

Table 5.6 Overview of the procedures for conformity assessment of radio equipment including a transmitter

Conformity assessment procedure	Condition for application	Role of the accredited laboratory (if applicable)
Internal production control and specific apparatus tests	Radio equipment including a transmitter complying in full with harmonised standards and harmonized standard comprising complete test suites	*Involvement not mandatory*
Technical construction file	Radio equipment including a transmitter not complying or only partially complying with harmonised standards	*Involvement mandatory* Opinion on the conformity of the equipment based on the review of the technical construction file established by the manufacturer
Full quality assurance	Any equipment covered by the R&TTE directive	*Involvement mandatory* Certification of the manufacturer's quality system

manufacturing process. Attention is drawn on the fact that different conformity assessment procedures may have to be used for each essential requirement.

The complexity of the procedures increases from 1 to 3. In case of full compliance with a harmonised standard, the assessment procedure is least burdensome for the manufacturer. When however a harmonised standard does not exist, has not been fully followed, or the test suites in a harmonised standard are incomplete, a manufacturer needs to demonstrate more extensively how the requirements of the Directive were met. In other words, the presumption of conformity with the corresponding essential requirements bestowed on products manufactured in compliance with harmonised standards[28] translates in a simpler conformity assessment procedure.

[28] Article 5(1) of the R&TTE Directive.

5.5.2.3 Harmonised Standards

The technical specifications of products meeting the essential requirements set out in the directives are laid down in harmonised standards. Harmonized standards are a particular form of European Standard (EN) and can only be produced by the three recognized European Standards Organizations (European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI). The European Commission mandates harmonised standards from these standardisation organisations.[29]

Essential requirements define the results to be attained, or the hazards to be dealt with, but do not specify or predict the technical solutions for doing so [34]. This flexibility allows manufacturers to choose other ways to meet the requirements. Technical solutions laid down in harmonized standards can be used to meet the essential requirements of the R&TTE Directive, but they are not mandatory. Application of harmonised or other standards remains voluntary, and the manufacturer may always apply other technical specifications to meet the essential requirements [34]. However, as stated previously, if a type of radiocommunication apparatus is covered by a harmonised standard, abiding to the specifications and test suites devised in it provides the simplest route to market. A third party assessment is considered necessary where products are not manufactured in compliance with harmonised standards, in absence of such standards, or if the essential test suites in these standards are not complete or missing.

5.5.3 Issues Pertaining to CR/SDR Arising from Actual Market Access and Compliance Regulation

CR is believed to include necessarily SDR functionalities [35].[30] SDR is defined as radio equipment (including a transmitter) in which the RF operating parameters comprising *inter alia* frequency range, modulation type, and/or output power can be set or altered by software, or the technique by which this is achieved [36]. Furthermore, it is imaginable that signal processing could be handled over general purpose processors, rather than done using special purpose chips, such as application-specific integrated circuits (ASIC) [37]. Accordingly, it would be in the normal course of events that CR/SDR devices in use would be reprogrammed, i.e., functions would notably be changed, reconfigured without modifying the hardware, after first placement on the European market.[31]

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[29] Article 2(h) of the R&TTE Directive.

[30] In other words, SDR technology is a precursor and an enabler of CR technology.

[31] ETSI uses the term Reconfigurable Radio Systems (RRS): Such systems exploit the capabilities of reconfigurable radio and networks and self-adaptation to a dynamically changing

It is assumed that the R&TTE Directive will apply to CR/SDR devices as they usually will be transmitting radiocommunication equipment. Accordingly, all the different possible stages of configurability of such a device would *in theory* have to fulfil the requirements of the R&TTE Directive. But the paradigms of the R&TTE Directive do not appear to be well-suited to field-programmable CR/SDR equipment. This is particularly true when one entity manufactures the hardware, other ones develop software steering the operational parameters for spectrum use, and the software reconfiguration is subject to no safeguards. Dealing with this type of technology (pertaining foremost to the issue of who should be responsible for overall R&TTE compliance) will be less straightforward than in the case of 'regular' devices [38].

The matter of the need of an evolution of the regulatory scope of the R&TTE Directive in order to accommodate CR/SDR has been under study by European market surveillance authorities for many years. A first set of questions flows from the uncertainty whether the R&TTE Directive provides certain categories of CR/SDR with loopholes that impede the achievement of the intended goals of the directive. If existing, could these gaps simply be closed by means of new interpretations of the R&TTE Directive's current text or is there a need for modified or new provisions? The second battery of questions results from the suspicion that the R&TTE Directive in its present-day reading could not be applied in a workable manner to some categories of CR/SDR.

The solutions springing from these reflections found their concretisation in the actual proposal for the Radiocommunication Equipment Directive [33] that should supersede the present-day R&TTE Directive in the course of 2014 (Fig. 5.8).

5.5.3.1 Essential Requirements

Market surveillance authorities apprehend that the potential advantages of flexibility (adjustment of parameters generated by a combination of hard- and software modules following a reconfiguration of the software) could increase the risk either that equipment which is or could become non-compliant would be placed on the market or that compliant equipment on the market would be rendered non-compliant afterwards by reconfigured software.[32] Pieces of equipment that lawfully displayed a CE mark when they were first placed on the market could sometime become non-conformant due to *ex post* modifications to the operating parameters of the equipment—and display of the CE mark would actually become illegal.

(Footnote 31 continued)
environment (ETSI TR 102 802 *Reconfigurable Radio Systems* (*RRS*); *Cognitive Radio System Concept*).

[32] First cases were reported by market surveillance authorities where wrong or old firmware installed by the supplier on request of customers or directly by the end user appeared to disable the Dynamic Frequency Selection (DFS) mechanism of Wireless Access Systems (WAS) operating in the 5 GHz range. This requirement flows from the necessity to prevent undue interference to meteorological radars by WAS [66].

