An Analysis of Regulatory Frameworks for Wireless Communications, Societal Concerns and Risk:

The Case of Radio Frequency (RF) Allocation and Licensing

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ABSTRACT

This thesis analyses how and why culture and geography influence the allocation and licensing of the radio frequency (RF) spectrum in different nations. Based on a broad study of 235 countries, an inter-disciplinary approach is used to explore regulatory frameworks and attitudes toward risk. In addition, detailed case studies of the UK, France, the US and Ecuador provide deeper insights into the main contrasting regulatory styles.

Three alternative sociological theories are used to analyse and explain the results for both the in-depth and broad brush studies. The Cultural Theory of Mary Douglas and co-workers is first used to categorise countries in terms of perceptual filters. The empirical findings indicate some countries to be apparently exceptional in their behaviour. The theory of Bounded Rationality is used to investigate and explain these apparent irrationalities. Finally, Rational Field Theory shows how beliefs and values guide administrations in their RF regulation.

A number of key factors are found to dominate and patterns emerge. The European RF harmonisation is unique. Following European unification, wireless regulation is divided into two major camps (the EU and the US), which differ in their risk concerns, approach to top-down mandated standards, allocation of RF spectrum to licence-exempt bands and type approval process. The adoption of cellular and TV standards around the world reflects geopolitical and colonial influence. The language of a country is a significant indicator of its analogue TV standard. Interestingly, the longitude of a country to a fair extent defines RF allocation: Africa and West Asia follow Europe, whereas the Americas approximate the US. RF regulation and risk tolerability differ between tropical and non-tropical climates. The collectivised/centralised versus the individualised/market-based rationalities result in different regulatory frameworks and contrasting societal and risk concerns. The success of the top-down European GSM and the bottom-up Wi-Fi standards reveal how the central-planning and market-based approaches have thrived. Attitudes to RF human hazards and spurious emissions levels reveal that the US, Canada and Japan are more tolerant of these risks than Europe. Australia, Canada, New Zealand, UK and USA encourage technological innovation.

A practical benefit of this study is that it will give regulators more freedom to choose a rational RF licensing protocol, by better understanding the possibly self-imposed boundaries of cultural and geographical factors which are currently shaping allocation. Academically, there is utility in undertaking a cultural and geographic analysis of a topic that is mostly the domain of engineering, economic and legal analysts.

Contents

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Abbreviations

3G	Third Generation
3GPP	Third Generation Partnership Project
ALARP	As Low As Reasonably Practicable
ANFR	*Agence Nationale des Fréquences*
ANSI	American National Standards Institute
APT	Asia Pacific Telecommunity
ARIB	Association of Radio Industries and Businesses (Japan)
ATSC	Advanced Television Systems Committee (USA)
ATU	African Telecommunications Union
BR	Bounded Rationality
CAATEL	*Comite Andino de Autoridades de Telecomunicaciones* (South America)
CAN	*Comunidad Andina de Naciones* (South America)
CANTO	Caribbean Association of National Telecommunication Organisations
CAPTEF	*Conférence Administrative des Postes et Télécommunications des pays d'Expression Française*
CCIR	*Comité Consultatif International de la Radio* (the former name of ITU-R)
CDMA	Code Division Multiple Access
CEN	*Comité Européen de Normalisation*
CENELEC	*Comité Européen de Normalisation ELECtrotechnique*
CEPT	*Conférence Européenne des Administrations des Postes et des Télécommunications*
CFR	Code of Federal Regulations (USA)
CITEL	*Comisión Interamericana de TELecomunicaciones*

CPP	Calling Party Pays (contrary to cellular Receiving Party Pays, RPP)
CSN	*Comunidad Sudamericana de Naciones*
CT	Cultural Theory
CTO	Commonwealth Telecoms Organisation
dB	deciBel
DECT	Digital European Cordless Telecommunication System
DMB-T	Digital Multimedia Broadcasting – Terrestrial (China)
DVB-H	Digital Video Broadcasting – Handheld (Europe)
DVB-T	Digital Video Broadcasting – Terrestrial (Europe)
EBU	European Broadcasting Union
EC	European Community (subsequently also European Union, EU)
ECC	European Communications Committee
e-Communications	Electronic Communications
EDGE	Enhanced Data rates for Global Evolution
EEC	European Communities Commission
EFTA	European Free Trade Association
EMF	Electro Magnetic Fields
ERO	European Radiocommunications Office
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communications Commission (USA)
FM	Frequency Modulation
FRATEL	*reseau FRAncophone de la régulation des TÉLécommunication*
FTAA	Free Trade Area of the Americas
GDP	Gross Domestic Product
GE89	Regional Agreement for the African TV Broadcasting Area (Geneva 1989)
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	*Groupe Spéciale Mobile;* Global System for Mobile communication
GSO	Geostationary Satellite Orbit
HDTV	High Definition TV
HF	High Frequency (3-30 MHz)
Hz	Hertz (the base unit of frequency)
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IFC	International Finance Corporation
IIRSA	Initiative for the Integration of South America region
IMF	International Monetary Fund
IMT-2000	International Mobile Telecommunications-2000 (ITU); termed IMT, following the 2007 Radio Assembly RA-07
ISDB-T	Integrated Services Digital Broadcasting- Terrestrial (Japan)
ISM	Industrial Scientific and Medical
ISO	Industrial Organisation for Standardisation
ITU	International Telecommunications Union
ITU-D	ITU- Development Sector
ITU-R	ITU- Radiocommunications Sector
ITU-T	ITU- Telecommunications Sector
LAFTA	Latin American Free Trade Association

