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An examination of the evolution of broadband technologies in the UK

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Submitted in Accordance with the requirements for
the Degree of Doctor of Philosophy

The Open University

Department of Computing and Communications

Faculty of Maths, Computing, and Technology

Abstract

The aim of this thesis is to examine the reasons due to which Digital Subscriber Line (DSL) became the most widely used technology to deliver broadband connectivity in the United Kingdom (UK). The research examines the outcome starting with events in 1960s when broadband as it is defined today did not exist. The research shows that a combination of factors involving regulatory decisions, changing market conditions, and unexpected technological breakthroughs contributed to the current day mix of broadband technologies in the last mile access in the UK.

To interpret the events that have shaped the development, deployment, and adoption of broadband technologies in the UK, the thesis draws from various theoretical ideas related to Science and Technology Studies (STS) to understand and analyse the events. In order to discover and establish the historical context, the thesis employs original, unpublished interviews along with the extensive use of archival material and secondary sources. Influenced by some of the core ideas of social constructionist studies, this research combines concepts from economic studies of technological change along with themes involving maintenance of technology, path dependence, and the role of bandwagon effect.

These research threads are combined to understand the way development, deployment, and adoption of broadband technologies took place in the UK. The research is intended to contribute to the understanding of technology in a constantly changing regulatory and socio-economic environment and how it is shaped by multiple factors. The targeted readership is researchers, analysts, and decision makers working with broadband technology, telecommunications policy,

and STS. Further research is suggested in the form of studies of wireless broadband technologies and the role of regulatory policies in the development of the UK communications market.

Keywords: *British Telecom, Broadband, Evolution of broadband, Science and technology studies, Technological changes, UK communications industry*

To,

Gadgil Sir

Acknowledgements

First and foremost, I want to thank my supervisors Dr. Allan Jones, Prof. Chris Bissell, and Dr. David Chapman. Without their guidance and encouragement this thesis would not have been possible. Thanks to Allan for all the weekly meetings, detailed and wide-ranging discussions on topics related to (and sometimes not related to) my work. Without Allan's timely suggestions, nuanced advice, and sometimes just kind words I could not have stayed on track. Thanks to Chris for agreeing to meet me in the first place way back in 2008 and then encouraging me to apply for the PhD despite some of the professional and personal difficulties that were holding me back. Chris' experience and insight has been crucial to this thesis. Thanks to David for all his technical inputs, advice on structuring the thesis, and the occasional discussions on football and cricket.

I am grateful to other senior colleagues in the department – Karen Kear, Ian Martin, and Magnus Ramage for their support and encouragement. Karen took a keen interest in my work, offered friendly advice, and had a seemingly amazing knack for egging me on when I was flagging in my efforts. Mark Woodroffe, my third party monitor, often rallied around and offered a sympathetic ear when it all seemed too much to handle. Without his support I could not have survived the 'writing up' phase.

All the departmental secretaries – Donna Deacon, Audrey Ibbotson, Danielle Lilly, Mary McMahon, Patricia Telford, and Angela Walters have been wonderful in their

assistance on administrative and non-academic matters. Thanks in particular to Patricia and Donna for their help when I was conducting the research interviews.

The staff at BT Archives and Porthcurno Telegraph Museum was very helpful during my visits there. Charlotte Dando at the Porthcurno Telegraph Museum was of particular help and deserves a special mention.

Thanks to all the past and current students in S1005 for just being there and all the relevant / irrelevant banter – Alam, Badrudozza, Bola, Catherine, Faisal, Geraud, Hnin, Parminder, Richard, Smarti, and Trish. Special thanks to Trish for her constant encouragement during the early part of the 'writing up' phase and her feedback on my writing. I hope to return the favour starting from October 1, 2015.

I would also like to thank Simone Arthur and her husband Diego Saiz-Gonzalez for my comfortable stay at 16 Perivale throughout the last 3.5 years. My housemates at 16 Perivale – Adam, Amy, Catherine, Darius, Ellies, Fook, Inga, Mala, Maria, Murilo, and Richmond have been just the right kind of mates one needs during the good, the bad, and the ugly times.

My parents Seema and Ramesh Deshpande have been terrific with their support back home. If it were not for them, I would not have been able to leave everything behind and pursue a PhD. My grandmother Sumati Kulkarni completed her PhD at the age of 50 and has been a lifelong inspiration. My aunt and uncle Anagha and Jaideep Dudhbhate provided the initial spark of encouragement and support when I was unsure about whether to pursue a PhD. My friends Amruta Borwankar and

Ashish Jain have always been there for me on every occasion I needed it. Above all else, thanks to Tejaswini for her patience, kindness, understanding, and for being my partner in crime.

Finally, I would like to thank the interview participants who gave me their valuable time. Without their insights, this thesis would have remained a pipe-dream.

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Abbreviations and Acronyms

2B+D	2 Bearer channels (64 kbit/s each) + 1 Delta channel (16 kbit/s). Also known as 2B1D.
2G	2nd Generation (wireless network)
3G	3rd Generation (wireless network)
4G	4th Generation (wireless network)
ACTS	Advanced Communications Technology and Services
ADSL	Asymmetric Digital Subscriber Line
ADSL ₂	Asymmetric Digital Subscriber Line version 2
ADSL ₂₊	Asymmetric Digital Subscriber Line version 2+
ANT	Actor-Network Theory
AOL	America OnLine
ARPANET	Advanced Research Projects Agency Network
ARPU	Average Revenue Per User
AT&T	American Telephone & Telegraph
ATM	Asynchronous Transfer Mode
B-ISDN	Broadband Integrated Services Digital Network
BBC	British Broadcasting Corporation
BBTG	Broad-Band Task Group
BDOUK	Broadband Delivery UK
BIB	British Interactive Broadcasting
BIS	Department of Business, Innovation, and Skills
BPO	British Post Office
BPON	Broadband Passive Optical Network

BR-ISDN	Basic Rate Integrated Services Digital Network
BRI	Basic Rate Interface
BS	Base Station
BSB	British Satellite Broadcasting
BSG	Broadband Stakeholder Group
BSkyB	British Sky Broadcasting Corporation
BT	British Telecommunications plc. (original description. Later just British Telecom)
C&W	Cable & Wireless
CA	Cable Authority
CAP	Carrierless Amplitude Phase modulation
CCITT	Comité Consultatif International Téléphonique et Télégraphique (original description in French) or Consultative Committee on International Telegraph and Telephone (in English).
CD	Compact Disc
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (in French) or Atomic Energy and Alternative Energies Commission (in English)
CEO	Chief Executive Officer
CMT	Communications, Media, and Technology
CPE	Customer Premise Equipment
CPW	CarPhoneWarehouse
CRI	Centre for the study of Regulated Industries
CTO	Chief Technology Officer
DARPA	Defense Advanced Research Projects Agency

Datel	Data Telecommunications
DCMS	Department for Culture, Media & Sports
DLL	Digital Local Loop
DOCSIS	Data Over Cable Service Interface Specification
DoD	[US] Department of Defense
DGT	Director-General of Telecommunications
DMT	Discrete MultiTone modulation
DP	Distribution Point
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Dynamic Spectrum Management
EC	European Commission
ECU	European Currency Unit
EDF	Électricité de France S.A
EDFA	Erbium-Doped Fibre Amplifier
ENI	Ente Nazionale Idrocarburi (original Spanish i.e. National Hydrocarbons Authority. Now just Eni S.p.A)
EThOS	Electronic Theses Online Service
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communications Commission
FRIACO	Flat Rate Internet Access Call Origination
FT500	Financial Times 500
FTP	File Transfer Protocol
FTTC	Fibre-To-The-Cabinet

FTTH	Fibre-To-The-Home
FTTO	Fibre-To-The-Office
Gbit/s	Gigabits per second (unit of data rate)
GEC	General Electric Company
GHz	GigaHertz (unit of frequency)
GPON	Gigabit Passive Optical Network
GSM	Global System for Mobile (in English) or Groupe Spécial Mobile (original description in French)
HDSL	High-bit-rate Digital Subscriber Line
HFC	Hybrid Fibre Coax
HSPA	High Speed Packet Access
IBA	Independent Broadcasting Authority
IBCN	Integrated Broad-band Communication Network
ICBM	InterContinental Ballistic Missile
ICT	Information and Communication Technologies
IDN	Integrated Digital Network
IEE	Institution of Electrical Engineers
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
IMCN	Integrated Multi-service Communication Network
INCA	Independent Networks Cooperative Association
INMARSAT	International Maritime Satellite Organization (original description, now just Inmarsat plc.)
INTELSAT	International Telecommunications Satellite Organization (original description, now just Intelsat S.A.)

IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISO	International Organisation for Standardisation
ISP	Internet Service Provider
ITA	Independent Television Authority
ITC	Independent Television Commission
ITU	International Telecommunications Union
JANET	Joint Academic NETwork
kbit/s	Kilobit per second (unit of data rate)
KCom	Kingston Communications
KfW	Kreditanstalt für Wiederaufbau (original German)
Km	Kilometre
KPN	Koninklijke PTT Nederland
LAN	Local Area Network
LBS	London Business School
LE	Local Exchange
LG	Lak-Hui Goldstar (original description, Leokki Geumseong in Korean)
LLU	Local Loop Unbundling
LTE	Long Term Evolution
LTS	Large Technological System
Mbit/s	Megabit per second (unit of data rate)
MCI	Microwave Communications, Inc. (original description)
MHz	MegaHertz (unit of frequency)
MIT	Massachusetts Institute of Technology
MMC	Monopolies and Mergers Commission

MoU	Memorandum of Understanding
MST	Les macro-systèmes techniques (original French)
Mux	Multiplexer
N-ISDN	Narrowband ISDN (same as BR-ISDN)
NAO	National Audit Office
NESCO	North Eastern Electric Supply Company
NGA	Next Generation Access
NGN	Next Generation Network
NICC	Network Interoperability Consultative Committee
NTL	National Transcommunications Ltd (original description, later just NTL)
NTT	Nippon Telegraph and Telephone Corporation
Ofcom	Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
Oftel	Office of Telecommunications
OLO	Other Line Operator
OSAB	Ofcom Spectrum Advisory Board
OU	Open University
P2P	Point-to-Point (fibre)
PBX	Private Branch eXchange
PC	Personal Computer
PCM	Pulse Code Modulation
PCP	Primary Connection Point
PhD	Doctor of Philosophy
PON	Passive Optical Network

POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
PTT	Postal, Telegraph, and Telephone company (original description) or Public Telegraph and Telephone company (alternative, less common description)
QAM	Quadrature Amplitude Modulation
QMUL	Queen Mary, University of London
R&D	Research & Development
RA	Radiocommunications Agency
RACE	Research in Advanced Communication in Europe
ROI	Return On Investment
RPI	Retail Price Index
RWE	Rheinisch-Westfälisches Elektrizitätswerk AG (until 1990. Just RWE AG afterwards)
SAGE	Semi-Automatic Ground Environment
SCOT	Social Construction of Technology
SEC	Securities and Exchange Commission
SME	Small and Medium Enterprise
SST	Social Shaping of Technology
STL	Standard Telecommunication Laboratories
STS	Science and Technology Studies
TAT	Trans-Atlantic Telecommunications submarine cable system
TCP	Transmission Control Protocol
TPON	Telephony over Passive Optical Network