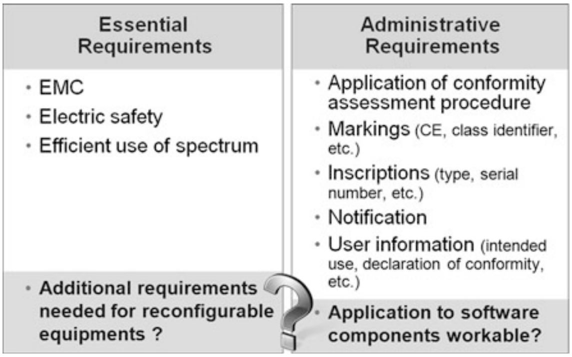

Fig. 5.8 Selected questions on the adequacy of the R&TTE Directive with upcoming CR/SDR systems

Specifically, operating parameters could contravene with regulatory conditions of use of spectrum following a reconfiguration. Conformity with the essential requirement of efficient use of spectrum is resource-consuming to enforce. Indeed it is often difficult for authorities to find non-compliant equipment put into use and generating harmful interference. The potential damage provoked by such interference is easy to visualise in the scenario of jammed air traffic management, public safety, or security services' frequencies.

The analysis over the last years has shown that no supplementary mandatory essential requirement is needed. However, additional (or "elective") essential requirements might have to come into operation for some configurations of CR/SDR.

CR/SDR operating under the control of a network

Under this configuration radio transmitters can only transmit under the control of a network and thus do not need any technical adjustment by the user (who may not even be given the opportunity to undertake them). This configuration does not really raise concerns of market surveillance authorities as the conformity of all hardware and software (initial or updates in the course of the life cycle) is likely to be monitored and controlled by the operator of the network. Control of both the reconfigurable platform and software is centralised (though it is unlikely that it will be in the hands of the manufacturer who is principally responsible for the equipment's compliance according to the R&TTE Directive). Unlawful equipment would be prevented from operating by the operator and could thus not create much harm.

CR/SDR where reconfiguration can be undertaken autonomously

In order to facilitate the legal handling of this type of CR/SDR, regulators envisage classifying them in two categories [39]:

- *Vertically integrated CR/SDR*

All hardware and software during the whole life cycle are controlled by the manufacturer who can ensure that software is only loaded through well-controlled mechanisms. This means that one entity could be held responsible of the combination platform/software. Accordingly, market surveillance authorities are not acutely concerned about this configuration either.

- *Uncontrolled CR/SDR*

In this case the products of independent hardware and software providers are combined. Independent companies develop and sell hardware and CR/SDR software separately—it may be the intention of the hardware manufacturer or due to his lack of caution to implement safeguards preventing the free installation of software. In this configuration it is expected that it will be very complex to assign responsibility for faulty combinations of platform/software. Consequently, the regulatory questions raising most concern emerge where software is developed by an entity other than the manufacturer of the hardware.[33]

In order to mitigate the concerns of market surveillance authorities with respect to uncontrolled CR/SDR, different ideas were brought forward. Discussions produced a scheme to include a new provision for an additional—or "elective"—essential requirements in the proposal for the Radio Equipment Directive. This provision empowers the Commission to require "tamper-proofness" from certain CR/SDR:

- Security and integrity requirement (hindrance of inappropriate downloads): Ensuring that only compliant combinations of software and hardware come together and that the equipment only accepts authorized software [39, 40].[34]

Under this scheme the manufacturer can be obliged to make sure that only particular types of software (those registered—similarly to an AppStore) would be obtainable [38].

An unmet demand concerned the ready availability of information which would notably assist market surveillance authorities in order to determine the respective responsibilities of persons brought in association with an non-compliant CR/SDR equipment:

- Traceability requirement: Histories of (i) software changes/versions and (ii) reconfigurations (logs) [39].

Harmonised Standards

It is reminded that the simplest way for manufacturers to prove compliance is to apply a harmonised standard, if available.[35] Harmonised EN Standards define one

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[33] As seen previously, difficulties may also occur when several versions of firmware exist, some of which causing the equipment to contravene with an essential requirement.

[34] See [33], drafts of Article 3(3)(g) and considering (17): "The user, the radio equipment or a third party should only be able to load software into the radio equipment where this does not compromise the subsequent compliance of the radio equipment with the applicable essential requirements.".

[35] Although manufacturers always have the choice of involving a notified body, they may self-certify against the relevant harmonised standards that references complete test suites and make an EU Declaration of Conformity: harmonised standards give a presumption of conformity with the R&TTE Directive for the equipment to be placed on the market in the EU.

of the possible technical specifications as the one where, if complied with, a device certainly meets an essential requirement of the R&TTE Directive.

But standardisation of efficient spectral utilisation[36] by CR/SDR will be addressed by European standardisation bodies[37] gradually. For example, the European Commission has only recently mandated ETSI to produce a harmonised standard on reconfigurable radio systems [41]. The mandate's most tangible part addresses white space devices operating in the UHF TV band and getting access to spectrum through a geo-location database.[38]

"Harmonising essential requirements and making them mandatory by directives is appropriate only where (…) a wide range of products [is] sufficiently homogenous, or a horizontal hazard identifiable, to allow common essential requirements. The product area or hazard concerned must also be suitable for standardisation" [34]. Furthermore, once the specifications are drafted, it must also be ensured that most of the specifications of test procedure aiming at ensuring the compliance of CR/SDR devices should be included in the harmonised standard ("Essential Radio Test Suite") [42].

When moving from the research and development phase to commercial deployment, the lack of harmonised standards which complicates the placement of innovative products on the market and the unavailability of suitable spectrum allocations and associated conditions of use creates legal uncertainty. This can deter potential investors in technology [43]. Thus, the R&TTE Directive appears to be less suited to allow the placing on the market of products based on fundamentally new radio technologies not yet covered by harmonised standards. Indeed, in the absence of harmonised standards, the manufacturer has to consult a notified body for placing a product on the market. For both of them there is no certainty when attempting to establish under these circumstances the conformity of radio equipment with the essential requirements of the R&TTE Directive [44]. Another obstacle in the standardisation process for innovative technologies is that ETSI's work is more accessible to larger market players. Small and medium enterprises (SMEs) and societal stakeholders are underrepresented in the European standardisation process [45].

Nevertheless, the future may bring interesting developments in favour of CR/SDR as the Commission has plans to allow references in public procurement of ICT to ICT

[36] For example harmonised standards dealing with spectrum access of one type of proto-CR/SDR should include specifications for the exchange of information between a devices and a database, ensuring that the devices will be connected with the relevant database, on the geo-location systems, on the need for the devices to obtain the authorisation to emit from the database.