LDC	Least Developed Countries
LE	Licence Exempt
MAC	Multiplexed Analogue Components
MERCOSUR	*Mercado Común del Sur* (South America)
NAFTA	North America Free Trade Agreement
NRA	National Regulatory Authority
NRPB	the former UK National Radiological Protection Board
NSO	National Standards Organisations
NTSC	National Television System Committee (USA)
OAS	Organisation of American States
OECD	Organisation for Economic Co-operation and Development
OFDM	Orthogonal Frequency-Division Multiplexing
PAL	Phase Alternation by Line (Germany and UK)
PLC	Power Line Communication
PTT	Postal, Telegraphic and Telecommunications
R&TTE	Radio equipment and Telecommunications Terminal Equipment (EC)
RCC	Regional Commonwealth in the field of Communication (former USSR)
RF	Radio Frequency
RFID	Radio Frequency IDentification
RFT	Rational Field Theory
RLAN	Radio Local Area Network
RMS	Root Mean Square
RR	Radio Regulations (of the ITU)
RRC-06	Regional Radio Conference 2006; also titled GE-06 and Geneva-06 Agreement
SAR	Specific Absorption Rate
SECAM	*SÉquentiel Couleur Avec Mémoire* (Sequential Colour with Memory) (France)
SRD	Short Range Devices
ST61	Regional Agreement for the European Broadcasting Area (Stockholm 1961) (ITU)
T-DAB	Terrestrial Digital Audio Broadcasting (CEPT)
TD-SCDMA	Time Division Synchronous Code Division Multiple Access (China)
TETRA	Trans European Trunked RAdio (ETSI)
TIA	Telecommunications Industry Association (USA)
UHF	Ultra High Frequency (300-3,000 MHz)
UMTS	Universal Mobile Telecommunications System (ETSI)
UWB	Ultra Wide Band
VHF	Very High Frequency (30-300 MHz)
WARC	World Administrative Radio Conference (ITU)
WB	World Bank
WHO	World Health Organization
Wi-Fi	Wireless Fidelity (IEEE)
WRC	World Radio Conference
WTA	Wireless Telegraphy Act
WTO	World Trade Organisation

Introduction

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1 Overview

Wireless rules indicate how a society functions and its decision-making processes; RF (Radio Frequency) thresholds reveal the national risk attitude. The research explains how choices are unnecessarily bound by culture; it contrasts rationalities and RF regulation in the European and American hemispheres. This research breaks new ground by correlating regulation with geography and colonial heritage. Technical wireless regulation is not usually perceived as related to culture, but the research highlights the links and correlations between the two. This dissertation presents 'multiple case studies' on selected countries, as well as a wider reference of all countries.

Suggesting a correlation and explaining the influence of the culture and geographical latitude on RF allocation and licensing is unique. *Cultural Theory*, *Bounded Rationality* and *Rational Field Theory* have never been used before in this context. For the first time research has been carried out to investigate the validity of these sociological theories within the regulatory framework of wireless communications; there is utility in doing so.

The three theories set out a framework for explaining social responses to risk, and the different decision makers' rationalities are highlighted. A comparison of *societal* and *risk concerns* contributes to the debate about the relative cautiousness of the US relative to Europe. This knowledge provides more freedom to regulators around the world in understanding their possibly self-imposed or externally-imposed boundaries and hence having opportunities to break out of them. The cultural and geographical dimensions in analysing RF allocation, licensing and adoption of standards have generally been neglected. The central thrust of the analysis is coming from cultural influences on RF allocation.

The research questions are:

1) *How* and *why* do culture and geography influence RF allocation and licensing?

2) To what extent do sociological theories of risk offer an explanation of the pattern of allocation of the RF spectrum, including licensing and issues of *risk tolerability*?

3) What are the different *rationalities* in RF allocation and licensing?

2 Methodology

2.1 What was Done: the Structure of the Chapters

This section describes how the research for this dissertation has been carried out and how sociological theories have been applied to *case studies* of RF allocation and licensing. This thesis explores 'how' and 'why' cultural and geographic attributes shape the regulation and standards of wireless communications; and the focus of the study is on the setting of standards and risk thresholds. Figure 2-1 'The structure of the research' depicts the logical flow of information and ideas, what was done, the integration between the chapters and the empirical and theoretical studies required for answering the research questions. This introductory chapter and the *Literature Review* (chapter 1) serve as groundwork for the empirical and theoretical studies; they introduce the methods and components of the research: *Introduction* presents the methodology, and the essential technical information on RF standards and emission limits; *Literature Review* appraises the current knowledge and primary reports on *regulatory frameworks*, *societal* and *risk concerns*, regulation and theoretical approaches. The empirical survey begins (chapter 2) with *International and Regional Regulatory Frameworks*: the relevant rules of the intergovernmental organisation ITU (International Telecommunications Union), the supranational Europe as represented by the EU[1], international South America and *CAN* (*Comunidad Andina de Naciones*) are explored; quantitative and qualitative data is offered; and the regional agencies are compared. Chapter 3 *Case Studies* proceeds down the regulatory hierarchy to national regulation and standards, looking at the impact of international and regional regulation on national RF standards; the chapter discusses the detailed *regulatory frameworks*, RF licensing and attitudes to risk in European countries (UK and France) and the Americas (the US and Ecuador); the *Case Studies* chapter compares the most influential powers in wireless industry (EU and the US), and the most influential standardisation institutions (European Telecommunications Standards Institute - ETSI and the US Federal Communications Commission - FCC). Chapters 2 and 3 essentially contrast Europe versus the US. The research comprises multiple *case studies* focusing on 'thick' specifics, followed by a 'thin' data collection of all countries. Chapter 4 *Indicators* expands to a comparative survey spanning the entire globe: a cross-national study of wireless regulation, standards and attitudes to risk; the *master-data* is an Appendix of *Indicators.* Chapters 2, 3 and 4 comprise the empirical study: the *regulatory frameworks*, patterns and varieties of wireless standards

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[1] "For convenience we refer to institutions of the European Union as 'EU' throughout, though strictly speaking most of the regulatory activity described falls within the narrower European Community jurisdiction" (Hood *et al.* 1999:162).

in the selected regions and countries and around the world; these chapters correlate the adoption of standards with geographic and cultural differences, compare the various agencies and explore national attitudes to risk.