TSR	Telecoms Strategic Review (shortened description. Original description – Strategic Review of Telecommunications)
TV	Television
UCL	University College London
UK	United Kingdom
UKB	UKBroadband
USA	United States of America
VCR	Video Cassette Recorder
VDSL	Very-high-bit-rate Digital Subscriber Line
VDSL ₂	Very-high-bit-rate Digital Subscriber Line version 2
VDSL ₂₊	Very-high-bit-rate Digital Subscriber Line version 2+
VHS	Video Home System
VMED	Virgin Media
VOA	Valuation Office Agency
VOD	Video-On-Demand
VVDSL	Vectored Very-high-bit-rate Digital Subscriber Line
WBA	Wholesale Broadband Access
WDM	Wavelength Division Multiplexing
WiFi	Wireless Fidelity (unofficial)
WiMAX	Worldwide Interoperability for Microwave Access
WLR	Wholesale Line Rental
WWII	World War II
WWW	World Wide Web

1 Introduction

1.1 Background

As of 2012-2013, copper-based Digital Subscriber Line (DSL) provides broadband connectivity to 75% of the United Kingdom (UK) premises (Ofcom, 2013b) and is thus the most widely used technology to deliver broadband connectivity in the last mile access in the UK. Next in order of market share is coaxial cable/Hybrid Fibre Coax (HFC) at 20% (Ofcom, 2013b). The remaining 5% is accounted by optical fibre and wireless technologies (Ofcom, 2013b). Of these technologies, coaxial cable and optical fibre are generally deemed superior to DSL in terms of data rates and are relatively immune to loss of signal¹ due to crosstalk and noise². In contrast to coaxial cable and optical fibre, both of which were being developed in the late 1970s, DSL was first introduced only by the end of 1980s. The dominance of DSL therefore looks paradoxical, and examining this paradox is part of the aim of this thesis.

The ascendancy of DSL in comparison to other broadband technologies such as optical fibre or coaxial cable is often attributed to the extensive presence of copper in the Public Switched Telephone Network (PSTN) (Starr et al, 1999). In addition, the technical and economic merits of DSL vis-à-vis other broadband technologies

¹ Although each of these transmission technologies suffers from loss of signal, with copper DSL the signal loss occurs over a much shorter length of wire. As Valdar (2006) notes, after the first 3 km, depending on the quality of the copper wiring, DSL can lose close to 50% of the signal. Copper being a good conductor of electricity, DSL is also impacted by signal interference and crosstalk.

² Noise refers to the unwanted signal generated intrinsically by the medium (e.g. thermal noise). Crosstalk refers to the induced noise from outside sources (e.g. crosstalk from adjacent transmission systems). See Valdar (2006).

are also deemed to be important factors in the continued success of DSL (Starr et al, 1999; 2003). The limited presence of coaxial cable and optical fibre is often attributed to the high cost of deployment and extensive nature of civil works involved³. As a result, the present dominance of DSL can be deemed as an outcome based on the best possible trade-off between performance and cost. However, such a view overlooks the historical background of these developments and the ways in which these particular technologies emerged as the ones in contention for their current use. The aim of the thesis is to trace these developments in a historical context and understand why DSL has turned out to be the most cost-effective alternative to deliver broadband connectivity.

A major theme of this thesis will be that the outcome was not determined by any single factor or a simple set of factors. Looking back to the 1980s, an outcome with DSL as the technology with the largest market share in the last mile access was far from probable. An overview of the events until the late 1990s suggests that copper was not considered an adequate medium for delivering high-bandwidth connectivity for significant durations of time (Maxwell, 1998). Although broadband Internet access is the most common use for copper-based DSL today, this technology was in fact invented to deliver video-on-demand (VOD) services in the early 1990s. Before DSL came in contention for delivering high-bandwidth connectivity, Integrated Services Digital Network (ISDN), Broadband ISDN (B-ISDN), coaxial cable, and optical fibre were favoured at various times. Each of these

³ The Broadband Stakeholder Group (BSG) quoting the estimates from Enders Analysis' January 2007 report 'Very High Speed Broadband: A Case For Intervention' states that the incremental costs per household for ADSL2+, Fibre-To-The-Cabinet (FTTC) and Fibre-To-The-Home (FTTH) deployments are €60 (£45), €300 (£250) and €1000 (£800) respectively (2007). In the same report, the cost of deploying FTTH to 90% of UK households is estimated to be €14B.

alternatives was in the fray at different times throughout the 1980s and 1990s. Commercial considerations were only part of the factors in the development, deployment, and adoption of each of these technologies. As later parts of this thesis show, these commercial considerations have to be seen in the context of an increasingly liberalised UK communications market. This market has been governed by regulatory policies focussed on competition as the means of delivering the best-possible deal to the end-users.

1.2 Broadband – meaning and evolution

The broadband technologies mentioned above evolved not only in response to technological innovation within the communications and computing industry but also in response to competitive pressure and regulatory intervention. Starting with the 1980s, the term "broadband" and the technologies associated with it were closely influenced by the contemporary developments. Not only were these broadband technologies designed with different purposes in mind, but in reaching their current day market share each of these technologies has also taken a very different path from the others. Although the term "broadband" is now synonymous with Internet access, it seems to have originated in the 1980s in reference to the provision of video and broadcast services on demand (see Fox, 1990). The efforts to deliver broadcast services on telephone networks can be seen to have their roots even as far back as the 1960s when telecom service providers began to deliver data communications to the enterprise/business end-users⁴. These services paved the way for packet

⁴ These data services to enterprise/business end-users were delivered by using Pulse Code Modulation (PCM). Although it was invented in the 1930s, PCM and its use in data communications

switched networks which are at the heart of the Internet Protocol (IP) that powers much of the Internet infrastructure. Seen from this perspective, this thesis uses the term "broadband" somewhat anachronistically to describe the data communications technologies in use from 1960s onwards. This is despite the fact that the term "broadband" is not seen in significant use until the late 1980s⁵. As the narrative and theoretical discussion in chapters 4 to 7 will show, all the points mentioned in this paragraph are pertinent to how broadband technologies evolved in the UK.

1.3 Current research and the scope for this study

At present, there are not many studies of the way broadband technologies have evolved in the UK. The available research has tended to focus more on the technical aspects of the broadband technologies such as how DSL technology developed (Cioffi, 2011; Maxwell, 1998; Starr et. al, 2003), improvements in compression techniques to increase DSL throughput (Ginis and Cioffi, 2002; Lee et. al, 2007), ways of increasing the capabilities of optical fibre networks (Shibutani et. al, 1997; Cale et. al, 2006), new methods of low cost rollout of optical fibre networks (Schumate, 1990; Ren et. al, 2010) and better use of wireless spectrum in case of mobile networks (Rysavy, 2007). The research examining history of

became practical only in the 1960s on the back of introduction of transistors and miniaturisation. See Bray (1995).

⁵ One of the first notable references is in BT's annual report for the year 1983-84:

An optical fibre broadband network has been provided for the City of London. Its purpose is to provide customers with on-demand services for videoconferencing, point-to-point video transmission, ultra-high speed data links and bulk distribution of information.

Source: BT (1984, p. 19)

telecommunications has tended to either focus on the early telegraph and telephony development (Marvin, 1988; Perry, 1992; Standage, 1998) or cover UK telecommunications history across a broad spectrum of technological developments (Bray, 1995; 2002; IEEE ComSoc, 2012; Solymar, 1999). Given the very recent nature of broadband technology-related developments, coverage of the events from 1980s tracing the evolution of broadband to date in detail is not readily available.

On the other hand, by its very nature, a significant body of research within science and technology studies (STS), social studies of technology, and economic history of technology about the communications industry tends to focus on either social or economic perspectives (for example, Rosenberg, 1994; Rohlfs, 2001)⁶. A more detailed survey of the literature in chapter 3 suggests that any framework or models for understanding technological changes based solely on a specific perspective such as economic theories or social constructionist ideas may no longer be sufficient in a globalised, liberalised, and yet regulated market economy such as the UK. This thesis aims to address this gap in current literature by examining the events starting in the 1960s that led to the current market share of broadband technologies in the UK.

⁶ Bray (1995; 2002) and Solymar (1999), mentioned in the previous paragraph, are more of traditional historians of technology relying on a narrative history (see Buchanan, 1993 cited in Fox, 1996 for a discussion of such an approach) rather than being historians in discipline of the science and technology studies.

1.4 Thesis overview

In order to examine this very recent history of broadband technologies the thesis draws from a range of ideas primarily within science and technology studies, social studies of technology, and the economic history of technology combined with the more technically orientated studies of the broadband technologies. The choice of technologies being examined is influenced by the latest Office of Communications (Ofcom) reports on market shares (Ofcom, 2011b; 2012a; 2013b). The thesis mainly investigates the development, deployment, and adoption of following technologies – DSL, coaxial cable, and optical fibre. For this purpose, the thesis focuses on the key players such as the UK government, the regulators, cable industry, and British Telecom (BT), the former public sector monopoly operator in the UK. Some of the other players including Kingston Communications, wireless/mobile operators, and community broadband initiatives are not discussed at great length.

Given that fixed-line technologies account for a very large percent (close to 90%) of the network length even in wireless networks (Valdar, 2006), the narrative in chapters 4 to 7 concentrates mostly on fixed-line technologies. Thus despite the importance of wireless technologies such as WiFi and the growth in adoption of mobile technologies 2nd Generation (2G)/Global System for Mobile (GSM), 3rd Generation (3G), High Speed Packet Access (HSPA), HSPA+, and 4th Generation (4G)/Long Term Evolution (LTE), the thesis is focussed on fixed-line technologies that are central to delivering high-bandwidth capabilities that define a broadband connection. At the same time, the thesis also considers other fixed-line technologies that may no longer be in prominent use but were at different points of time in

contention. The fixed-line technologies considered for their historical importance are - ISDN, B-ISDN, and millimetre waveguide.

The narrative of why broadband technologies evolved to their current market share is presented in a near-chronological manner starting with the 1960s when the first building blocks of today's high-bandwidth data connectivity were formed. Before beginning such a narrative however, the research methodology is explained at length followed by a survey of the literature that underpins the discussion in the thesis. The synopsis of each of the thesis chapters starting with the definition of the research objectives is as follows.

Chapter 2 – Research questions, objectives, and methodology

This chapter discusses the research questions the thesis is trying to answer, the relevance of those questions, and the way in which the research was conducted. The method of enquiry used for the research and the reasons for which a specific method of enquiry was used, is analysed. The discussion on the methodology involves the availability of archival resources, the need for research interviews, the method of identifying and contacting interview participants, and the way in which the research interviews were conducted. The advantages and disadvantages of the archival resources, research interviews, and secondary sources are considered. The method of analysing the research data collected and the way in which the data was used in the thesis narrative is also discussed in detail. The process for triangulating the interview data and the resources available to corroborate and authenticate the data is covered.