[37] Though it is admitted that Harmonized Standards (HS) for Cognitive Radio are being developed by ETSI. For an overview of the ETSI Technical Committees and their responsibilities relevant to CR/SDR.

[38] Actually, the master–slave model with geolocation database as described in the mandate is at best a rudimentary type of CR/SDR system with a network-centric "intelligence": it rather is a network with a basic automated frequency assignment method.

standards developed by other standards development organisations than European Standardisation Organisations, provided that these standards comply with quality criteria [45].

5.5.3.2 Administrative Requirements

The prime issue is the presumption of conformity associated with the CE mark and the declarations of conformity. The CE mark is placed on a radiocommunication apparatus by the manufacturer after its conformity has been assessed. In the case of CR/SDR, software patch may be loaded into the radio equipment that compromises the radio equipment's subsequent compliance with the applicable essential requirements. Under these circumstances, is it still fair that the manufacturer (who has affixed the CE mark and underwritten the declaration of conformity at the origin) is held responsible for any non-conformity, as prescribed by one of guiding principles of the R&TTE Directive?

The discussions about the applicability of the R&TTE Directive to dematerialised "components" of radiocommunication equipment like software (especially if it would be programmed by another entity then the integrator manufacturing the equipment) are also intricate. This is especially true for the application of administrative requirements like marking and user information,[39] whose application to over-the-air reconfiguring software opens up many regulatory questions. Another captivating question is whether every combination of hardware and software will need to undergo conformity assessment. Or would authorities be tempted to distinguish between routine updates and more substantial software updates?

The current Directive, however, was not written with software in mind. It may therefore have to be clarified in future how objectives like traceability, marking and user information are to be achieved for software should it be subject to these requirements [46]. As far as CR/SDR is concerned, it is likely that with respect to a number of administrative requirements, market surveillance authorities will have to demonstrate some flexibility. In particular, it is doubtful whether compliance with administrative regulations of software "components" of reconfigurable systems at all times and under all circumstances would be straightforward.

It is worth drawing the readership's attention on the fact that it is likely that the Radio Equipment Directive will compel CR/SDR manufacturers or software developers to make available information on the compliance of intended combinations of radio equipment and software in order to facilitate competition and provision of software by independent parties.[40]

[39] Respectively Articles 12 and 6(3) of the R&TTE Directive.

[40] See [33], drafts of Article 4 and considering (19).

5.5.3.3 Responsibility Ascription

Where more than one manufacturer produces components, each of them can assume responsibility for its own component according to the R&TTE Directive.[41] The company that integrates these components into an equipment will warrant that the new product is also compliant with the requirements of the R&TTE Directive. Often, it may not be practical to perform a assessment of the requirements on the module alone and a complete assessment only takes place after integration.

Today most SDR implementations remain under the control of a single manufacturer. Many base stations and handsets include already proto-SDR technology and some operating parameters are implemented in software. Yet, the hardware and the related software are typically highly optimized. Sometimes the upgrade of the software accommodating different standards may actually not be foreseen. A third party would hardly be in a position to tamper with this software.

What is at stake is to establish responsibilities if the hardware-software combinations do not adhere to the regulation (due to whatever cause[42]). The R&TTE Directive, which assumes that a single legal entity designs the equipment and ensures its compliance once and for all,[43] is not well adapted to address the flexibility where equipment can be reconfigured during operations by users and/or an entity other than the initial manufacturer [43]. It was not drafted with software in mind (Fig. 5.9).

Market surveillance authorities have an interest in rules clearly ascribing responsibilities in the case of non-compliance. The question for them is how to materialise this desire with regard to wireless systems dynamically reconfiguring and upgrading purely by software means. At present the approach where the combination of hard- and software that are produced by different legal entities implies that each legal entity is responsible for its own product is rather rejected.

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[41] ETSI has produced Guides to the application of harmonized standards to multi-radio and combined radio and non-radio equipment: ETSI TR 102 070-1 *Electromagnetic Compatibility* and ETSI TR 102 070-2 *Effective use of the radio frequency spectrum*.

[42] The lurking complexity can be visualised by means of a very few examples: (a) A user deliberately downloads reconfiguration software in defiance of the use intended by the software programmers and/or the hardware manufacturers; (b) Several third party software applications run in parallel on a hardware platform, creating thus a multitude of combinations which could cause non-compliant behaviour of the radiocommunication equipment; (c) In case of concomitance of several software versions, which software version (the latest?) is used for compliance assessment; (4) Availability of older firmware abiding by specifications of outdated versions of a harmonised standard but no longer compliant with the essential requirements.

[43] According to the R&TTE Directive, manufacturers have the sole and full responsibility (sometimes taken over by the importer) of ensuring through testing that their products are compliant to the applicable directives. The liability of the manufacturer (or the importer) hinges on the CE mark and on the declaration of conformity: the responsibility for an equipment is assigned to the entity affixing the CE mark—who's also the "declarer".

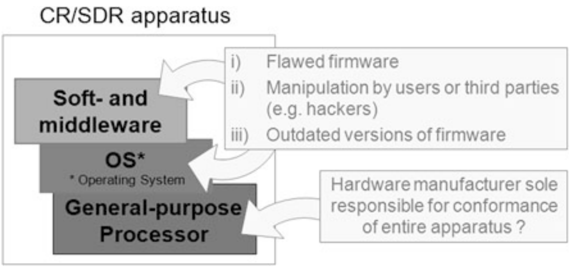

Fig. 5.9 Issues arising from reconfigurability having an impact on responsibility ascription

A rule where the person who puts a product into service must assume the responsibilities instead of the manufacturer (compliance with the requirements and accomplishment of the conformity assessment) would only be workable with professionals. For example, nowadays the system integrator for fixed link systems assembled on-site is responsible for ensuring compliance of the system with the Directive when the system is brought into service. The same applies for products manufactured for own use. In the case of mass-market pieces of equipment the users usually do not know—and can mostly not know—the technical specifications and internal operation/design of their device. They cannot determine whether their actions lead to R&TTE incompliant situations. Moreover, such users cannot be expected to have access to or utilise test equipment to assess conformity of their device.