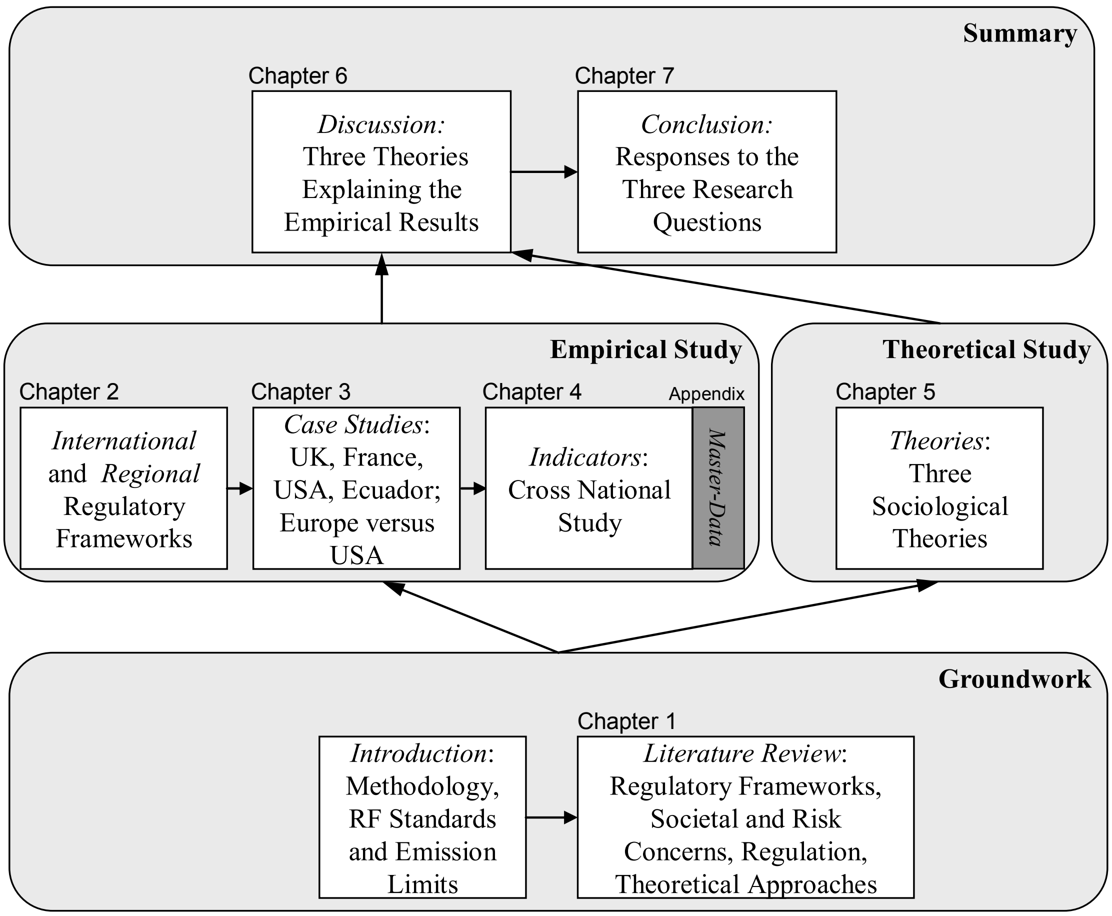

Figure 2-1 The structure of the research

Three contending theories categorise the regions and countries in terms of perceptual filters and distinguish them by *risk tolerability* and different styles of rationality: risk-averse versus risk-seeking and central-planning versus market-based. Chapter 5 *Theories* explores the three sociological theories. Chapters 6 *Discussion* and 7 *Conclusion* evaluate the findings and summarise the research. The empirical and theoretical studies (chapters 2 to 5) lead to chapter 6*; Discussion* explains and interprets systematically the results of the global, regional and national data using the three alternative theories. Chapter 7 *Conclusion* demonstrates the responses to the three research questions and concludes the study. The bibliography, list of external experts (Appendix A) and the *master-data* (Appendix B) are at the end of the thesis.

'Compare and contrast' tables and statistical figures illustrate the empirical data; world and regional maps highlight the findings and depict the exceptional countries (relative to neighbours); schematic models categorise countries and illuminate the discussions; professional templates classify the countries and present philosophical values.

2.2 How it is Done: Multiple *Case Studies*

The comparative method is often treated as a subsidiary version of statistical analysis, in which the important observations to be drawn from the cases are taken on the values of the dependent variable: in this thesis, RF standards and rules. The comparative method is a distinctive approach that offers a rich set of observations, comparing a theory's prediction about causal processes, and may force us to change our views in important ways (Mahoney and Ruesche 2003:411). This method in particular suits the study as it enables observations to be presented systematically, in order to analyse the data, to reach the conclusions and to justify them, using the theories.

The thesis comprises multiple *case studies* (see Robson 2002:183), which illuminate the RF regulatory patterns and exemplify the columns (explanatory and dependent variables) in the *master-data*: the empirical data of all countries. The multiple *case studies* focus on regional and national specifics: *regulatory framework*, *societal concerns* and risk attitudes. The *case studies* indicate detailed, intensive facts about regional agencies and four countries; their national RF allocation and licensing approaches illustrate the global data and help its generalisation and understanding. After examining the countries with a mainly Christian heritage (three developed and one tropical-developing) in Europe and America, the cross-national chapter *Indicators* provides a worldwide perspective to the *case studies*. The statistics illustrate how culture and geography influence RF allocation and licensing; they correlate geography and culture with RF standards, they reveal links between variables and provide significance to the results (the observed values); the statistics also indicate the exceptional countries.

2.3 *Case Studies*: Choice of Regions and States

This research refers to the regional and national *regulatory frameworks* employed as *multiple case studies*. The EU and *CAN* are the regional organisations; the US, UK, France and Ecuador are the selected national administrations.

The EU and the US were chosen because they are the dominant superpowers in e-Communications in the 21st century; their regulations and standards are the most widely-accepted around the world. UK and France have adopted opposite regulatory styles (market-based versus central-planning approach); they differ in their cultural attributes: language, religion and legal origin. There is a further interest in UK and France because of the additional EU *regulatory framework* that adds to (or departs from) their national regulatory approach. Throughout their history the US, UK and France have tried to spread their worldview (and gain more power); it seems that ex-colonies tend to preserve the culture bestowed upon them.