Chapter 3 – Literature review

The survey of the literature discusses various themes within science and technology studies and how these themes inform the choices being made in relation to the use of theoretical ideas. The currently available literature in relation to technological change and the communications industry is discussed to identify the gaps that the thesis needs to address. Starting with the technologically determinist tradition of writing on science and technology, the emergence of social studies of science/scientific knowledge form a part of the survey. The extent to which social studies of science influenced studies of technological change and led to the growth of social constructionist studies of technology along with social shaping of technology approaches is also discussed at length. The overlapping boundaries between social constructionist/social shaping approaches and the work of historians of technology such as Hughes and Edgerton is considered. The way in which historical studies of technology inform the discussion in the following chapters is also a part of the analysis. The limitations of the social constructionist studies and the need to cater to political and regulatory influences are covered with a discussion of critical theory of technology and how related ideas contribute to the theoretical analysis in the thesis. The way in which historical and social studies of technology ignited the interests of economists in relation to technological change and its influence on economic growth is discussed. This discussion sets up the relevance of economic studies of technology to the understanding of technological change. The literature survey is then rounded out with an analysis of the interdisciplinary approach that the concept of path dependence enables. The summary of the chapter

presents the limitations and the gap in the currently available literature to set up how the thesis will contribute to the field of science and technology studies.

Chapter 4 – Datel, early digitisation, and "wideband" connectivity

This chapter discusses the period of 1960s and 1970s and the way in which digitisation of electronics and communications technologies began to change the nature of signal transmission. The influence of pulse code modulation being practical and how that resulted in higher bandwidths being possible on copper is covered. The aim is to show that the perception of what constituted high-bandwidth connectivity was very different in the 1960s and 1970s due to the limitations of technology available. An additional thread is how the monopoly of the Post Office influenced the nature of decisions being made in relation to transmission technologies. In particular, the end-to-end ownership of the networks by the Post Office and how that dictated the incubation of technologies such as optical fibre and millimetre waveguides is considered. The use of the term 'wideband' to indicate high-bandwidth connectivity and the various services offered by the Post Office such as Datel, Dataplex, and its plans for a Videotex system is also discussed.

Chapter 5 - Denationalisation of BT, cable franchise allocation, and the quest for "killer application"

This chapter covers the events from the 1980s with the main points of discussion being -

- The denationalisation of British Telecom (BT),

- Licensing of Mercury Communications,
- Revival of multi-channel cable transmission systems and the allocation of cable franchises in the form of regional monopolies, and
- The creation of regulatory bodies such as Office of telecommunications (OfTel), and Cable Authority (CA).

The various attempts to introduce higher bandwidth technologies such as ISDN, optical fibre, and coaxial cable are also covered. The way in which the privatised BT's focus began to change and attempts on the part of the regulators to create a competitive market by placing restrictions on BT is considered in order to understand how it influenced the decisions by various stakeholders. In particular, the set of circumstances in which deployment of ISDN remained restricted to business end-users in the UK and the factors contributing to its overall commercial failure are discussed. The problems faced by the cable industry at an early stage of the market rollouts are included in the discussion. The pursuit of a 'killer' application in the form video-on-demand services and how that influenced the choices of various operators in relation to high-bandwidth technologies is also discussed.

Chapter 6 - Golden shares, global ambitions, and the emergence of the Internet/Web

This chapter covers the events from the 1990s with a focus on the duopoly review and the increased liberalisation of the UK markets. The focus of the regulatory policies on infrastructure competition and price regulation is discussed along with the way in which the UK cable industry increasingly struggled in the absence of

unique content. The challenge posed by the emergence of British Sky Broadcasting (BSkyB) and how the cable industry was squeezed on the margins for its telephony and television services is analysed in order to show its influence on the rollout of the coaxial cable network. In the context of the restrictions on BT in relation to broadcasting services, the way in which the privatised BT's ambitions to become a worldwide leading communications group grew forms an important part of the discussion in the chapter. In particular, BT's extensive investments outside the UK and the manner in which BT's ambitions for global expansion affected its investments in the UK infrastructure is considered to show the absence of alternatives to copper DSL by the end of the decade. The way in which the unexpected emergence of the Internet/World Wide Web (WWW, hereafter "Web") changed the landscape of the communications industry is discussed with a view to its influence in relation to the selection of broadband technologies. The various technologies discussed are -

- B-ISDN which much like ISDN was a commercial failure,
- Coaxial cable/HFC and how its deployment had slowed down by mid-to-late 1990s due to the problems in the UK cable industry,
- Optical fibre which saw deployment only in the core network, and
- Copper-based DSL which emerged as an expedient choice owing to BT's financial limitations by the end of the 1990s and regulatory pressure.

Chapter 7 - Uncertain market conditions, bankruptcy in the cable industry, and the bandwagon effect

This chapter focuses on the events in the 2000s to the present, with a particular emphasis on BT's financial difficulties that influenced the initial selection of DSL. The role of regulatory pressure in the form of local loop unbundling and the manner in which cable modem-based broadband connectivity had an early lead in relation to broadband adoption is also discussed. Despite the consolidation in the cable industry, how the bankruptcy of NTL and Telewest held back the deployment of cable network is considered. BT's DSL registration scheme and the how Asymmetric DSL (ADSL) adoption grew in numbers is analysed. The resulting stronghold of BT's wholesale DSL product and the approach of the newly merged super-regulator for the communications industry i.e. Ofcom is discussed in order to understand the push for the second wave of unbundling. How the functional separation of BT's network and retail operations resulted in increased competition in the retail broadband space is considered in relation to understanding the deployment of ADSL₂, ADSL₂₊ products and further increase in DSL numbers. The current market share of broadband technologies and how DSL broadband looks set to remain the most widely used broadband technology is discussed in the end.

Chapter 8 – Summary, discussion, and conclusions

The final chapter in the thesis summarises the key findings of the previous discussion and the way in which the thesis makes an original contribution. The research questions set up in chapter 2 and the answers that have emerged are

considered from a theoretical perspective combined with the way in which the narrative in the chapters 4 to 7 provided the answers to the questions. The contributions of the study in relation to the history of broadband technologies in the UK, the way in which DSL became the most used technology, and the role of unintended consequences of regulatory policies are also established. The possibilities for future research in terms of wireless broadband access technologies and the need to examine regulatory issues in further depth independently are considered towards the end.

1.5 Summary

This chapter discussed the key themes explored in the thesis along with a brief discussion on the current status of research in relation to broadband technologies. A concise overview of the remaining chapters in the thesis was also covered. The next chapter focuses on the research objectives that underpin the thesis and the methodology used to conduct the research.

2 Research questions, objectives, and methodology

2.1 Introduction

Chapter 1 established the basic premise of the research and this chapter explores the research questions this thesis aims to address. The research objectives are described along with the research methodology used to collect and analyse data. Before setting out the research questions and methodology, the gap in knowledge this thesis addresses is covered. This discussion is followed by the relevance of this research and the reasons for which it focuses on the UK.

2.2 Addressing a gap in knowledge

Although the term broadband is now synonymous with Internet/Web access, for much of the time until the mid-1990s it was used mainly in conjunction with delivering video-on-demand services. With the growth in Internet/Web services, and the escalation of end-user demand, broadband has become increasingly important from a political and economic perspective. This importance has been reiterated through a number of reports in which the growth of the UK economy has been consistently associated with the availability of better bandwidth. In 2001, UK government's stated ambition was *"to have the most extensive and competitive broadband market in the G7 by 2005"* (Ofcom, 2001b, p. 3). In 2009, the UK government published a report titled "Digital Britain" in which the need to invest in next generation access for better bandwidths through a market-based, competition-driven mechanism was discussed in detail (BIS, 2009). The House of Lords Select

Committee's (2012) report "Inquiry into Superfast broadband" further highlights the importance of broadband connectivity to the UK economy.

As noted in chapter 1, despite the importance attached to broadband technologies, the available studies of broadband have focused on specific technical or socio-economic aspects. An account of development, deployment, and adoption of technologies that delivered high-bandwidth connectivity in its historical context remains unexplored. Although the role of government policy in creating a competitive market and its effect on the telecommunications industry has been covered by Mansell (1994; 1997) and Cave (2006; 2010a; 2010b), the focus is on specific policy instruments such as spectrum auctions or unbundling initiatives. In contrast, this thesis concentrates on the interaction of many factors that have resulted in the current market share of the different broadband technologies and the association of broadband with Internet access over a number of years. Examining the evolution of broadband technologies in such a manner is particularly important in a technology-intensive sector such as the communications industry, where market changes have been rapid and a number of stakeholders have been involved. Understanding the outcome of such technological changes in a dynamic socio-economic, political context is very relevant not only because of the increased importance associated with broadband but also to understanding the way in which a competitive, liberalised market and the interconnected, interdependent nature of the various stakeholders has shaped the outcome.

Although DSL has become the technology with the highest market share (i.e. 75%) in the last mile, its ascent has hardly been straightforward. At various times in the

last 30 years, other fixed-line technologies such as B-ISDN, coaxial cable, and optical fibre have been in contention. In addition, the growth in mobile connectivity and wireless networks has not only provided an effective alternative to broadband connectivity for some areas but has also captured certain niche segments of the market¹. The resultant market share of a number of the various fixed-line broadband technologies and the events that have contributed to the outcome suggest a layered, complex narrative with multiple stakeholders working with different purposes. Given the absence of any study that illuminates the dominance of DSL in comparison with other broadband technologies in the last mile, a gap exists in current knowledge. Before setting up the research questions that will address this gap in knowledge, the next section discusses the reasons for which this research is relevant.

2.3 Relevance of the research

Although a number of studies related to telecommunications, particularly early telegraphy and telephony services, in a historical, socio-economic context, exist, no major study of the evolution of broadband technologies in the UK has been undertaken (see chapter 3, section 3.2 for more details). The studies undertaken by government, regulatory, or industry organisations have tended to focus on policy aspects to deliver better bandwidth, achieving higher economic growth via broadband, or increasing competition for broadband connectivity rather than examining broadband in a historical context (see BIS, 2009; BSG, 2007; Oftel, 1999b;

¹ Ofcom (2013b) states that between 2008 and 2012 the number of mobile broadband connections had grown from 2.6M to 4.9M. Compared to 21.7M fixed-line broadband connections in 2012, this represents a sizeable niche.

2001b for examples of governmental, industry-supported, and regulatory studies). In consequence, the technological changes that took place during the evolution of broadband with consideration to the multiple factors that influenced it remain unexamined.

As the following narrative will demonstrate, current understanding of broadband technologies is shaped by its universal association with Internet access. However, on looking at the events that resulted in the development, deployment, and adoption of broadband technologies in a historical context, a very different picture emerges. The current market share of broadband technologies and its association with high-bandwidth Internet/Web access has been the result of various interacting factors, many of which were contingent on events that were far from predictable. The interpretation of these events is critical to strengthening an appreciation that technological changes related to broadband were not always directed towards a specific outcome. Instead, how broadband technologies developed, got deployed or were adopted was inherently uncertain. For broadband technologies, this understanding of the influence of the various unpredictable factors is very relevant to any future decisions for government policy, regulatory interventions, and investments from the markets.