Presently, apparatus which at the time of supply has provision for later user-added components that fall under the R&TTE Directive but are otherwise not covered by the Directive (e.g., computers without an integral modem and/or wireless capability) should not be marked according to the Directive. One can very well imagine programmable CR/SDR devices where the hardware is not specific to any particular radio technology: amongst other things a software would be needed to create a radiocommunication equipment [47]. Under the current interpretation of the R&TTE Directive this piece of hardware would not have to abide by the compliance provisions of the directive.

Another potential evolution is associated with Open-source software (OSS)[44] developers working in the wireless space and not affiliated with device manufacturers. These developers are already at work now [48]. It is feared by market surveillance authorities that user-modifiable code (which is a subset of OSS) will make it difficult to identify the "author(s)" of a non-conform product (software) and to establish when modifications of software leading to an irregular situation were made.

[44] Open-source software (OSS) is computer software that (i) is available in source code form and where (ii) the provision of the source code occurs under a "public" software license. This means there is a freedom to run the program, for any purpose and a freedom to study how the program works, modify it, and release the improvements to the public.

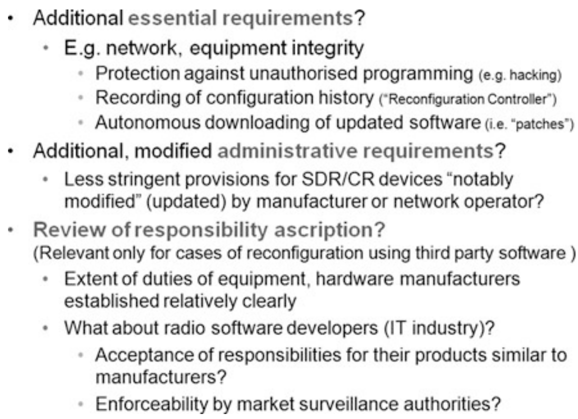

Fig. 5.10 Key points for certain categories of CR/SDR under the current regime of the R&TTE Directive

5.5.4 Outlook

It emerges from the above discussion that the R&TTE Directive in its present-day form is challenged primarily by CR/SDR with very specific features ("uncontrolled autonomously reconfigurable") (Fig. 5.10).

CR/SDR with such features could become a possible far-reaching problem at earliest in the medium-term. The challenges foreseen in this contribution for market access and compliance regulation in Europe are currently mostly theoretical in nature. In particular, the border cases identified would prove critical only if a market for user-reconfigurable devices starts to form.

Some emerging problems are tackled in the proposal for the Radio Equipment Directive. Yet it would be inefficient and ineffective to anticipate already now in detail any imaginable issue (e.g., rogue software loaded on mass market consumer equipment) that might arise when CR/SDR becomes pervasive.

Consequently, the most reasonable approach under the present circumstances is to maintain the present-day responsibility-ascription scheme also for CR/SDR products. The future structure of the market deploying CR/SDR may require adjustments but there is no urgency to modify this scheme in anticipation. Furthermore, for the time being it is realistic to command that CR/SDR meet the essential requirements under all circumstances.

Finally, the future will also show whether European standardisation organisations, and in particular ETSI, manage to draw up harmonised standards which aim at ensuring that CR/SDR meet essential requirements set out in mandates of the European Commission. Will SMEs and academia participate actively in and provide their innovative technology solutions to these standardisation efforts?

Acknowledgments My gratitude goes to Mr Lucio Cocciantelli, Head of Market Surveillance at OFCOM, for his valuable insights. However, any errors remain the sole responsibility of the author.

5.6 Helping Innovation of CR

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5.6.1 Introduction

This section analyses possible reasons of rather sluggish pace of CR innovation with the aim of suggesting a range of suitable policies to boost further and more fertile developments of CR technology.

Thanks to its advanced features of environmental awareness and, ultimately, propensity for autonomous decision making, CR represents a significant evolutionary step from traditional radiocommunications systems. The autonomous, cognitive re-configuration of CR opens up opportunities for new business models in the wireless communications marketplace built on the novel utility profiles of CR, as was discussed in second chapter. Yet this also means that fledgling CR innovation must overcome significant technological and other challenges on its road to practical implementation. If not addressed properly and quickly, these challenges may fester and become “reverse salient” barriers [49] in the composition and functioning of an eco-system of CR innovation and thus restraining the impetus of CR development.

Therefore this section sets out to explore the technology-push and demand-pull processes [47] as applied to CR [50], and then tries to identify and discuss the barriers that may be stalling CR innovation and how they might be reduced or overcome.

5.6.2 CR Innovation: Technology-Push and Demand-Pull

In the context of modern wireless markets, it can be argued that CR represents an important new option that contributes to a variety of competing technological solutions. Therefore successful implementation of CR technologies should become a matter of heightened attention by regulators, who might need to address the situation in order to provide opportunities for CR to succeed. This attitude of “creating windows of opportunity for new radio services and applications”[45] is not something new, in fact the very same stance was quite often taken by regulators over past decades, whenever allocating spectrum to broad swath of untried

[45] This visionary expression is credited to Mr. Reiner Liebler of German regulatory agency for posts and telecommunications (RegTP, later BNetzA), at the time of his leadership of the CEPT’s Working Group Frequency Management, which he chaired between 1998 and 2003.

technologies and systems, many of which eventually flopped in the marketplace, such as e.g., Terrestrial Flight Telephony Systems[46] or quixotic Meteor Scatter Applications[47], to name but a few. In fact one could argue, that European regulators have witnessed so many technology innovation proposals that went awry, that they became increasingly reticent whenever asked to take bold decisions for promoting new types of wireless systems. However the CR technology is different in that it embodies not a specific system or technology, but rather a family of technologies, a new paradigm of wireless networking and innovation. Therefore of all proposals, this should really deserve a closer consideration as it might be laying foundation for new wave of unconstrained wireless innovation for the years to come.

The evolutionary perspective leads us to consider two complementary yet distinct strategic forces shaping the dynamics of innovation and impacting the transfer of technology from the research labs to the market. The first of these forces can be described as the "technology-push", which explains technology transfer as motivated by means. In this process, the sheer technological superiority of the innovation compared with traditional technologies dictates its broad acceptance by an industry. A second contributing force is characterized as a "demand-pull" or "market-pull", the intensity of a market proposition and a commercial promise of a new technology [47]. It may be hypothesized that the halting dynamics of CR innovation may be indicating some barriers that inhibit the workings of one or both of these forces.