South America can be seen as representing the other continents (such as Africa and Asia) and *CAN* (Bolivia, Colombia, Ecuador and Peru) exemplifies other regional institutions. The relations of intergovernmental *CAN* and South America are compared to supranational EU and Europe. Ecuador is a typical example of a developing country; 134 countries are classed as developing, 49 are least developed and only 48 are developed countries; see the *master-data*[2]. Moreover, Ecuador and *CAN* countries are typical of tropical countries; most of the world: 130 out of 235 countries. The columns of the *master-data* show that Ecuador and *CAN* are near the media: the latitude of Ecuador is **2.0** degrees, the cellular percentage per inhabitant in 2003 is 18.3 %; the average (and standard deviation) values for Bolivia, Colombia, Ecuador and Peru are latitude **8.3** (6.8) degrees and cellular penetration 14.6 (3.1) %; 117 tropical countries (which updated their cellular statistics) are located in latitude **12.7** (6.9) degrees; their average cellular penetration is 19.3 (23.1) % .

2.4 Empirical Data Answers How Culture and Geography are influential

2.4.1 The Statistical Variables

The quantitative study includes an empirical survey of all countries. The study links cultural and geographic factors to RF regulation, and indicates the anomalous countries. The main variables of the *master-data* are geographical and cultural features, international membership, mains electricity (50/60 Hertz), colour TV standard adoption (NTSC, PAL or SECAM) and cellular (GSM, CDMA, UMTS and TETRA) operation. The explanatory variables serve to indicate the clusters of countries, to identify the anomalous countries and to compare *societal concerns* and risk tolerability. The dependent attributes for the research are the adoption of TV and cellular standards, the permitted levels of RF *human hazards* and RF *spurious emissions*.

– Over-the-air analogue TV (in the 20th century), digital TV, and cellular technologies (in the 21st century) are the leading RF services and the most significant wireless applications; therefore, they are repeatedly used throughout the research.

– The RF thresholds are used to compare the *societal* and *risk concerns*; these objective

[2] No data in all the thesis sources (ITU, World-bank UN and CIA), about the remaining 4 South Pacific islands: Christmas, Cocos (Keeling), Norfolk and Pitcairn; it exemplifies a difficulty in collecting data.

records attract much public interest (especially *human hazards*) and reveal the *risk tolerability* and the regulator's type of rationality.

The language, religion and legal origin of a country are elementary cultural attributes; these independent explanatory variables are not *sui generis*. The main independent geographical variables are the continent in which the country lies, and its latitude. The independent factors explain the dependent variables, in order to answer half of the first research question: **how** culture and geography influence RF licensing; for example how language guides the adoption of TV standards, and how latitude influences the cellular penetration rate and the RF *human hazards* limit.

2.4.2 Collection of Data

The author has ensured that the data for the quantitative analysis is as accurate and reliable as possible. The dependent variables are formal and official data provided by the 191 countries of the ITU, World Bank, World Health Organisation (WHO) and international telecommunications institutions. The study is comparative; in order to apply an objective comparison, one main source is used for any variable (e.g. cellular penetration) and other sources are used to recheck the data; see the sources in table 7-2 in the *Indicators* chapter. The study uses original data; the records describing the *regulatory frameworks* and the *master-data* are primary data; they are derived from basic sources: official data originated by administrations and institutions. High-ranking officials (in the ITU, CEPT, Ofcom, ANFR, FCC, NTIA, SUPTEL) and worldwide RF decision-makers and colleagues (national RF spectrum managers), who are acquainted with the author provided new primary data, orally and by electronic correspondence. Moreover, the author interviewed (during the 2006 Anatolia ITU-Plenipotentiary) two telecommunications Ministers (Brazil and South Korea) to understand their decisions on adopting the digital TV standard. Secondary data is used to compare the findings with other researchers; e.g. the work of Paik with others (2002) on 'strategies of wireless service using the license exempt RF bands'.

The main difficulty encountered in the collection of data was completing the data for all countries; many countries (generally the least developed countries, some developing countries or non-sovereign countries) do not provide information on their RF factors (e.g. TV standard and cellular penetration). Therefore, the author searched all available sources: public domain publications and regulators around the world; the data of most countries is included in Appendix B *master-data*, so the level of missing data is insignificant to the results. Some information is fluid: many countries that operated SECAM in the past are now changing to PAL standard; the first decision for analogue TV is used in the *master-data* and the statistics. Regarding new wireless technologies (such as third generation ‘3G’ cellular and Digital TV standards), many countries remain undecided as to which standard to use; the data represents a “snapshot” as of 9 January 2008.

2.4.3 Multiple Observers

The author benefited from colleagues' assistance; international experts were asked to look at small sections of the thesis and were invited to comment on data and ideas. These ‘multiple observers’ provided important information, assured the accuracy of the data and the accumulation of worldwide knowledge and experience; the multiple observers serve to bridge the practitioner's and academic knowledge. Appendix A specifies the external experts.

2.5 Three Sociological Theories Explain Different Rationalities

2.5.1 Choice of Theories

To explore RF allocation and regulating uncertain risks three sociological theories are used. *Cultural Theory* is the obvious choice to explain why culture influences RF allocation and licensing; it has been widely used to analyse *societal* and *risk concerns*, with considerable success. *Bounded Rationality* is chosen as it can also analyse attitudes to risk; *Bounded Rationality* is most suitable to explain the apparent irrationalities and the exceptional findings. With respect to *Rational Field Theory*, this is an emerging approach which so far has been applied mainly in the health sector, but which has useful attributes for the purpose in question; as philosophical beliefs, desires, worldviews, ethics and values influence the regulatory policy, they are included through the *Rational Field Theory*, to make the research more meaningful. So, all three theories shed useful insights and are hence successful in that sense. This in fact fulfils the second half of the first research question and the second research question.