By interpreting the events in their own non-linear, historical context, this thesis aims to address an overlooked area of technology study with significant relevance to policy-related decision making. It does so by focussing on the key players i.e. the UK government, the regulators, cable industry, and BT. The thesis will show how technological change was influenced by multiple factors in an increasingly

liberalised market. Before defining the research questions and objectives that guide this study, the unit of analysis is defined next followed by the reasons for choosing the UK as the region of study.

2.4 Unit of analysis

This research focuses on the technology that is used in what is referred to as the last mile i.e. the part of the network from the end-user's premises to the nearest cabinet or wireless base station (BS). The reason for specifying the technology in the last mile as the primary unit of analysis is that it is the key parameter used to determine the bandwidth available to the end-user. This focus on the last mile is similar to the criterion used by Ofcom to assess the market reach of technologies for delivering broadband to end-users' premises (see Oftel, 2002a; Ofcom, 2013b). Thus, while the end-user's area may have Fibre-To-The-Cabinet (FTTC) connectivity for broadband, if the last mile is connected through a wireless network the broadband technology delivering service to the end-user is deemed to be wireless. Similar implications follow for DSL networks or coaxial cable/HFC networks.

In defining the primary unit of analysis as the technology in the last mile, the way in which the UK network has developed as a complex mesh of different technologies also needs to be considered. Because of the overlapping nature of technological developments and standards in the telecommunications sector, most of the communications networks in UK use more than one technology or set of protocols. Consequently, the fixed line network is a mesh of different technologies including optical fibre in the core network, copper, optical fibre, and coaxial cable in the

access network and sometimes wireless networks for parts of last mile connectivity in rural areas. The mesh of networks can be understood better based on the following figure provided in Valdar (2006).

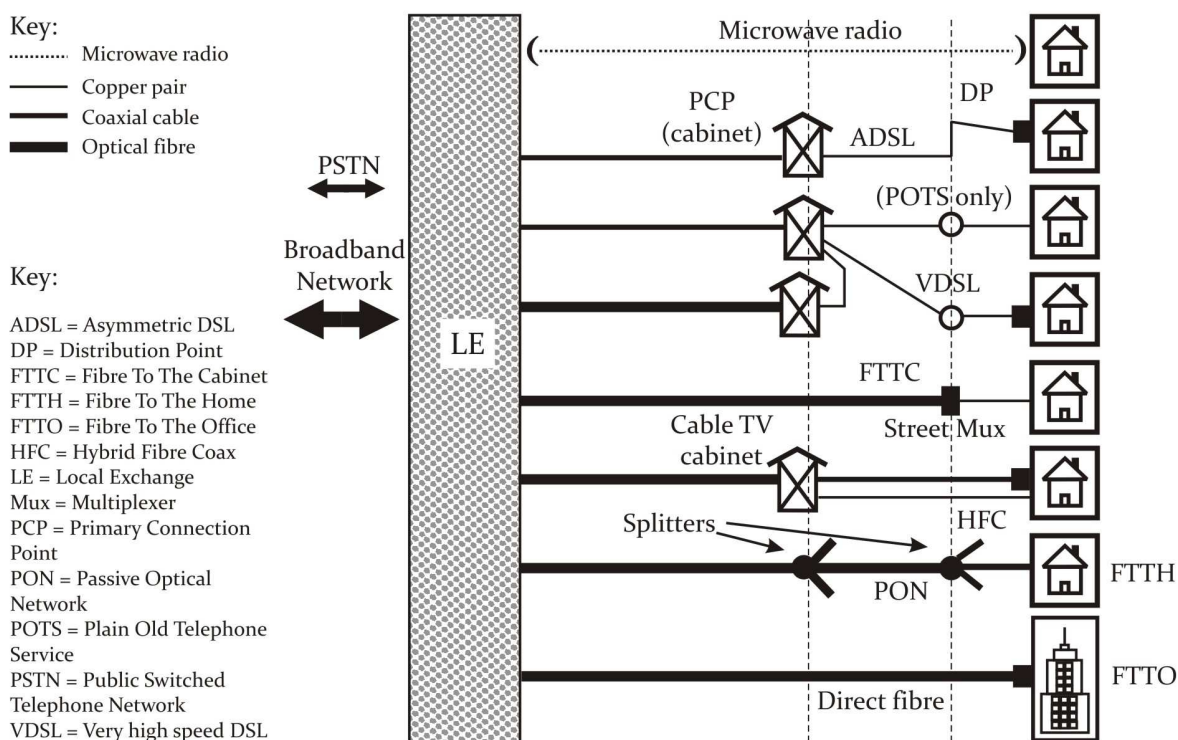


Figure 2.1 - Broadband options for the access network (Source: Valdar, 2006, p. 110)

As the figure shows, a number of different technologies and configurations are possible within the access network and very often the result is a form of hybrid network depending on the location of end-user premises and the operator's choice of technology deployed. Thus the bandwidth available to the end-user for upstream and downstream traffic depends on many factors. Distance from the exchange and the technology used in the last mile from the cabinet to the end-user premise are critical factors for copper networks. For optical fibre networks, the nature of the deployment in the last mile, i.e. passive optical network or point-to-point fibre, is

very relevant to the bandwidth. For cable networks, the number of subscribers in the area sharing the same cable bandwidth is a key criterion. For wireless networks, the nature of standards used for wireless connectivity (i.e. 2G, 3G, or 4G/LTE) is important along with the coverage provided by wireless base stations.

Given the complex mesh of the networks and despite the importance of technology in the last mile, technology in the core network, equipment in the local exchanges, and other parts of the access network including the equipment at end-user premises (such as modems, routers) are also very relevant in relation to what constitutes as "broadband technology". Thus although the primary unit of analysis is technology in the last mile, the term "broadband technology" is not restricted to only the last mile. Used in such a manner, the term "broadband technology" reflects the use of the term in an everyday context. As the discussion in chapter 4 to 7 will show, broadband technologies cover a larger context and do not conform to an artefact-centred view of technology. Given the importance of socio-economic and regulatory factors to the events that shaped the deployment and adoption of broadband technologies, the role of various services such as video-on-demand, Videotex, and the Internet/Web in relation to high-bandwidth connectivity, and the inherently systemic nature of the communications industry (see chapter 3, section 3.8), the term "broadband technology" has a much broader connotation in the narrative that follows. For this reason, the term "broadband technology" is used for the sake of brevity and it encompasses the wider meaning that the following chapters explore in detail. The use of the term "broadband technology" in such a broader, everyday context constitutes the secondary unit of analysis in the discussion presented in chapters 3 to 8. In doing so, the thesis engages in the more complex association of

what broadband technologies mean while at the same time retaining the end-user's perspective of broadband in terms of the last mile access.

2.5 Selection of UK as a region of study

This research also focuses on the UK as a region because the UK communications industry has several distinctive attributes that make it atypical and hence an interesting case to study.

The UK was one of the first countries to denationalise its telecom monopoly, in 1983, ahead of other Western European countries such as France and Germany. Although competition and liberalisation had been introduced in the United States of America (USA or US) a year earlier in 1982, it was done to break the existing private monopoly of American Telephone & Telegraph company (AT&T). In contrast, British Telecom and other monopolies in the Europe that were subsequently denationalised were public-sector monopolies. The public sector telecom monopolies in Germany and France were privatised more than a decade after the UK (Germany in 1996 and France in 1998. See Perrucci and Cimatoribus, 1997 for a discussion on the different regulatory policies in France, Germany, UK, and the USA). This meant that the early regulatory policy measures adopted by the UK regulators such as the Office of telecommunications (OfTel) and the Cable Authority (CA) were without the benefit of hindsight that their European counterparts had. A significant part of the UK regulatory policy was influenced by an ideological focus of relying on competition as a way of increasing efficiency of operations, lowering the cost of services available to end-users, and accelerating

deployment of new technologies in the infrastructure. As the discussion in chapters 5 and 6 will show, such ideological focus was behind a number of key decisions related to the BT-Mercury duopoly, cable franchise allocation, and the constraints on BT's UK operations. As a result, the distinctly different set-up followed in the UK (in comparison to not only the US but also France and Germany) for regulation of the communications industry played an important part in the way deployment of infrastructure took place in the UK.

As the narrative in chapters 5, 6, and 7 will show, a number of additional policy measures on the part of the regulators, strategic choices by the telcos and cable operators, and resultant outcomes in terms of infrastructure investment mean that the UK is not a typical example as a communications market. In order to analyse the factors that influenced the development, deployment, and adoption of broadband technologies, the next section defines the research questions and the research objectives that will shape the discussion in the following chapters.

2.6 Research questions and objectives

With the aim to interpret and understand the events that led to the ascendancy of DSL as a broadband technology in the UK, the overall research theme of this thesis is defined by the following research questions –

1. Why did DSL become the most widely used technology to deliver broadband connectivity in the UK?
2. How do theoretical insights from historical and social studies of technology help us to understand the evolution of broadband technologies in the UK?

Each of these research questions is, in turn, linked to specific research objectives which are outlined in the next two sections.

2.6.1 The first research question

Why did DSL become the most widely used technology to deliver broadband connectivity in the UK?

Throughout the 1980s, 1990s, and the 2000s a number of other alternatives such as ISDN, B-ISDN, optical fibre, and coaxial cable were in consideration to deliver high-bandwidth connectivity. As a result, the first research question focuses on the following research objectives in order to ensure that the narrative analyses the emergence of DSL in contention with other competing technologies -

1. Conduct a comparative study of DSL with other alternatives such as ISDN, B-ISDN, coaxial cable, and optical fibre to understand why DSL became the most widely used technology to deliver broadband connectivity.
2. Examine the role of socio-economic conditions, historical contingency, changing political landscape, market mechanisms, influence of regulatory requirements, unexpected technical breakthroughs, unintended consequences of business and policy decisions, and other auxiliary factors in the selection and subsequent consolidation of DSL as a broadband technology in the UK.

2.6.2 The second research question

How do theoretical insights from historical and social studies of technology help us to understand the evolution of broadband technologies in the UK?

As the narrative in chapters 5, 6, and 7 will show the success of DSL was due to the interaction of multiple factors. In such a context, the second research question covers the following research objectives -

1. Understand the various theoretical perspectives within the historical and social studies of technology and their relevance to studying broadband technologies in a socio-economic, political context.
2. Discuss the extent to which the ideas from various studies on technological change help explain the development, deployment, and adoption of broadband technologies in the UK.