The main impetus of the classical technology-push is built on the premise of the technological soundness and superiority of new innovative solutions compared with existing state-of-the-art technologies. Normally this requires a clearly formulated technological concept and an initial working prototype that can pass the elaborate testing of the market and convince stakeholders of the emergence of a new, dominant technological design [51, 52]. Such scenario, however, is made much more complicated in the case of CR due to the principal multi-dimensionality of this concept as a family of technologies and their inherent complexities, which are likely to require some phased implementation (see discussion on this in Sect. 2.8). So for the

[46] TFTS was allocated frequency bands 1670–1675 MHz/1800–1805 MHz by CEPT in 1997 (cf. ERC/DEC(97)08) and envisaged to provide voice communication to passengers on planes flying over the European continent. A great effort was put into establishing the system: from allocating necessary frequency bands to carrying out a meticulous planning of terrestrial base stations and their frequency assignments to provide suitable pan-European coverage for air traffic. However after brief period of limited deployment the system was deemed a fiasco and rolled down, the allocation of frequency bands was cancelled in 2003 (cf. ECC/DEC(03)03).

[47] The Meteor Scatter Application system was a land mobile system working in the range 30–50 MHz promoted by industry in 1990s with the aim of providing low bit-rate pan-European coverage for truck fleet management and similar applications, by using the phenomenon of (very weak) reflection of radio waves from ionised gas trails of microscopic meteorites that constantly bombard the Earth's atmosphere. The ultimate regulatory recommendation allowing the use of such systems was taken in CEPT in year 2000 (cf. ERC/REC(00)04), however practical implementation of such systems never took off.

development of CR technology, it can be suggested, and duly observed, that the technology-push may be happening along two paths.

The first path is an incremental process of wireless innovation by equipment vendors whereas CR-related technologies and use cases of various stripes are making their inroads into wireless marketplace. Characteristically, these innovations might not even be consciously associated to the "making of CR", as often happens in the CR application areas other than the DSA. Nevertheless, all these incremental innovations would eventually add up to creating the critical knowledge base that would propel the CR technology to the centre-stage of wireless innovation and provide it with the sense of maturity and status of de facto dominant industrial concept. At that moment the "paradigmatic" switch would occur toward the embracing new technology by means of industry consensus [51].

If looking at the situation today, one may observe that the process of incremental innovation does take place, as evidenced by attention to CR technology from existing wireless players. However, the traditional operators may be tempted to act with great caution to avoid disturbing the status quo. Therefore, it is likely that these operators would proceed in carefully measured steps to ensure that any realized technological gains are harnessed as part of the toolbox of existing wireless service offerings or through a carefully screened set of CR use cases that may be of interest to the incumbents [53].

The second path is through a standardization process in which the incumbent wireless stakeholders as well as CR proponents without current stakes in the wireless industry but wishing to enter the field, are pushing CR technology to the position of a recognized industry standard by means of standardization processes that involve formal Standards Development Organizations (SDO), such as IEEE or ETSI. It is important to note that the formal standardization process might be an effective avenue of technology-push toward gaining market recognition of the disruptive aspects of CR. However the interests of the different lobby groups, and then individual companies deeper down inside the respective camps, would often clash making the standardisation process lengthy, perilous and, sometimes, inconclusive.

This situation may be observed clearly in the case of CR. Standardization efforts were initiated in several SDOs, such as the IEEE Standards Committee DySPAN (former DySPAN-SC), IEEE 802, ETSI Technical Committee RRS, ITU-R and others. Of these, the IEEE SC DySPAN takes the most holistic approach. However, even there (or especially there because of the attempted wholeness of consideration), the standardization process is excruciatingly slow because it needs to reconcile technological advancement with business and policy considerations [54].

The market-pull of an innovative technology may be described as a gravitational force generated by market players that appreciate the commercialization prospects of the new technology. The question of a credible business case is of paramount importance when attempting to understand the gravitas of the market-pull.

So far the main focus of business forecasting in the field of CR was firmly concentrated on the application areas of DSA. A few early examples of CR technology road-mapping exercises [55, 56] highlight the potential for business propositions of CR in such scenarios. DSA should enable nearly instant access to radio spectrum usage gaps and transcending complex and cumbersome traditional administrative spectrum allocation procedures. This offers an attractive conceptual proposition for the many companies wishing to enter the fray of high-profile and profitable wireless businesses.

As regards the other application areas of CR family and noting their inevitable incremental implementation, they would seldom offer any distinctive business case in its own right, or significant changes to the primary business case of the wireless player. Therefore such incremental innovations would be relegated to the niche of process optimisation rather than generating their own commercial value. For example, the Self-Organised Networking solutions, which might be clearly attributed to be a sub-class of CR technologies, are making steady inroads into modern cellular mobile networks. Yet they do not change anything in the prime business model of the cellular operators and therefore do not command special attention other than being seen as yet another technological gimmick helping to deploy networks faster and manage them with lesser effort.

Alas, even the great promise of DSA has failed so far in generating the necessary commitment and investments sufficient to overcome the challenges of CR innovation. Other than the baffling complexity of implementation that deters the prospective interest, another reason for lacking attention might be indeed doubt in monetisation of whatever achievable DSA benefits [57].

5.6.3 Future Development Options

The previous analysis described a situation in which the innovative development of CR faces an uphill technological battle toward market recognition. This situation may lead to a standstill, described as a chicken-and-egg dilemma in which vendors wait for large operators to announce support for CR technology as an indication of sufficient volume potential, whereas the operators are reluctant to support new technology unless it is standardized and embraced by the manufacturers as a pre-requisite of acceptable pricing for mass-market devices [58].

This situation is suggestive of (market and government) failures to provide the necessary testing ground for the trial-and-error dynamics required for efficient evolutionary processes [59]. Thus, the next issue to consider could be the type of regulatory intervention that might be considered appropriate to facilitate the innovative process of CR.

The barriers in the CR innovation path prevent any substantial opportunity for CR to quickly push the market into a Schumpeterian cycle of destabilization and a subsequent innovation leap. Accordingly, governmental policy to clear that path seems crucial. Policy failure (or, in some cases, policy absenteeism) is as important as market failure [59].