2.5.2 Interdisciplinary and Multi-Rationality Approach

The theories are used to explore the empirical findings through diverse cultural prisms. The different perceptual filters, the bounds of rationality and regulators' beliefs illuminate decisions in ruling, adopting wireless standards and regulating uncertain risks. Plurality of rationalities are analysed; interdisciplinary perspectives cover a wider range of considerations. Because of its centrality, risk is of interest to many disciplines: scientists, engineers, economists, social and political scientists. The allocation and licensing of RF is tackled as an inter-disciplinary research in the fields of social sciences and engineering. Three sociological theories are synthesised for the first time to analyse *societal* and *risk concerns* in allocating the society’s resource RF, and licensing services of general economic interest. A multi-theoretical approach is essential in investigating this complex pattern of regulation; as a consequence, three theories explain the different aspects of the wireless rules and standards. The synthesis of the theories ties the results together and, it is hoped, generates a useful output. The analysis of multi-rationality in regulating RF and uncertain risks fulfils the third research question.

2.6 How Components of the Methodological Framework Fit Together

The dataset is large, and undergoes considerable exploration. The research includes descriptive data on *regulatory frameworks* for wireless communications and RF limits of *human hazards* and *spurious emissions*. The *case studies* cover the most influent continents and countries, and the developing world; the *master-data* correlates the significant wireless applications to geographical and cultural attributes. The thesis takes a worldwide, multi-geographical, multi-cultural and multi-disciplinary approach. The regional and administrations *case studies* are explored systematically. Their *regulatory frameworks* are analysed by presenting the main players and the overall approach; the synthesis combines tables to 'compare and contrast' regions and countries. Three sociological theories are synthesised and offer different prisms through which to explain the empirical results and the exceptional findings.

3 Theories

Since there is no best or optimal solution to RF regulation, the research is about choices and bounded decisions. The regulatory regimes in different sub-regions and countries are introduced and analysed by three theories: *Cultural Theory*, *Bounded Rationality* and *Rational Field Theory*. The thesis revolves around the application of these sociological theories of risk to the management of the RF spectrum and associated risks. It does not deny that there are other ways of looking at the issues, e.g. historical and political analysis; colonialism is considered as the central source of the currently most common languages, religions and legal origins, analysed in the thesis.

1) Based mainly on the publications of Michiel Schwarz and Michael Thompson (1990)[3], Mary Douglas and Aaron Wildavsky (1982)[4], *Cultural Theory* describes the four cultural worldviews, classifies individuals and countries into four cultural prototypes, contrasts collectivised with individualised rationalities and explores the regulation of uncertain risks.

2) Herbert Simon (1982)[5], Daniel Kahneman and Amos Tversky (1979)[6], and Vernon Smith

[3] *Divided We Stand- Redefining Politics, Technology and Social Choice*.
[4] *Risk and Culture: an Essay on the Selection of Technical and Environmental Dangers*.
[5] *Models of Bounded Rationality*.

(2002)[7] established the idea of *Bounded Rationality*, according to which, culture and geography may bound the rationality of individuals and decision makers. If we understand the rationality of the regulators, their mental horizons and what determines them, then we have the prospect of seizing new opportunities, according to this theory.

3) David Seedhouse (1997)[8] founded the *Rational Field Theory*; it explores allocation and licensing processes. The contribution of *Rational Field Theory* to the research is in indicating how values guide regulators. *Rational Field Theory* explains the 'rationale' and the philosophical values inspiring RF allocation and the regulation of uncertain risks.

The thesis analyses the rationality in regulating RF and the social response to risk; the common denominator of the three theories is the regulator's rationality. The national RF regulation and standardisation are linked to sovereignty, as countries joining regional organisations concede some of their sovereignty. The thesis compares the relationship between national and regional regulation, and contrasts the European and South American institutional types of regulator.

4 RF in General

Between 1864 and 1873 James Clerk Maxwell (1831-1894), a Scot theoretical physicist, demonstrated that four relatively simple equations could fully describe electric and magnetic fields and their interaction. He described how charges and currents produce an Electro Magnetic Radio wave. In 1887, in the research laboratory of a young German physicist, Heinrich Hertz, the first radio transmitter began working briefly over a range of just a few metres. Alexander Popov (1859-1906) demonstrated his instrument for the detection and recording of electrical oscillations on 7 May 1895. In the spring of the same year, Guglielmo Marconi (1874- 1937) took his wireless experiments outdoors and soon discovered that an intervening hill was no barrier to the reception of electromagnetic waves. Today there are more than 3 billion cellular telephones worldwide.

The Radio Frequency (RF) spectrum is a natural resource; it is commonly agreed that wireless telecommunications need regulation at national, regional and global levels. The first sentence of the International Telecommunications Union (ITU) constitution fully recognises "the sovereign right of each State to regulate its telecommunication". The sovereign right of states to act independently within their territory is enshrined in general international law. RF is a national limited resource, much like water, land, gas and minerals. Like these, it is

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[6] 'Prospect Theory: an Analysis of Decision Under Risk', *Econometrica* 47, 263-91.
[7] "Constructivist and Ecological Rationality in Economic" *Nobel Prize Lecture*.
[8] *Health promotion: Philosophy, Prejudice and Practice*.

scarce; however, the RF is renewable and not nearing exhaustion. It requires optimal utilisation; on the other hand, if we do not use the RF spectrum in real time, this is an economic waste of a national resource. The RF is an ethereal medium, carrying wireless e-Communications: a networked service of general economic interest (similar to transport, gas and electricity). RF regulation is nationally important in theoretical, policy and practical terms. Technological advances, innovation, penetration of new technologies, economic and military power is directly connected to wireless regulation. The radio frequencies serve as a lever to raise the economic and social conditions of the society.

The RF ether is not related to any cultural factor per-se: history, tradition, language, religion or legal origin. RF is perceived as a technical rather than cultural factor; as compared to currency, legislation, taxes or left-hand driving issues. In RF allocation the common denominator among countries may dominate the whole. For this reason the RF standards can be harmonised more easily (in comparison with, for example, foreign affairs), and the national RF allocation chart can be copied as is, from country to country (if located in the same ITU Region). Lessons, ideas and technologies can cross the ocean easily, as RF is identical worldwide, exists everywhere, serves all races, and deserves to be utilised rationally, for worthwhile applications- i.e. safety of life, emergency, multi-cultural broadcasting, health, education and human welfare.