2.7 Research methodology

In order to understand the reasons that led to the dominance of DSL as a broadband technology in the UK, this research focuses on discovering and interpreting the events that have shaped the outcome. As the discussion in chapters 4 to 7 will show, the use of a single theory or hypothesis does not suffice for the analysis of the various factors that influenced the technological changes related to broadband. As a result, the narrative in chapters 4 to 7 relies on multiple strands of theoretical ideas from history of technology, social studies of technology, economic studies of technological changes, and the overall discipline of science and technology studies which are surveyed in detail in chapter 3. Each of these theoretical ideas has been

used to interpret the actual outcome and thus the use of theories and hypotheses has been dependent on the emergent narrative. Since the aim of the research is to interpret the events in the evolution of broadband technologies in the UK, the research is neither intended to develop a theory nor designed to test a specific hypothesis. The study thus uses the abductive logic of enquiry² in order to examine "*the residue of the unexplained*" in relation to the events that contributed to the current market share of broadband technologies (Stainton-Rogers, 2006, p. 89). In order to establish the events to be interpreted, the research focuses on two specific methods -

1. The use of archival research and secondary sources
2. Semi-structured interviews with a wide range of stakeholders from the industry and academia

As the sections 2.7.1 and 2.7.2 will discuss, because of the recent nature of the history and despite the extent of material available, each of the sources, on their own, only provides a partial picture of the events. The archival material often provided only a limited view of the events in relation to BT, Mercury or the regulatory bodies. The secondary sources, on the other hand, analysed the events, policy measures or strategic choices from a specific socio-economic or regulatory perspective. The research interviews often took the form of first-person, inside

² As Stainton-Rogers (2006) explains, three different logics of enquiry exist - Inductive, Deductive, and Abductive. Inductive logic of enquiry gathers data to develop theories. Deductive logic of enquiry gathers data to test theories. Abductive logic of enquiry gathers data to develop hypotheses. Thus given that the evolution of broadband technologies in the UK remains unexplored in a socio-economic and historical context, the use of abductive logic of enquiry is the most suitable approach for this thesis.

accounts of events based on the individual's experience and expertise. As a result, in order to triangulate the data more effectively -

- The archival material and secondary sources were used to form a baseline of events starting from the 1960s.
- The information provided in the research interviews in relation to specific dates, financial data, regulatory measures, government policies, and important industry-specific events was verified for accuracy, and then
- The research interviews were used to build the narrative in chapters 4 to 7.

Through the use of the multiple sources the story that emerges is a combination of various facts, opinions, and recollections of the stakeholders, contemporary analysis, and an account of the events in their historical context. As a result, the narrative presented in chapters 4 to 7 is constructed by combining factual information cross-checked from multiple sources with original, unpublished data provided by the interviews. The next two sections discuss the relevance, advantages, and issues associated with the use of archival material, secondary sources, and research interviews.

2.7.1 Archival research and secondary sources

The archival research was based on material available at the archives of the various organisations involved. The material was primarily in the form of documents and reports available in the public domain and without any copyright restrictions for non-commercial use. Other documents such as internal memos and in-house reports protected by confidentiality clauses were mostly not available due to the

very recent nature of history. The material was collected from the following organisations -

1. BT Archives for annual reports, internal journals, and articles from the Post Office era to the present.
2. Kingston Communications (KCom) annual reports starting with 1989 until the present³. Additional material was available in the form of a currently published KCom report that discusses fibre rollout in the Hull area (Stevenson, 2012).
3. Porthcurno Telegraph Museum – Annual reports, documents, leaflets, reports and responses to regulatory consultations related to Mercury Communications and Cable & Wireless (C&W). This material was collected as part of a 5-day visit and work at the Telegraph Museum in Porthcurno.
4. Oftel and Ofcom archives – A number of documents, reports, consultations, and advisories by Ofcom and its predecessors available at the Ofcom website. The emphasis was on documents related to broadband developments and regulatory interventions (and thus the Independent Television Authority i.e. ITA/ Independent Broadcasting Authority i.e. IBA/ Cable Authority (CA) archive at the University of Bournemouth which focuses on broadcasting and media history was not included).
5. The Institution of Engineering and Technology (IET) and Institute of Electrical and Electronics Engineers (IEEE) publications were used mostly for articles focussing on technical attributes of the technologies and related

³ Prior to 1989, Kingston Communications was a department in the Kingston-upon-Hull council and no annual reports were published. The nature of material available at Hull History Centre was mostly in the form of departmental meetings and memos – with no specific focus on broadband developments (Tanner, 2011).

discussions.

6. Virgin Media – A number of filings to the Securities and Exchange Commission (SEC) of the US by NTL, Telewest, and Virgin Media were retrieved from online resources based on the information provided by Virgin Media Investor Relations Mangers (Bassi, 2012). Due to the frequent changes of ownership in the cable industry, only the following annual reports were available - NTL (1997-2006), Telewest (1997-1999), and Virgin Media (2006 onwards).
7. Research notes from Investment Banks – These became available via a source that cannot be revealed due to anonymity conditions. Once available, permission was sought from the original authors. Any references to these research notes in the thesis have been with the expressed approval of the authors and copyright holders concerned (Edwards, 2012; Murdock-Smith, 2012b).
8. Resources available at the Broadband Stakeholder Group (BSG) – This includes the "Pipe Dreams" report and a number of other reports and documents related to broadband development, deployment, and adoption in the UK.
9. Resources available at the UK government websites - The Digital Britain report published in 2009 and the preliminary findings by the House of Lords Select Committee on Communications focusing on superfast broadband in the UK.

In addition, material was also collected from a number of books and publications related to broadband technologies. This involved exploration of telecoms-centric

articles at journals and proceedings such as *BT Technology Journal* and IET Colloquiums. Documentation of standards and policies on standardisation by organisations such as International Telecommunications Union (ITU), CableLabs, and Broadband Forum has been relied upon to verify some of the technology-specific details. Journals specialising in telecoms policy and strategy such as *info*, *Competition and Regulation in Network Industries*, and *Telecommunications Policy* have been relied upon to get a better idea of the views prevalent in a historical context. The intent with such articles and resources was to gain an understanding of events such as liberalisation, government policies, regulatory interventions, and strategy decisions being taken by companies such as BT, cable companies, and wireless operators as they were unfolding.

Despite the extent of material available, however, such resources also have significant limitations. The annual reports published by BT, Kingston Communications, and Mercury Communications, and filings to the SEC by NTL, Telewest, and Virgin Media reflect only specific aspects of the events, regulatory policies, market conditions, and the strategic choices being made by such organisations. For companies listed on the stock markets, such annual reports and filings serve important public relations function in relation to the investors, shareholders, and the stock markets on an annual basis. For example, during the late 1990s – early 2000s when the telco stocks had seen a rapid fall in share prices (see chapter 6 and 7) and the dotcom crash was at its peak, such reports offered the various companies an opportunity to justify their prior decision-making. A key limitation of such reports is that their authorship cannot be determined beyond the organisation that published it (i.e. the authorship of such reports is effectively

anonymous). In addition, the intended audience in the form of investors and stock markets expect a specific kind of input focussed on financials and plans for delivering profits on a quarter-by-quarter by basis for the next financial year. As a result, the information available in such reports has largely been used to quote factual information related to financials and any investments being made thereof. These annual reports have also been used to understand the response of the organisation in relation to regulatory policies such as price regulation, local loop unbundling, and market conditions such as perceived or actual threat of competition. Even when factual information has been quoted from such sources, caution has been exercised given that such information is often likely to reveal only certain aspects of the actual outcome. In particular, given the extent of BT's market dominance, BT's annual reports have been a rich source of such information. Examples of scenarios where BT's annual reports revealed only a specific side of the story can be particularly seen in the discussion in chapters 5 and 6.

The reports and consultations published by government departments and regulators such as Oftel, CA, and Ofcom although not as commercially focussed as annual reports and financial filings to the stock exchange, also need to be understood in the light of the political environment and the ideological goals that drove strategic choices and policy measures in such a situation. Thus although the Oftel and Ofcom documents offer significant consensus on the merits of measures such as infrastructure competition, price regulation, and local loop unbundling, it is only when sources in the form of journals such as *Telecommunications Policy*, *info*, and *Competition and Regulation in Network Industries* are included that alternative perspectives and possible limitations of such policy proposals can be discerned. This

is not to suggest that regulatory or government consultations do not deliberate over the implications of the policy measures being introduced but to acknowledge that a more independent analysis as presented in a journal like *Telecommunications Policy* provides a more rounded assessment of the possible outcomes and a critical view of the potential drawbacks of such proposals. Used in such a manner, the articles in journals such as *Telecommunications Policy* and *info* provide a more academic and less commercial view of the regulatory measures and analysis of market conditions. Unlike the documents and reports produced by various regulatory bodies and operators, the authorship of such articles is also clearly identifiable and hence has additional credibility given the peer-reviewed nature of the journals.

Since the documents and reports published by various stakeholders including the operators, regulators, or government agencies are likely to reflect a certain perspective, the reports by advisory bodies such as the BSG or the Independent Networks Cooperative Association (INCA) offer useful insights from a less partial view as chapters 6 and 7 will show. The documents distributed by standardisation bodies such as Consultative Committee on International Telegraph and Telephone (CCITT)/ International Telecommunications Union (ITU), CableLabs, and Broadband Forum, although often intended to promote the capabilities of the standard, are also useful sources for factual information and performance metrics in relation to various technologies as the discussion on ISDN, B-ISDN/Asynchronous Transfer Mode (ATM), DSL, and Data Over Cable Service Interface Specification (DOCSIS) standard will show in chapters 5 to 7. However, even the information available via such sources has been verified by referring to more technically orientated resources such as IET archives, IEEE journals, and the *BT Technology*

Journal. The use of research notes published by investment banks (as used in chapter 7) has also been cautious in nature. These research notes have only been used to gauge the prevailing market sentiments rather than assess the merit of the stakeholders' strategies or understand the actual market conditions themselves.

In addition to the limitations of these resources and their inherent biases, there were additional restrictions on the documents available because of the very recent nature of the events. These restrictions were in the form of confidentiality clauses, restrictions due to perceived commercial sensitivities, or even loss of archival material due to passage of time (such as the ones related to Kingston Communications. See footnote 3). Given that a number of these resources available in archives or secondary sources were often likely to correlate to a specific viewpoint (either of the organisation or of the author) rather than the actual events, an additional source of information was needed to corroborate the different version of events. In order to effectively triangulate the information from the diverse sources mentioned above, semi-structured interviews were conducted to ensure authenticity and accuracy to the extent possible. More importantly, the semi-structured interviews also provide an original, previously unavailable perspective for the analysis. The next section discusses the way in which the interview participants were chosen, the terms and conditions of the interviewing process, and the importance of the interviews in relation to the narrative in chapters 4 to 7.

2.7.2 Semi-structured interviews

A semi-structured interview is a flexible interviewing process most commonly associated with qualitative research in which the interviewer does not follow the same structured sequence of questions for all the participants (Fontana and Frey, 2000; Myers and Newman, 2007). As used in this research, the semi-structured interviewing process was intended to elicit first-hand accounts from the interview participants. Although a similar set of questions was used for each of the participants, the questions were not rigidly structured and variations on the question set were used in accordance with the participant's experience and expertise. The main purpose behind the use of semi-structured interviews instead of a structured one, questionnaire or survey, was to allow the participants to express their opinion about the events and also discuss their analysis of the outcomes in relation to the development, deployment, and adoption of broadband technologies. Thus used, semi-structured interviews offered two key advantages (Kvale, 2006) -

1. By enabling the participants to provide a form of personal testimony not only did the interviewing process use open-ended questions but also allowed the freedom to explore topics or events specific to participant's experience and expertise at a greater length.
2. Since the interviews were not conducted with a set of rigidly-defined questions, the issue of pre-judgement i.e. pre-determining what will or will not be discussed in the interview and the researcher's bias being introduced was significantly reduced.