Table 5.7 Regulatory policies to assist the innovative dynamics of CR development

Innovation force	Assistive regulatory policy examples	Implementation status
Technology-push	Promoting development of CR standards	Work of ETSI TC RRS and IEEE SC DySPAN
	License and technical conditions for spectrum access conducive to implementation/experimentation of CR technologies	e.g., new proposals of Pluralistic Licensing concept for licensed bands, or ISM-Advanced concept for unlicensed bands, see Chap. 7
	Allocating dedicated exclusive spectrum band as testing and development incubator for CR-enabled applications	New proposal
Market-pull	Technology-neutral liberal spectrum licensing (i.e., with right of change of radio service/application)	European WAPECS initiative
	Governmental support to chosen business applications of CR technologies	Development of ASA/LSA concepts and regulatory framework

So what kind of policies might help spurring technologically neutral CR innovation (because it is not yet clear, and probably will never become definitive, how the CR framework of technologies will look like), while avoiding earlier pitfalls of making over-confident bets on new wireless technological propositions?

With reference to previous discussion, it may be argued that CR innovation would be boosted if both the technology-push and the market-pull forces might be allowed to unleash their full potential and dynamics. Interestingly, it was previously already observed that the incremental innovation is more likely to respond to demand-pulls than technology-pushes, and non-incremental innovation is more responsive to technology-pushes [60]. This implies that, by providing unrestricted working of both forces, the CR eco-system would be able to develop in any imaginable way. In other words, the regulatory policies should be designed so as to establish those "windows of opportunity" through creation of some kind of conditions where CR innovation could flourish in a kind of controlled learning environments. Table 5.7 outlines a set of possible regulatory options that could help improving the innovative dynamics of CR.

All regulatory options mentioned in Table 5.7 contribute to creation of liberalised spectrum access conditions, which foster wireless innovation in general, and CR as the most prominent case of such wireless innovation.

It may be also noted that it is important to reduce the risk that CR testing may cause direct disturbances of existing markets. Therefore exiting incumbent users, traditional wireless systems, should be protected by either defining clear frequency boundaries, such as with proposed dedicated CR band, or establishing spectrum access rules that are conducive to CR deployment while ensuring the reasonable degree of protection to incumbents, such as with proposed Pluralistic Licensing scheme [61], for further discussion on this see Sect. 7.1.

Fig. 5.11 Working of CR innovation forces in liberal CR-friendly market

The ultimate aim of such policies should be to create certain "safe havens" where CR technology could evolve and mature in a kind of learning platform that provides the necessary freedom for experimentation. This would effectively remove the identified barriers and would allow more practical experience to be gathered in using this technology, as illustrated in Fig. 5.11 [50].

It is notable that many of the identified regulatory options are already being implemented or in the process of consideration. An example of more radical intervention, which was not yet seriously considered by regulators, would be allocating a designated band for CR-enabled wireless applications. On several earlier occasions providing dedicated frequency bands for innovative technologies has proven to be a wise choice that established the technological trajectory and provided the necessary regulatory certainty for innovating companies to concentrate their focus and investments [62]. Successful examples of aiding innovative ideas by allocating a designated frequency band include the allocation by the FCC of a spectrum for cellular telephony in 1970 that led to the first commercial deployment of a cellular system in 1983 by Bell Labs and the designation of the 2.4 GHz ISM band for spread spectrum technologies in 1985 that paved the way for widespread WiFi systems.

5.6.3.1 Conclusions

The process of CR innovation is slowly progressing within a complex environment shaped by the combined workings of technology-push and market-pull forces. However, these forces are being stifled by reverse salient barriers that inhibit the development and dissemination of CR technologies and applications.

The provided analysis supports the notion that an effective means of overcoming these extant barriers and revitalizing the innovation process for CR technologies could be for governments to provide some kinds of "windows of opportunity" for CR technologies, i.e., certain spectrum access conditions conducive to deployment of CR or outright safe heavens, such as dedicated licensed or unlicensed frequency bands where CR technologies could mature through repetitive learning cycles of trials and errors.

Providing the CR innovation community with an open and unrestrained testing grounds would represent a plausible solution for effectively removing the identified innovation barriers: "Governments can […] encourage innovation in two ways: they can implement measures that reduce the private cost of producing innovation, technology-push, and they can implement measures that increase the private payoff to successful innovation, demand-pull" [47].

This is not to suggest a mere "engineering" approach to CR innovation, where CR will be able to flourish and be adopted widely as soon as some spectrum will be made available to experiment with CR. Technology-push has been crucial, but demand-pull issues are also relevant. Barriers on both sides need to be reduced to capture the effective essence of CR. Therefore, regulatory intervention seems appropriate to provide conditions for finding out whether stalling CR innovation is due to barriers on the technology-push side, or rather on the demand-pull side. In the end, it might be found that CR is not as beneficial (nor disruptive) as a decade of research has tried to suggest—but at least there will have come a time when innovators should not bother with CR anymore, as trials might prove they have been erring.

5.7 CR Policy Analysis: "Agreement Framework" and its Implementation

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5.7.1 Policy Issues

This section will propose a method for structured representation and analysis of CR policies, by considering regulation of White Space Devices (WSD) as a representative example discussed in the first chapter. The aim of the proposed methodology would be to create a general framework for aiding an assessment of existing and future CR policies. Such framework would be especially useful as basis for organizing productive debate around any contemplated regulatory changes.

We adopt the methodology of positive and normative policy analyses elaborated in [63] with regard to environmental policy. The viewpoint of positive analysis allows focusing on how things stand with regard to CR, as well as on how CR systems are described and modeled. The normative analysis offers focus on how things should be, in order to implement meaningful CR policy, according to a few (explicit) value judgments on critical aspects. Drawing a clear-cut line between positive and normative analyses is normally not possible. Robert and Zeckhauser recall that "any normative or prescriptive analysis necessarily includes positive analysis, plus values" [63]. They also propose a few key elements of positive and normative analyses, which can be seen as the fundamental ones for policy discussion: "Any positive analysis will tend to include elements of scope, model and estimation, though often these elements are either implicit of undifferentiated. Likewise, normative analysis will additionally include elements of standing, criteria and weights, whether or not these distinctions are recognized" [63].