Regulation and standards vary across cultural regions. By studying the RF *regulatory frameworks, societal* and *risk concerns* both theoretically and empirically, the thesis seeks to advance our understanding of the ways and factors in which culture and geography matter. This thesis concerns the diffusion of technology and regulating RF risks– in particular how standards for cellular radio and television have spread around the world, and how the discrete geopolitical power of US and EU has influenced these standards adoption.

5 RF Standards and Emission Limits

Preamble

The following citation of Malcolm Johnson[9] highlights the importance of the standards and universal thresholds: 'A common set of standards is like a universal language: it brings people, businesses, functions, economies and societies together. In a world constantly growing in complexity, common standards make things easier'. This section provides informative material on the RF standards referred to throughout the thesis. It is a comparative background section describing the RF standards and RF emission limits. This

[9] Malcolm Johnson, Ofcom UK, International Co-ordinator with lead responsibility for UK in ITU and CEPT. Malcolm has been elected on 14 Nov. 2006 as Director of the ITU-T; he appears in the experts' list Appendix A.

material is helpful in order to understand the technical differences. Colour TV standards (NTSC, PAL or SECAM) and cellular standards (GSM, CDMA, UMTS or TETRA) are the dependent columns in the *master-data* of the thesis. Standards evolve on the basis of existing technology; for example, the digital TV standard is related to the analogue colour TV standard, which in turn is built on the older black and white TV standards. Once the operators, suppliers and users have invested in one system or standard, they will be reluctant to change to another system swiftly; operators and end-users will default to purchasing from the present suppliers. Therefore, the present RF standard influences the adoption of the future standard.

The exploration of emission limits serves to compare the *societal concerns* and different levels of risk tolerability worldwide; this section explores the permitted quantified RF limits for *human hazards* and *spurious emissions*. The emission thresholds are related to the planning process and the equipment standardisation. The bounds can be divided into requirements limiting RF wanted (intentional) and unwanted (non-intentional) emissions. The wanted emission thresholds (*human hazards*) are motivated by health safety concerns and quality of service, while the unwanted emissions in the spurious domain are motivated by RF sharing considerations. In this section these two emission concerns are considered. It is a comparative study of the EMF (Electro Magnetic Fields) exposure levels from cellular (base stations and handsets) and power lines, and the regional levels of *spurious emissions* from transmitters.

RF standards rest on RF bands; the RF allocations are different in the three ITU Regions (see next chapter): Europe-Africa (Region 1), the Americas (Region 2) and Asia (Region 3). The standards and emission thresholds are compared mainly in the European and US hemispheres; Japan is repeatedly referenced, as Japan applies unique standards and emission thresholds. Sections 6.1 to 6.3 introduce the RF standards (television and cellular), 6.4 and 6.5 detail the RF limits (*human hazards* and *spurious emissions*).

5.1 Television Standards

The broadcasting service consists of sound, video and data broadcasting. Video broadcasting is a point-to-multipoint TV transmission for public reception, typically from a fixed emitter to fixed and portable receivers. The black-and-white (B&W) TV standard is characterized by a field frequency and a certain number of lines in the picture. When a country established an analogue colour standard, it was in such a way to be compatible with its existing B&W

standard[10]. The horizontal frequency (line repetition frequency) was defined by the field frequency: the early B&W scanners were all driven by electrical Alternating Current (AC) synchronous motors (50 or 60 Hz); moreover, field frequency was set in the vacuum-tube era, so it had to coincide with the mains electricity frequency to avoid picture waving. The analogue colour systems had to use the same B&W TV country standard for B&W compatibility. Consequently, even the more modern analogue colour standard remained tied to the main frequency of the AC supply 50/60 Hz; moreover some digital TV formats are also linked to AC supply frequency, as the picture may be viewed on a legacy screen, through a digital to analogue converter (set top box) or other means. The channel bandwidth of the colour TV (6 MHz in America and Japan, 7-8 MHz in Europe) must fit the B&W bandwidth. Digital television is incompatible with analogue TV in terms of how the broadcasted information is represented as a signal. However, it must have RF spectrum compatibility. An important factor in defining the digital standard is to consider the channel bandwidth of existing analogue standards (or smaller bandwidth). Countries currently using PAL or SECAM with an 8 MHz UHF bandwidth are likely to choose only a standard that can handle such channels (DVB-T), while those which use NTSC or PAL with 6 MHz bandwidth may choose any of the standards, while maintaining the bandwidth compatibility[11].

5.1.1 Analogue TV Colour Standards

The world has been divided into three major colour television systems: NTSC, SECAM and PAL; there are also sub-variants (such as NTSC-M, PAL-N and SECAM-D). The standards are not compatible: television sets, Video Cassette Recorders (VCRs), DVD players and camcorders must be multi-standard[12] in order to decode the colour signal of more than one of these, making it difficult to internationally exchange programs or transmitters. The number of lines and frame (or field) rate are correlated to the power supply, 50/60 Hz alternating current[13]. The details on the terrestrial analogue TV standards are based mainly on Recommendation ITU-R BS.707-5. The basics of the three standards are very similar. The TV signals include black and white information (having a bandwidth of about 5 MHz), a relatively narrow band of several hundred kHz wide colour signal and a sound signal. Table 5-1 compares technically the three analogue TV Standards; it illustrates that:

[10] For example: colour standard NTSC-M is backward compatible with B&W-M, and PAL-N with B&W–N.
[11] On 16 Nov. 2007 there is no digital TV equipment of the American ATSC and Japanese ISDB at 7 or 8 MHz bandwidth to operate properly in Europe, Africa and West Asia, due to the dissimilar bandwidth.
[12] This is the case in Israel (VCR, TV and camcorders are multi-standard); however, in the USA it is hard and expensive to order a multi-standard TV since it is so unpopular. Are Americans ethnocentric and not adapted to what is going on elsewhere in the world?
[13] In old analogue colour TV receivers, it was preferable to match the screen refresh rate to the power source, to avoid wave interference that would produce rolling bars going up and down on the screen.

—PAL and SECAM have a sharper picture (more lines per frame) than NTSC, 625 lines versus 525;

—The fields per second are derived from the different mains electricity (60 Hertz and 50 Hz);

—PAL and SECAM make use of similar video bandwidth;

—PAL-M and NTSC are alike.