The semi-structured interviews were intended to capture the individual perspectives and undocumented segments of the broadband history. The main purpose was to capture an account of the events according to the stakeholders in relation to the various technologies in the fray, regulatory and government policies, and the implications such choices had for the outcome. To ensure a rounded perspective, a deliberate effort was made to ensure a wide set of participants within the communications industry. By the time the interview process had concluded, research interviews had been done with a number of key people in the UK communications industry covering⁴ -

- Various stakeholder organisations i.e. BT, Openreach, Cable & Wireless, Sky Network Services, Virgin Media, Oftel, Ofcom, BSG, Alcatel-Lucent, The Cloud (now part of Sky Network Services), UKBroadband (UKB), Vodafone, Freedom4/Pipex (now part of TalkTalk Communications), Broadband Forum, and EuroDOCSIS.
- Academic experts in telecommunications, data communications, and regulatory economics at Cambridge University, Cranfield University, University College London (UCL), and Queen Mary, University of London (QMUL).
- Independent consultants and subject matter experts within the UK communications industry.
- An expert in the field of Investment banking with a focus on communications, media, and technology (CMT) sector in the UK.

⁴ A more complete list of the participants, their experience, and affiliation in the industry at the time of the interview is available in Appendix B.

Before approaching any of the interview participants, the terms and conditions of participation were submitted for scrutiny to the Open University (OU) Ethics Committee. Based on the OU Ethics Committee's recommendations, the conditions for anonymity and confidentiality were made clearer and strengthened further (Banks, 2011a, 2011b). The terms and conditions of participation approved by the OU Ethics Committee (Reference number: HREC/2011/#1098/1) were then used to inform the participants of their rights prior to the interview (see Appendices C, D, and E for a copy of the Information sheet, the Data retention policy, and the Agreement to participate that governed the terms and conditions of participation).

The initial set of participants was identified on the basis of the archival material and secondary sources combined with their role and visibility of the events over a period of time. The subsequent set of participants was contacted by following the actors based on referrals from interviewed participants and casting the net as wide as possible in terms of the participants within the communications sector. The collection of personal testimonies was halted once the nature of material appearing and being discussed began to repeat itself (see Seidman, 2006 for further discussion on determining the end-point for the interviewing process). In the large majority of cases, participants were willing to be interviewed. Some participants associated with community broadband initiatives could not commit time for an interview despite expressing an initial interest. The only refusals were by representatives of KCom (Kingston Communications, Hull) citing constraints imposed by the KCom's legal department.

Where possible, interviews were conducted face-to-face. Those that were not face-to-face were either done by a telephone conference or via Skype (see Appendix A for details of the mode of interviewing, date and location of the interview). All the interview conversations were recorded with the explicit permission of the participants. Since the emphasis was on capturing the personal testimony, the participants were requested, where time permitted, to provide their own perspective on what were the important events and milestones in relation to broadband technologies in the UK. Except in one case⁵, questions were not revealed to the participants in advance to retain an element of freshness in the responses and avoid "cleaned-up" versions of events or premeditated answers. For participants who could spend the time to provide personal testimonies, the questions were worked around the narrative they had provided to ensure completeness to the extent possible. At the conclusion of the interview, the participants were provided with an opportunity to include any key points overlooked in the discussion and additional references they could provide. To protect the identity of the participants, the names of participants already interviewed were not revealed to other participants (unless of course, the participant had been referred by someone already interviewed). The participants were given an opportunity to retain a copy of the recorded conversation for their personal record. Four participants requested a copy and were sent a recorded Compact Disc (CD) via post. The participants were also given the option of

⁵ Only Prof. Andy Valdar was given an advance notice of some of the questions related to UK network configuration, technologies such as ISDN, B-ISDN/ATM, and optical fibre, and the way in which unbundling is implemented at the exchange level. These questions were revealed because of their focus on technical aspects and to enable the participant to have the relevant data ready for reference at the time of the interview. Questions related to socio-economic, historical, regulatory, and BT related aspects of broadband technology deployment were not revealed in advance to any of the participants.

having the recorded conversation destroyed after the completion of research. Only one participant requested that the recorded conversation be destroyed.

Once completed, the interviews were summarised to enable further analysis. Except for one of the interviews which was not summarised due to limitations of time, in each case the summary was sent to the participant for feedback. In the case of those participants who responded with feedback, corrections were made to the text and the summary was re-sent for their record. As part of the feedback process, the participant details and the way in which the interview would be referenced was also verified. In accordance with the participant's wishes either their name or parts of the conversation were anonymised in line with the terms and conditions of their participation. Parts of the interview that were identified as confidential by the participants were completely excluded from consideration in the thesis and the interpretation of events offered. Although the confidential material was interesting in its own right, it did not directly relate to the evolution of broadband technologies in the UK. As a result, excluding confidential material did not affect the discussion in chapters 4 to 7 in a significant way.

Since the material to be anonymised or marked confidential was clearly identified, there were no major disagreements in relation to the summary provided, except minor changes, corrections, or rewording of the text. Given the large amount of qualitative data available, not all of the interview material could be used. Because the focus was on interpreting events related to the development, deployment, and adoption of fixed-line broadband technologies, interview material related to wireless technologies, discussion on pros and cons of regulatory policies, and specifics of the

relations between BT and the Other Line Operators i.e. OLOs (including minutiae such as pricing and terms of interconnect agreements) remained mostly unused in the narrative presented in chapters 4 to 7. Factual information quoted by the participants in relation to important timelines, implementation of regulatory policies, financial data pertaining to operators, and end-user adoption of various services and products in relation to broadband technologies was cross-checked and verified for accuracy with the archival material and secondary sources.

Given the breadth and depth of subject matter expertise and industry experience of the participants, the use of semi-structured interviews allowed the participants to discuss the outcomes of a variety of factors in depth. The participants also shed light on each other's viewpoints which although it provided differing perspectives in some cases, a number of events such as denationalisation of BT, cable franchise allocation, growth of satellite broadcasting, industry perceptions about the potential of video-on-demand service, and the role of the Internet/Web in relation to the emergence of DSL as a broadband technology were also corroborated. The narrative presented in chapters 4 to 7 attempts to interpret the events described in these personal testimonies in tandem with archival material and secondary sources. Despite the extent of subject matter expertise and industry experience of the participants, throughout the interviewing process, the author remained aware that interviewees might not always be reliable and might see the interviews as an opportunity for self-justification, redress, or for airing prejudices. However, given the depth and breadth of interview participants' expertise and experience, the problem of possibly incorrect or false information being provided by the participants was minimised due to the extent of overlap in the testimonies and the

cross-verification of the information quoted with archival material and secondary sources.

An important aspect of the personal testimonies thus collected was not only the uniquely personal and in-depth nature of perspectives in relation to the evolution of broadband technologies in the UK but also the highly original and unpublished nature of data available for analysis in the thesis. Since many of the participants were providing a previously unavailable piece of information, they were also providing an inside, unheard of account of the events that shaped the outcome in terms of deployment and adoption of broadband technologies.

2.8 Summary

This chapter established the research question and the research objectives at the core of the thesis. The research methodology used to collect and analyse the data for the narrative in chapters 4 to 7 was also covered in detail. Given the variety of perspectives presented in the research interviews and the breadth of information available in the archival and secondary sources, a wide range of theoretical ideas and approaches were found relevant to understanding the outcome. The following chapter surveys the literature in studies of technological change that covers these ideas and approaches in detail with a view to establishing the analytical framework that will underpin the subsequent narrative in chapters 4 to 7.

3 Literature review

3.1 Introduction

With the research questions and methodology identified in chapter 2, this chapter surveys the various themes and ideas that inform the discussion and analysis that will be part of the narrative in chapters 4 to 7. A survey of the existing literature covering the history of communications industry is presented first followed by a discussion of literature within the disciplines of history and sociology of technology. In doing so, the relevance of the various theoretical approaches to the narrative in chapters 4 to 7 is also discussed.

Since chapters 4 to 7 present a historical narrative of events starting from the 1960s, this research is largely situated within the discipline of history of technology. However with a significant overlap between the fields of history and sociology of technology, the distinction between the different strands of theories covering a myriad of factors such as social, political, economic, and technical influences on the outcome of technological change is no longer as clear as it used to be (see Cozzens, 1989). In this relation, the thesis narrative draws from Walsham's (1993, p. 6) argument that, *"In the interpretive tradition, there are no correct and incorrect theories but there are interesting and less interesting ways to view the world. [...] A particular theoretical perspective blinds us to other perspectives at its moment of application."* As a result, rather than adhere to strict disciplinary boundaries, the survey of literature is driven by the aim to offer an explanation of the events that resulted in the emergence of DSL as the most widely used broadband technology. In

consequence, various perspectives covering the influence of social, historical, political, and economic factors in relation to technological change are considered. The chapter concludes by identifying the gap in current literature and the theoretical ideas that are most relevant to the discussion in the following chapters.

3.2 Studies of technological change and the communications industry

Although several book-length studies relating to the early telegraph industry and development of telephony in the UK exist (for example see Kieve, 1973; Standage, 1998), the insights offered by such studies tend to be specific to the events and circumstances prevailing at the time. Usually these circumstances were very different from the liberalised and globalised communications industry of recent decades. Thus although the early telegraph industry in the UK developed in a competitive manner, it was subsequently nationalised. In contrast, telephony services in the UK were part of the nationalised Post Office service to begin with. However, the modern communications industry is distinctive not only because of the influence of globalisation and economic liberalisation, but also because of the influence of computing industry, the scale and manner of digitisation, and the role of improvements in signal processing, as chapters 6 and 7 explore.

3.2.1 Narrative histories and social, economic, and regulatory perspectives

Several studies about the communications industry such as John Bray's (1995; 2002) works about the various inventors and advances in telecommunications technologies, Solymar's (1999) treatment of the growth in the communications industry starting from the telegraph system to modern-day optical fibre systems, Jeff Hecht's (1999) account of the history of fibre optics, or Huurdeman's (2003) worldwide history of telecommunications, focus significantly on the events and a method of storytelling that would fit what Buchanan (1991; 1993 cited in Fox, 1996) has described as 'narrative history' i.e. a narrative that focusses on description of historical events and does so without theoretical explanations (see section 3.5). More recently a number of articles and papers discussing various aspects of telecommunications history in terms of development and deployment of technologies or standards such as Hayes' (2008) article on the first transatlantic cables, Andrews' (2011) analysis of T-Carrier lines, Prof. John Cioffi's (2011) article on the competition between Discrete MultiTone modulation (DMT) and Quadrature Amplitude Modulation (QAM)/ Carrierless Amplitude Phase modulation (CAP) methods in the context of DSL, or the history of ALOHAnet (Abramson, 2009) have been available. However these are again mostly narrative histories and in addition also focused on a more artefact-centred view of technologies used in the communications industry.