5.7.2 Positive CR Policy Analysis

As a general observation, CR policy falls in the area of wireless communications business. Hence, discussion is immediately placed within the context of using a valuable natural resource (i.e., radio spectrum). Today CR technology seems reaching its maturity, but it has not yet crossed the commercial deployment milestone. However, solid evidence of maturity can be derived from the recent increase in the number of pilots (such as pilots using white space in the and the UK) and appearance of new cases and applications, most notably the LSA[48] concept.

Based on this premise, we outline some criterions that, on one hand, describe technology maturity, and, on the other hand, establish an applicable time horizon for our analysis. Generally speaking, technology can be considered mature when real-life field pilots (test deployments) are taking place, and business proposition looks promising, i.e., cost-benefit analyses support the case either for-profit or non-profit deployment.

As regards time horizon, it is proposed to consider a short-to-medium time frame, some 3–5 years. This would correspond rather well with the usual cycle of regulatory policy developments (i.e., time usually elapsing from novel regulatory proposals to effective legislation being in place).

With those criterions in mind, we elaborate on the "taxonomy of disagreement" and the three elements of positive analysis [63]—i.e., scope, model and estimates—which we apply to the case study of WSD policies.

Building on the taxonomy of disagreement, potential disagreement areas will be outlined, as pertaining to a particular consideration aspect. However, it should be noted that this does not presume that disagreement shall be always present. To the contrary, such taxonomy may just provide a helpful check-list of issues, where the agreement could be thought by different stakeholders when developing new policy, thus building ground for well-informed and compromise-driven decision making process.

5.7.2.1 Scope of Application

In the case of policy analysis of WSD applications, the scope of analysis can be narrowed with regard to sector/area, therefore considering the wireless (mobile) data market segment, predominantly in city areas with high population and business user densities—i.e., where the demand for mobile services is highest and puts great pressure on mobile network resources.

Primary stakeholders in such case can be grouped as follows:

- mobile operators, who are interested in offloading the excess data capacity overloads from their Wide Area Networks (3G/4G);

[48] That is, Licensed Shared Access, see Sect. 2.6.

- mobile network users, who are interested in getting higher data throughputs (and, probably, reduced or zero fees) at their dominant “hang-out” spots (such as home or office);
- equipment vendors.

So when analyzing the scope, one could consider where the *potential disagreement* areas might emerge. For instance, disagreement might be on the most appropriate level of decision and policy making (i.e., global, regional or national level?). Also, there might be different views on the list of stakeholders involved. The degree of disaggregation might bring to a clash those who favor application-tailored policies against those who favor CR generic policy. Last but not least, strategic considerations might be relevant: for instance, what is the role of CR as possible catalyst of wireless innovation and enabler of new paradigms of spectrum management?

5.7.2.2 Model of Policy Relationships

We identify the following institutional actors in modeling the CR policy interaction area:

- the National Regulatory Authority (NRA), i.e., the governmental agency/department dealing with radio spectrum management;
- geolocation database (GDB) operator(s), or in more general sense—spectrum broker(s);
- telecommunication service providers;
- end users;
- equipment vendors.

The general routes for policy impact may be depicted as shown in Fig. 5.12. Note that large arrows indicate strong policy impact connections, while line-arrows indicate weak impact connections.

For instance, the NRA has strong policy impact on operation of spectrum broker(s) and service providers through issuing of spectrum access rules (incl. GDB operation rules as relevant). It has somewhat lesser impact on equipment vendors/manufacturers (e.g., through endorsing specific standards or type approval norms) and end users (e.g., in cases of market interventionary measures such as service price control, or licensing process conditions).

With regard to CR policy model, *potential disagreement* areas might involve, for instance, the following considerations:

- Should the GDBs be only facilitators of opportunistic access?
- Are the links among stakeholders appropriate?
- Is uncertainty taken into account? If yes, how? For instance, although policy provisions for CR are provided, it is possible that the technology does not progress into the commercial deployment phase.

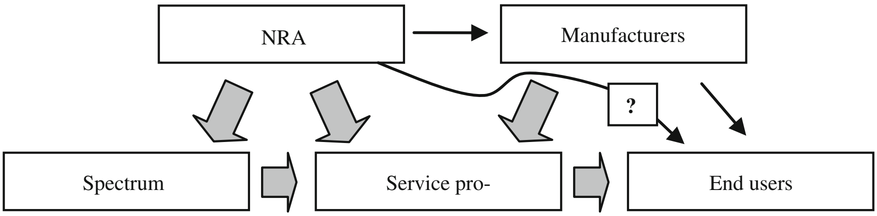

Fig. 5.12 The policy relations model for CR deployment (in TVWS)

5.7.2.3 Estimates

This part of policy analysis is concerned with estimates of model parameters—e.g., (comparative) indication of strength/extent of those identified policy impact links (cf. Fig. 5.12). Although CR has been discussed for years, there is still little work on estimation of model parameters. Quantitative research, applied to CR, is still limited, especially if one considers that CR is still almost confined to laboratories. It may be of great relevance, for CR implementation, to illustrate the business impact of considered cases in a quantitative manner, based on thorough cost-benefit analyses. Calculations of CAPEX, OPEX, turnovers, GDP impact, etc. could enrich qualitative analysis and provide solid grounds for policy making.

With regard to estimates, *potential disagreement* areas might involve, for instance: (i) valuation of the (economic) impact on the constituents of a proposed model; (ii) estimation and quantification of model parameters; (iii) uncertainty (e.g., relevance of the pace of learning).

5.7.3 Normative CR Policy Analysis

The framework that we propose for normative CR policy analysis focuses on three elements: namely, standing—i.e., who counts?; criteria—i.e., what counts?; and weights—i.e., by how much?

Implementation of CR devices is not expected to radically change the configuration of stakeholder groups and, in general, the approach used for normative policy valuations. However, we consider that CR will—and, perhaps, should—have an impact on the relative strength of stakeholders, as well as on what counts (and by how much). Consumers and traditional business operators will not disappear from the list of major stakeholders. However, the most innovative business operators and flexible (ready-to-adapt) consumer groups should receive more consideration—and weight—from a normative perspective. At the same time, while innovation and consumer welfare growth should remain crucial criteria for assessment, issues of spectrum efficiency, QoS, innovation and investment are likely to become even more complex and valuable than in the past.