Table 5-1 Technical comparison of the three analogue TV standards

<table>
<tr><th></th><th>Lines per frame (visible lines)</th><th>Fields per second</th><th>Line Frequency (Hz)</th><th>Video Bandwidth (MHz)</th><th>Colour subcarrier (MHz)</th><th>Subcarrier Modulation</th><th>Year implemented</th></tr>
<tr><td>NTSC</td><td>525 (480)</td><td>59.94[14]</td><td>15,734.264</td><td>4.2</td><td>3.58</td><td rowspan="2">Quadrature Amplitude (QAM)</td><td>1954</td></tr>
<tr><td>PAL</td><td rowspan="2">625 (576)</td><td rowspan="2">50</td><td rowspan="2">15,625. Only for PAL-M 15,734.264</td><td rowspan="2">5; 5.5; 6</td><td rowspan="2">4.43; PAL-M 3.58, PAL-N 3.58</td><td rowspan="2">1967</td></tr>
<tr><td>SECAM</td><td>Frequency (FM)</td></tr>
</table>

5.1.2 Terrestrial Digital TV

In the 21st century analogue e-Communications are evolving to digital. Analogue TV therefore naturally evolves to digital TV. The digital TV technologies provide new possibilities to compete with the RF spectrum scarcity and TV quality; digital TV offers the possibility of transmitting a single high definition program or about 6 programs in a single TV RF channel. The three international standards for digital TV were developed by the so-called 'triad powers': the US (ATSC), Europe (DVB-T) and Japan (ISDB-T). The Japanese, American and European governments have been actively involved in making policies intended to promote national champions and impeded foreign competitors (Dupagne and Seel 1998:294). Japan convinced Brazil to adopt ISDB-T with technological and economic (such as building a television factory in Brazil) rationales; the US convinced President Carlos Menem in 1998 to adopt ATSC (now it is reassessed in Argentina); Europe organised the Regional Radio Conference 2006 (RRC-06) also to convince all ITU Region 1 to adopt DVB-T. DMB-T/H (Digital Media TV Broadcasting-Terrestrial/Handheld) is deployed in China.

Geography influences the adoption of digital TV modulation. Single 8-VSB is the 8-level amplitude Vestigial Side Band modulation method adopted for terrestrial broadcast of the ATSC. Orthogonal Frequency-Division Multiplexing (OFDM) is used in both DVB-T and

[14] The reason for the actual frequency 59.94 Hz, not being exactly 60 Hz, is to obtain chroma and luminance frequency interleaving.

ISDB-T; it enables high-speed mobility and interference immunity in urban propagation conditions. 8-VSB has some advantages with regard to data rate, spectrum efficiency and transmitter power requirements; OFDM is stronger in combating multipath[15] and in indoor reception (FCC 1999:27). The enhanced coverage of 8-VSB is an advantage for the many rural areas of North America which have a lower population density than metropolitan ones[16]. In peripheral areas, 8-VSB performs better than other systems; in metropolitan areas OFDM is better. Therefore, the comparison of 8-VSB and OFDM ties directly to the question of how important mobility is to TV. For Europe, mobility in receiving TV seems more important than for the US; it can be explained by the higher penetration rate of cellular (see Appendix B: *master-data*): in the US 77.4 mobiles per 100 inhabitants, in France 85.08, in UK 116.39 and in Europe 94.29 (year 2006). Table 5-2 compares the parameters of the three digital TV standards; it illustrates the likelihood DVB-T and ISDB-T.

Table 5-2 Technical parameters of the three digital TV Standards

	Reception speed	Scanning Lines	Image size Pixels	Modulation
ATSC	Portable	1125	1920x1080	Single 8-VSB carrier codes
DVB-T	< 90 km/h, for 8k carriers ; <180 km/h, 2k	Flexible		OFDM
ISDB-T				

5.1.3 Television Standards- Conclusion

B&W TV standardisation paved the way for analogue colour TV standards, and eventually for digital TV. The European hemisphere, characterised by 50 Hertz electrical power mains, operates PAL and SECAM colour TV and is evolving toward DVB-T; the US hemisphere, characterised by 60 Hertz electrical power supply, operates NTSC colour TV and is evolving toward ATSC. There was backward compatibility between the colour and B&W TV, but no compatibility between the digital TV and colour TV. Geography may influence directly the technical standard that is defined or adopted in a certain region: the modulation of ATSC is suited to the relatively rural North America, providing large coverage zones; whereas the OFDM scheme is suited to the more compact Europe and Japan, offering resistance to multipath from buildings in urban environments, and reception in high-speed mobiles (such as trains in Europe and Japan).

[15] Multipath: radio signals reaching the receiver by two or more paths; e.g. reflection from walls and buildings.
[16] In rural areas the main problem is coverage; due to the relative low signal to noise, 8-VSB is suitable to North America. OFDM solves the capacity problem in more condensed European and Japanese areas.

5.2 Cellular Standards

The success of cellular communications is derived from the solution to the RF spectrum scarcity in the way of frequency reuse. Mobile phones access the system by using cells in the immediate vicinity, which allows reuse of the frequencies in nearby cells, under the constraint that a minimal signal to co-channel interference is maintained. In conventional radio communications about 120 users could share one radio channel, on a time shared basis. It follows that there is not enough spectrum in the VHF/ UHF bands (appropriate for land mobile communications) to provide for 3 billion cellular users on a worldwide basis; however, by frequency reuse and the principle of cell splitting, capacity is almost unlimited[17]. In Israel, for example, with 2x10 MHz, one of the cellular operators provides 3G services (audio, video and data) to more than two million subscribers.

In 1983 the US started public mobile communications first with an analogue system (AMPS); Europe followed in 1991 with a digital system GSM; during these years, cellular services were denied from many European countries. The second US step was CDMA, which is a more advanced modulation than GSM. In the early 1990s, the analog cellular standards in Europe were fragmented; in 2005 Recommendation ITU-R M. 1073 (*Digital Cellular Land Mobile Telecommunication Systems*) lists only four cellular standards: GSM, the US TIA-136 TDMA (Time Division Multiple Access), the US TIA-95 CDMA (Code Division Multiple Access) and PDC[18] TDMA. Currently, there is still no single global standard[19] for mobile telephony, which the public can use around the world.