'A Brief History of Communications' (IEEE ComSoc, 2012) provides a narrative history of various communications technologies with a particular focus on the years 1952-2012. It also provides an oral history of important events and major breakthroughs in communications technologies from noted experts such as Vincent Cerf (often called the father of the Internet), John O'Reilly (who was interviewed for this thesis), and Mischa Schwartz (who edited the History column in *IEEE Communications* magazine during 2008-2010). Due to its approach and multiple contributors, it is more akin to an anthology on the various communications technologies covered. Since it offers limited theoretical engagement and discusses various communications technologies in a short space, it is similar to Bray's (1995; 2002) and Solymar's (1999) work in nature. Among article-length studies that adopt a similar narrative approach, Linge (2013) covers the history of the digital age of communications and *"examines the key technological advances that were made, where they occurred and what archaeological evidence remains of their existence"* (p. 45). Other works such as the history of the Post Office (see Perry, 1992; Robinson, 1953), the history of British Telecom (BT, 1998d), although they cover significant stretch of historical events, are focused on the organisations rather than specifically looking at the industry, the practices prevalent in the industry in relation to technological changes or examining the outcomes in their socio-political context.

Although De Sola Pool's (1977) 'The Social Impact of the Telephone' or Fischer's (1992) 'America Calling: A Social History of the Telephone to 1940' are notable examples of studies of telecommunications in a social context, both these book-length studies are focused on the US and in addition focus on the industry before liberalisation took hold. Among other notable examples of studies that consider the

communications industry in a social context is Lipartito's (2003) analysis of AT&T's Picturephone initiative and how its failure was socially constructed. Similar to Lipartito's study, Feenberg (1992), while discussing success of the Télétel system in France, focuses on the prevailing political environment and discusses the outcome in terms of social constructivist ideas. Feenberg's focus is not solely on a historical narrative but what Télétel as a Videotex technology represented to the various stakeholders and how that played a part in the outcome. Thus despite the fact that Lipartito (2003) and Feenberg (1992) are covering events in the communications industry, their emphasis is mostly on the broader themes of success and failure of technologies within social studies of technology.

In contrast to the narrative histories or the social studies exemplified by Lipartito (2003) or Feenberg (1992), Rohlfs (2001) focuses largely on the way in which economic processes (such as the network effect and the bandwagon effect) influence the technological changes in the communications industry. In doing so, Rohlfs expands on the conventional historical accounts related to the communications industry but does so through causal factors rooted in economic processes. As a result, Rohlfs' focus is more on the way in which an economic process such as the bandwagon effect operates rather than establishing the evolution of the technologies in a historical context. Similarly the work of Cave (with Randall, 2001; with Majumdar and Vogelsang, 2002; 2005), Mansell (1997; 2002; with Raboy, 2011), Dutton (1987 cited in Dutton and Blumler, 1988; with Blumler, 1988), and Thatcher (1999, 2002) although it focuses on the communications industry, is not specifically aimed at discussing the technological changes. Instead such work analyses the regulatory and economic aspects of the

functioning of the communications industry and the way regulatory and economic policy affects strategies of various stakeholders including operators, equipment manufacturers, standards-making organisations, and governments. The result, although rich in regulatory and economic perspective, leaves unexplored the technological implications of regulatory and economic policy in relation to the communications industry. The work of Whalley (with Curwen, 2008; 2010), Simpson (with Humphreys, 2005), Fransman (2001, 2002a; 2002b), Marsden (2000, 2010), and Giovannetti (2003; with Neuhoff and Spagnolo, 2007), although insightful in relation to the UK communications industry, is focussed on either the structure of the markets or policy aspects related to regulation, competition, and the Internet. Fransman (2012a; 2012b) and Giovannetti (2000) consider innovation and technological adoption respectively but their emphasis is on strategy or policy outcomes rather than technological change in a historical context.

Despite the presence of such different studies and various analyses, a study of the communications industry in the style of Hughes' (1983) analysis of the electricity industry taking into consideration a number of contingent factors that influence the outcome of technological changes, is not available. The kind of theoretical analysis that Rosenberg (1994) subjects the communications industry and the way in which the industry approaches technological changes and its outcomes, is not reflected in larger and longer discussion and book-length studies such as the ones mentioned in the above paragraphs. The available studies have often tended to focus only on specific aspects such as regulation, economic context or the influence of social factors - none of which work in isolation in the real-world. Such an absence of a study covering technological change within the communications industry by

combining socio-economic and political perspectives points to a gap in the present literature. In this context, Balbi's (2009) analysis of the various theoretical approaches to writing history of telecommunications is very relevant to this thesis. Although Balbi does not present a historical narrative himself, his approach is to consider the various theoretical ideas that explain the technological changes in the telecommunications industry in a socio-economic, political context – an approach closely followed by this thesis and reflected in this literature survey.

3.2.2 Studies about broadband and relevant PhD theses

Focussing specifically on the studies that cover broadband technologies, a search for terms such as "broadband", "history of broadband", "broadband evolution" in the Electronic Theses Online Service (EThOS) provided by the British Library reveals that a large number of Doctor of Philosophy (PhD) theses have covered broadband as a subject. However, a significant majority of the research focusses on the technical aspects of broadband such as improving signal transmission, new or updated methods for digital encoding, next-generation access technologies, and efficient use of the wireless spectrum amongst others. Amongst the theses that are less technical and focus on broadband in the UK, Dwivedi (2005) considers consumer adoption, usage, and impact of broadband in UK households, Enabuele (2008) focuses on the quality of broadband connectivity, and Oni (2007) examines broadband adoption by Small and Medium Enterprises (SMEs). Although such a search of PhD-level theses points to limited availability of treatises covering broadband in a socio-political context in the UK, a wider search of PhD theses on the Web / Google Scholar service reveals a few studies of note that focus on

broadband deployment, adoption, regulation, and the influence of policy measures specific to broadband technologies. These studies are -

- Sigurdsson (2007) investigates the deployment strategies for residential broadband access in Denmark and develops a quantitative simulation model based on existing techno-economic cost models.
- Cameron (2007) discusses broadband adoption in two regions of Australia and suggests a need to re-examine how broadband infrastructure needs to be resourced to support knowledge-based economy in Australia.
- Riihimäki (2010) analyses the problems and uncertainties in broadband access network investments in Finland with specific focus on Worldwide Interoperability for Microwave Access (WiMAX), ADSL, and Flash-Orthogonal Frequency Division Multiplexing (OFDM) technologies.
- Silvestri (2012) looks at broadband development and investment in Next Generation Network (NGN) and the role regulation would have to play to ensure a competitive market in Italy. The approach is to model competition across different scenarios involving regulatory strategies, incumbent operator, and the OLOs.
- Teppayayon (2012) presents an assessment of various European Union (EU) initiatives in order to develop a framework for broadband policy.

Despite the fact that these theses consider development, deployment, and adoption of broadband technologies, none of these are focussed on the kind of historical socio-political analysis of the events that this thesis aims for. Sigurdsson (2007) and Silvestri (2012), although they are closest to the thesis in terms of their focus on deployment and adoption of broadband technologies, rely on a combination of

quantitative analysis and model-based approach unlike the qualitative approach taken by this thesis. Thus the present study is also addressing a gap in relation to understanding development, deployment, and adoption of broadband technologies in a socio-economic, political context.

3.2.3 The need for socio-economic, political analysis of the recent events in the communications industry

As Balbi (2009) points out, history of communications (particularly point-to-point services such as telephony or telegraphy) has not been of major interest to either social scientists or historians. In consequence, history of communications has not developed as a field of study similar to the way in which various theoretical discussions and analyses have been presented in relation to the computing industry. Notable examples of studies about the computing industry are Mindell's (2002) work on cybernetics, control engineering, and digital computing, Campbell-Kelly and Aspray's (1996) work on the way computers grew in capability as information processing machines, and Ceruzzi's (2003) volume on modern computing. The extent to which these works focus on theoretical aspects varies and a number of them are decidedly empirical in nature. Most importantly however, as Martin (2010) contends, such literature points to History of Computing as a small but emerging field of studies. Martin's (2010; 2012) work itself, although centred around History of Computing is orientated towards social studies of technology and away from technologically determinist tradition – an approach this thesis aims to mirror in relation to the UK communications industry.

Despite the wealth of material available on the communications industry, there is not as yet a history of communications discipline, at least not identifiable in the same manner as the History of Computing. Although significant literature devoted to the developments in early telephony and telegraphy exists, a socio-economic, political analysis of more recent developments in the communications industry is not available. This thesis aims to address this gap in relation to broadband technologies in the UK. In doing so, the thesis underlines how conventional or traditional story telling about technology is limited because it often equates description with explanation with the explanation expected to be self-evident from the description (see section 3.5, Shapin, 1990). However such an argument then poses the challenge of determining what counts as an explanation in discussing the history of technology. For this reason, the following sections consider the approaches to historical and social studies of technological change that emerged in the 1970s. Various theoretical approaches such as Social Shaping of Technology (SST), Social Construction Of Technology (SCOT), Hughes' 'technology as a system' approach within historical and social studies of technological change are significant to this thesis is because they are implicitly trying to give explanations instead of simply relying on description. In consequence, these approaches are considered at length in the following sections beginning with a discussion on the extent to which technology can have agency and whether it functions independent of its social and cultural context.

3.3 Technological determinism – agency, autonomy, and the triumphalist narrative

Technological determinism is associated with a view of technology in which technology is considered to evolve according to its own logic. As a result, technology is deemed to be autonomous i.e. it is not influenced by social or cultural factors. In the 'determinist' tradition of thinking technology is assigned agency which means it can act independent of society and culture. However, the term 'technological determinism' is not precisely defined and it is also associated with a triumphalist narrative in which technology is seen to progress towards a goal which is implicit within technology itself. By the deterministic logic, the success or failure of a technology is inherent to the technology itself. Thus the success of a technology over another is often attributed to it being better, superior or the most suitable for its purpose over the failed technology. This argument is crucial to the thesis as it discusses the dominance of DSL and considers the extent to which its success was independent of influences other than the technology itself.

However, despite the prevalence of technological determinism in the literature, the arguments about technological determinism have not gone unchallenged. In particular, Smith and Marx (1994) explore the notion of autonomy and different sides of the debate about technological determinism at great length in their volume "Does Technology Drive History?: The Dilemma of Technological Determinism". Smith (1994) discusses how technological determinism has influenced the understanding and analysis of technological change. Thus, as Smith (1994) points out, 19th century thinkers such as Coxe, Jefferson and Franklin see technology in a

positive light. This theme about technology and technological change as an agent of progress and prosperity is also continued in the writing on industrial revolution (Smith, 1994). Smith and Marx (1994) suggest that the idea of technological determinism takes several forms and these forms occupy places along a spectrum between the "hard" and "soft" extremes. These extremes are exemplified by two prominent thinkers about technology in the mid-20th century – Jacques Ellul and Lewis Mumford. Of these, Ellul (1964) argues that human beings have come to rely on technology (or technique as he calls it) regardless of whether it is needed. This is because, he says, technology decides the outcome independent of other influences. However, the idea of technology succeeding in an evolutionary way, though common, and one strongly adhered to by Ellul, has been called into question by Mumford and others. Unlike Ellul, Mumford (1939) has a less pessimistic view about technology and its influence. Mumford's (1959) willingness to concede that technology is susceptible to outside influence makes Mumford a soft determinist. In contrast, Ellul's pessimism to label modern human existence as being too dependent on technology makes him a hard determinist. However, Falk (1965) suggests that Ellul's analysis of the past as being non-technological, is over-simplified. Inventions such as the paper, clock building, wind mills, and the use of weapons such as guns, gun powder, and the canon suggest the past as not being entirely devoid of technology (Nye, 2006). Such arguments establish how the determinist position about technology being autonomous and influencing its own outcome, overlooks a number of key arguments.