Development and successful implementation of CR devices may have a considerable impact on the current wireless ecosystem and its associated spectrum management regime. Traditionally, regulation and policy have been, to a large extent, network-centric and most of commercial wireless systems have developed around networks. However, a more CR-friendly spectrum management regime might enhance developments toward more device-centric (self) regulation and policy. Indeed, CR is likely to deliver its promises to an extent which critically depends on the ability of the wireless environment to dynamically change and adapt to new conditions in the realm of technology, policy and economic welfare.

In this subsection we propose an application of the framework for normative positive analysis to the case of WSDs. We will consider, in turn, the three elements of normative analysis [63] and we will also attempt to figure out, with regard to each element, areas of potential disagreement.

5.7.3.1 Standing

In the analysis of standing, three groups of stakeholders can (and—we believe—should) be seen as the major ones: operators; equipment vendors; and mobile device users.

It may be noted that large traditional operators were initially skeptical towards new CR technologies: CR was considered potentially disruptive to their business, as it would allow breaking their oligopoly on providing of wireless data services. However, the emergence of traffic off-loading concept—which could make good use of white spaces—might be changing their stance, by offering mobile operators some tangible business gains. Another potential advantage for mobile operators may be found in leveraging the joint benefits of WSD in TV bands with the use of the LSA solutions in the higher frequency bands (see the discussion of that concept in Sect. 2.5).

As regards the equipment vendors, in the short-to-medium term most of the large ones will be focusing their attention on roll-out of LTE technologies, and the complete overhaul/modernization of cellular networks that is often associated with introduction of LTE.[49] Hence any entries into the new and technologically challenging WSD niche could mostly be anticipated from small vendors seeking entry into the market.

Mobile users *per se* are not likely to care much about technology development, as they seem to be already spoilt by burgeoning supply of telecom/data services in various forms, especially in cities where the use of WSDs would be a very critical option due to spectrum overload. However, CR policy should consider the impact of technological change on mobile users' welfare, taking into account impacts on operators' as well as on equipment vendors' markets.

Potential disagreement areas with regard to standing might concern the role of licensing as guarantee of spectrum quality, and the use of GDB platforms as universal spectrum broker (including the extension of their scope across various bands, i.e., beyond TV bands).

[49] LTE represents a paradigmatic shift to an "all-IP" solution compared against the circuit-switched paradigm of previous 2G/3G network designs. Therefore it makes sense for operators to combine introduction of LTE with converting the rest of their network core to a new IP-based platform.

5.7.3.2 Criteria

In the context of this section, we are looking at the market domain through the prism of the service providers' business proposition to the end user. The underlying problem is that so far there is still no visible or obvious commercial benefit from exploiting the WSD, as compared with other already existing wireless data communication solutions—be it 3G/4G or Wi-Fi. The off-loading of traffic from the macro-network to small cells is, essentially, a pure internal technological efficacy improvement by operators, which does not directly translate into offering innovative/value added service to end users. Any (marginal) benefit of small cells (e.g., by bringing in more paying customers through more competitive payment plans with "home zones" with low or zero tariffs) could be achieved by using femto-cells of the same technology/frequency band as used in the macro network.

This means that we are excluding from the analysis various market players that the service provision segment could be made of. Such simplification is warranted because the future structure and revenue sharing models of service provision in the field of CR are not yet clear (and may take various complex forms, as discussed, e.g., in [64, 65]). In other words, that is one relevant area of *potential disagreement* as regards criteria. Disagreement about criteria may also concern, for instance, interference potential to incumbent users, in terms of interference to TV reception and interference to co-secondary users (such as users of wireless microphones).

5.7.3.3 Weights

The matter of respective weights may be considered through direct extension of the above debate on criteria. Thus we may move on to direct consideration of *potential disagreement* areas as regards weights, that is, by how much or to what degree the identified criteria should count. One such area might concern the relative importance and pervasiveness of the incumbent users, i.e., the primary users that need to be protected by WSD operation, say for TV bands:

- What is the proportion of households that still rely on over-the-air TV reception, as opposed to cable TV, IPTV, or satellite TV reception? (This question would have an obvious national context, as the situation will be different in each country.);
- How many of wireless microphones are there, and what should be the proportionate level of their protection?

5.7.3.4 Conclusions

The analysis carried out in this section is an attempt to build a structured policy consideration framework in the discussion of the future of CR. It is also an attempt to highlight considerations of "values" and to delineate areas where agreements

Table 5.8 The "agreement framework" for building and analyzing CR policies: WSD example

Positive analysis: Scope
• global, regional, or national level of CR policy most appropriate?
• degree of policy detail: application-tailored policies, or CR-generic policies?
• strategic considerations: i.e., the role of CR as catalyst of innovation and new spectrum management paradigm?
Positive analysis: model
• role of GDB as the only (prime) facilitator of opportunistic access?
• what links inside the model and their respective strength?
accounting for uncertainty: e.g., policy provisions for CR are provided, but technology does not progress to commercial phase
Positive analysis: estimate
• quantification and valuation of model parameters
• quantifying and valuing (economic) impact on the constituents of the model
• uncertainty parameters, including the pace of technological evolution
Values analysis: standing of stakeholders
• role and scope of licensing
• role/value of GDB platforms as universal spectrum broker across various bands (i.e., beyond TV bands)
Values analysis: criteria
• extent of market impact
• realistic interference potential to incumbent users:
–interference to TV reception
–interference to co-secondary users: wireless microphones
Values analysis: weights
• relative importance and pervasiveness of the incumbent users:
–proportion of remaining over-the-air TV users
–extent of the wireless microphone use, proportional level of their protection

should be thought in order to avoid conflicts. With this attitude in mind we propose building the "framework for policy agreement", as depicted in Table 5.8.

Note that here we take a more positive (non-conflicting) stance as compared to the approach of building the "taxonomy of disagreement" by [63]. We believe that positive attitude is appropriate for the case of CR policy discourse: we largely deal with the green-field situation where differences in opinions and values, held by the concerned stakeholders, are not yet deeply ingrained nor prominent.

To conclude, the above described framework of agreement may be used as reference template against which future normative policy analysis could be carried out in similar cases, with regard to emerging CR applications and CR technology in general. This kind of analysis may be also useful as part of the bigger picture concerned with spectrum management (i.e., the debate whether CR should be reflected as a salient entity in the ITU Radio Regulations and similar normative acts).

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