In the 21st century there is a cellular convergence toward two systems; in 3G mobile, two evolution paths have been recognised: the European led TDMA path, which starts with GSM evolving to UMTS (WCDMA-Wideband Code Division Multiplex Access), and the US led CDMA path, starting with TIA-95, evolving to CDMA2000. Both CDMA2000 and WCDMA have been endorsed by ITU as part of the IMT (International Mobile Telecommunications) family of 3G standards. WCDMA is the radio technology used in UMTS. As a result, the terms UMTS and WCDMA are often used interchangeably. UMTS is standardised by 3GPP[20], CDMA2000 by 3GPP2[21]. China has developed the UMTS Time Division Duplex component towards TD- SCDMA. Japan developed PDC (Pacific Digital

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[17] Limiting factors are the base station constraints - an objection of the public and economic restrictions.
[18] A Japanese digital system launched by DoCoMo in 1993.
[19] As opposed to the globally adopted Wi-Fi standard for wireless local area networks.
[20] 3rd Generation Partnership Project: a worldwide collaboration agreement that was established in Dec. 1998.
[21] GPP2 is spearheaded by ANSI (American National Standards Institute); GPP1 by a grouping of international standards bodies, operators and vendors.

cellular), which evolved to FOMA[22].

CDMA refers to digital cellular telephony systems that make use of this access scheme, such as those pioneered by Qualcomm[23]. CDMA is a method of multiple access that does not multiplex (divide up) the data stream (channel) in the time domain (as in TDMA) or in the frequency domain (as in FDMA), but instead spreads the carrier frequencies by a family of orthogonal codes, each associated with a specific user-channel. CDMA permits many users to share the same frequency band at the same time, while each uses a different (orthogonal) spreading sequence; it turns out that in a multi-cell environment more users can be served in a cell per MHz of bandwidth: larger numbers of phones can be served by smaller numbers of cell sites. Therefore, CDMA is the major access method in cellular 3G systems. Whereas the GSM is a specification of an entire network infrastructure, CDMA relates only to the air interface, i.e. the radio part of the technology. The CDMA family of the US national standards (including cdmaOne and CDMA2000) are not compatible with the WCDMA family[24]. Throughout this thesis 'CDMA' notation refers mainly to the US standards - narrow CDMA (TIA-95) and CDMA2000.

The 'CDMA' system includes highly accurate time signals, usually referenced to a GPS (Global Positioning System) receiver in the cell base station; UMTS is an asynchronous technology and hence, no need for GPS. Europeans perhaps prefer to refrain from relying on the synchronisation clock from the GPS satellites, a project controlled by the USA.

5.2.1 GSM (*Groupe Spéciale Mobile*[25])

The GSM standard is repeated frequently along the thesis. By the mid-1980s, many of the European countries developed their own cellular mobile telephony systems. This led to disagreement on what system to use across Europe. The political conflict almost stopped the project. However, the European Union intervened and all 15 countries decided to accept the CEPT (*Conférence Européenne des Administrations des Postes et des Télécommunications*) proposal, the GSM, which became the first cellular digital standard. The European GSM was initiated by France and Germany[26] in 1981 and imposed by a Council Recommendation 87/371/EEC. Today, the GSM is the most popular standard for mobile phones in the world, and is a *de-facto* global standard. GSM service is used by over 2.6 billion people across more than 221 countries (see *master-data*) (as of 18 November 2007); apparently in all countries,

[22] FOMA (Freedom of Mobile Multimedia Access), which is a UMTS standard.
[23] A commercial company holder of several key international patents of the CDMA technology.
[24] Maybe in this way the European GSM industry wanted to keep their captive market and the Americans their spirit of competition.
[25] Became later 'Global System for Mobile Communications'.
[26] Another example of the French/German axis leading to a greater unification of Europe.

except Japan. The ubiquity of the GSM standard makes international roaming among countries very easy, enabling subscribers to use their phones all over the world. GSM is a closed standard, allowing easy inter-operability among network operators, roaming services and the deployment of equipment from different vendors. GSM networks operate in four different frequency ranges. Nowadays, most subscriber units on the market (i.e. handset) support multiple frequencies used in different countries.

GSM is a second generation (2G) technology, precursor to 3G, with an evolution path called GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution). GPRS / EDGE, also known as 2.75G, is deployed in many places where GSM is used. Many operators install UMTS network, in order to support higher data rates. The GSM achievement is another reason of a greater cellular penetration in Europe, relative to the US (see the *Indicator* chapter). The success of GSM paves the way to the penetration of UMTS, also outside Europe.

5.2.2 Cellular Standards- Concluding Section

The cellular standards set the framework of a huge industry. The European GSM is accepted and operated in the entire world; the harmonised TETRA did not succeed as much as GSM. The US is dominant in the microprocessor and software industries (Hart 2004:226), whereas Europe is the main supplier of the cellular market, due to the top-down harmonization and the greater emphasis Europeans seemed to have been putting on personal mobile communications, with the rate of penetration exceeding that of the US.

5.3 TV and Cellular Standards- Conclusion

Backward compatibility and evolution are important: availability of the old services on the new infrastructure, with no need to change the user equipment, and as little as possible investment in the infrastructure. Therefore, existing standards typically lead to the new superior standards. The exceptional success of the European GSM opened the door to its successor UMTS; DVB-S (the satellite component of DVB) is already the leading preferred standard for satellite digital broadcasting. The successful penetration of DVB-T may be explained also by the top-down harmonisation and pulling of Africa (and part of Asia) toward Europe in RRC-06. The GSM success may promote in the future the development of other European 'cathedrals'. Globalisation has caused a convergence of the digital TV and 3G standards. Relative to Europe, the US is the pioneer of the new technologies (such as NTSC and ATSC); later, when Europe follows, it can start with a more advanced position (such as PAL/SECAM and DVB) on the evolution time axis.