Closer to the position of soft determinism, attempts have been made to bridge the determinist and non-determinist theories about technologies. Langdon Winner

(1977), another important thinker in the determinist tradition points out that technology is a political phenomenon. Thus technological change and its outcome can be potentially subject to political constraints. Winner acknowledges that decisions about technology are likely to be dictated by compromises inevitable in situations involving different stakeholders. Smith (1994) contends that such a position acknowledges that technology and the change it undergoes are not completely independent of outside influences. Despite these concessions however, the extent and nature of influence exercised on technology by the external factors is not clear. The thinking in determinist tradition often leaves questions about the agencies contributing to the technological change unanswered. Thus the emphasis of the determinist narrative overlooks accidental discoveries, serendipitous decision-making, and occasional failures despite planning and foresight that shape technological changes. The result is that the socio-political environment in which the technological change takes place and the unpredictability of the outcome may end up being overlooked in such a narrative tradition. As the discussion in chapter 6 and 7 shows, the unforeseen emergence of the Internet/Web had an important influence on the deployment of broadband technologies particularly DSL – underlining how technological change takes place in an unpredictable manner.

It is the limitations of the determinist thought in recognising the uncertainty with which technological changes unfold that began to be questioned in the 1960s. The alternative approaches that emerged have focused on proving that technology is not autonomous, lacks agency, and how the triumphalist narratives often do not consider the role of social, cultural influences amongst others. Part of the argument presented by these alternative approaches has been to show how the outcome is

influenced by other factors. Some of the early literature in this tradition is about the context in which science and scientific knowledge developed. This tradition subsequently made its way to the studies and theories about technological change that are central to this research. The next section surveys the various approaches in relation to understanding the development of science and scientific knowledge and how these approaches influenced the studies on technological change. The purpose of the following discussion is to cover the ideas that form the foundation of the various theoretical approaches employed in the discussion in chapters 4 to 7. It is important to discuss these ideas given that they are central to the various studies about the social, economic, and political influence on technological change that underpin the narrative in the thesis.

3.4 Factoring in the social influences on science and technology

The studies that began to question the determinist tradition of thinking about science (and later technology) are now identified with the "social studies of science". The fillip to such ideas is considered to be Thomas Kuhn's 1962 book "The structure of scientific revolutions". In the book, Kuhn discusses how the understanding of science follows prevalent 'paradigms' of thinking. A paradigm is defined as a piece of scientific work that has resulted in a research tradition of its own. According to Kuhn, once a paradigm has been accepted, scientists follow such a paradigm on a daily basis as part of their work. However, eventually anomalies may emerge that are not consistent with the understanding formulated by the prevalent paradigm. Once an anomaly has been identified, initial attempts aim to resolve it within the existing paradigm. When the anomaly cannot be resolved with the existing

paradigm that leads to a re-examination of the existing paradigm. Kuhn thus grounds science and scientific theories in paradigms with a periodic occurrence of anomalies and re-evaluation of existing practices. As a result, Kuhn suggests that science and scientific understanding needs to be analysed in the historical context in which the paradigm related to it had emerged.

With Kuhn's discussion on paradigmatic changes, he is discussing the stability of scientific practices and how scientific theory can be subject to interpretation in light of new discoveries and inventions. Kuhn is opening up the 'paradigm shift' to the influence of external, social factors. He is not questioning the validity of the scientific theories and practices themselves. Despite Kuhn's intention to the contrary, his analysis was seen to disassociate scientific theories and practices from the prevailing argument that deemed science and scientists as being objective, and *"independent of the personal attributes or social position of the knowers"* (Mulkay, 1979, p. 298). The inference was that science and scientific knowledge is influenced by other factors such as social factors and hence is not always rational and correct. The effect was to encourage the thought that the notions of correctness and rationality might be socially formed. Kuhn was reportedly not enamoured with the interpretation that social factors are at work in relation to science and scientific knowledge himself (see Kuhn, 1990; Mulkay, 1979). However, the suggestion that science and scientific knowledge is subject to change led to the prevailing arguments about the "rational" nature of science and scientific knowledge being questioned – a situation that played a key part in how the field of social studies of science grew in importance. Effectively, despite Kuhn's reservations, the subsequent

development of social studies of science can be considered an unintended legacy of his ideas.

3.4.1 Causal explanations and the possible limitations of an in-hindsight approach

Of the various approaches that developed within social studies of science, David Bloor's (1991) Strong programme contributes several ideas to the subsequent studies on technological change, particularly Social Construction of Technology (SCOT). Bloor's (1991) Strong programme is intended to ensure that science and scientific knowledge is understood correctly. In order to achieve such a result, Bloor argues that the studies within these disciplines have to be causal, impartial, symmetrical, and reflexive. Each of these terms contributes a specific nuance and approach to the nature of social studies of science/scientific knowledge and is explained as follows -

1. The word causal is used to indicate that the study should be about the conditions responsible for the beliefs or the state of knowledge in its existing form.
2. Impartial is designated to mean that the individual opinions of the researcher or any other third parties on the subject matter should not influence the final explanation offered on the subject.
3. Symmetrical explanation must be offered for the behaviour regardless of the result of the behaviour (i.e. whether it is true or false, success or failure, and so on).
4. The study should be reflexive in that any method applied to the sociology of scientific knowledge must be applicable to sociology itself.

Bloor (1991) argues that the sociology of scientific knowledge needs consistency and neutrality in its analysis regardless of the outcome it is attempting to explain. Such an insistence on methodological rigour in the Strong Programme has had its share of criticism though. Given the largely retrospective use of the tenets of the Strong Programme, Latour and Woolgar (1979) see it as an in-hindsight approach to studying science and scientific knowledge. Instead, Latour and Woolgar advocate a more hands-on, empirical, and real-time approach to science studies. In contrast to Bloor's more methodological approach, Latour and Woolgar (1979) emphasise witnessing the work of scientists as an anthropological study. Their approach is to follow scientific work as it happens on daily basis. Such a study eventually leads Latour (1987) to conclude that scientific facts are open to further analysis and interpretation. The result is an ethnographic approach with a focus on day-to-day science rather than a retrospective study of invention and innovation.

Partly in response to being considered an in-hindsight approach, Bloor's Strong Programme itself has been extended in the "interest" models such as the "Intellectual interest" model by Andrew Pickering (1984; 1995) and the "Cultural interest" model by Steven Shapin (with Schaffer 1985; 1995). In the "Intellectual interest" model Pickering (1984; 1995) considers the debate in the physics community about which model (charm or colour model) explained the behaviour of elementary particles better. Pickering suggests that the charm model was ultimately judged to be the best model not because it withstood the most rigorous trials better but because its proponents mobilised more intellectual and organisational resources than the proponents of the colour model. Thus the charm model was accepted

because it represented the views of a larger "intellectual" community in relation to elementary particle physics. With the "Cultural interest" model Shapin and Schaffer (1985) and Shapin (1995) look at historical practices to understand scientific "truth" in a historical context. Shapin argues that in the 17th century England, as a result of the rules of gentlemanly society and culture, certain individuals were implicitly trusted and could make claims about scientific "truth" that would otherwise have been subjected to greater scrutiny. Thus the prevailing "culture" played a part in the acceptance of scientific knowledge.

Part of the approach with the interest models is related to the tradition in political and economic history which has deliberately attempted to break away from the risk of revisionism i.e. interpreting events with the benefit of hindsight or simply misrepresenting the events out of their historical context (Jardine, 2011). Both these interest models devise different ways of looking at scientific knowledge while taking into consideration the extent to which historical revisionism could have played a part in understanding the outcomes (see Restivo, 2005). Shapin and Schaffer, in particular, approach history of science without trying to be influenced by the eventual outcome. In other words, by not trying to show that victors were rational and that the losers were irrational. Such an approach has also been influential in technology studies as a corrective to the idea that a successful technology is always the best suited to its purpose (i.e. the triumphalist narrative). Such a corrective approach is also central to this thesis as events related to the emergence and consolidation of DSL are discussed in chapters 6 and 7.

Social Construction of Technology (SCOT), one of the approaches in the studies about technological change that the narrative in chapters 4 to 7 draws from, borrows a number of ideas from both Bloor's Strong programme and Latour and Woolgar's ethnographic approach. SCOT is important because of the way in which it makes a break from the determinist traditions of thinking about technology typified in Ellul and Mumford's works. The strength of the SCOT approaches that came to prominence in a conference at the University of Twente in 1984 lies in their intent to open the "*black box*" of technology (Bijker and Pinch, 1984, p. 404). Towards this end, the SCOT approaches argue that social interactions define technology and influence its outcomes (Prell, 2009). Thus the main tenet of SCOT is that neither technological change nor its outcome is deterministic. In the book "The Social Construction of Technological Systems" edited by Bijker, Hughes, and Pinch (1987), a myriad of approaches is discussed that aim to establish the broader theme of social influence on technology. A number of these approaches present case studies of generally artefacts, highlighting an implicit view of what technology consists of. The core approaches that form part of the SCOT framework are generally attributed to Bijker and Pinch's social constructivism¹, Thomas P. Hughes' 'technology as a system' approach, and Latour, Law, and Callon's actor-network theory (ANT). Thus there is not a single version of SCOT but multiple approaches that adhere to similar philosophies about studying technological change and its outcome. Before exploring each of these approaches and their relevance to this research, it would be first important to consider the Social Shaping of Technology

¹ Although the terms social constructivism and social constructionism are sometimes used interchangeably, this thesis makes a clear distinction between the uses of these terms. Social constructionism signifies the larger paradigm of constructionist ideas that are not just restricted to technology studies. On the other hand, social constructivism is identified with the approach articulated by Bijker and Pinch as part of the SCOT approaches.

(SST) approaches which although aligned to SCOT, adopt a somewhat different perspective on the influences that shape the technological changes.

The SST approaches are not as stringent in their focus on the social factors as the SCOT approaches. SST approaches (see MacKenzie and Wajcman, 1990 for further discussion on how social factors shape technology) make allowances for other influences beyond social factors on technological change. Brey (1997), in a primer on social construction of technology, points out that within SST approaches the role of non-social factors in technological change is not rejected. Such flexibility allows SST studies to take less theory-bound and more empirical approach to understanding the technological change. An example is Schwartz Cowan's (1985) study of two different refrigeration systems in the US and how the success of the electric refrigerator was not just a question of it being a better, superior technology. In underlining the role of additional influences, Schwartz Cowan is challenging the traditional triumphalist narrative that would have deemed electric refrigerator a superior technology due to it being the victor. More importantly however, Schwartz Cowan's analysis does not rely on assembling theoretical ideas despite the role of social factors. This is in line with a number of the SST case studies presented in MacKenzie and Wajcman (1990). Compared to the SCOT approaches; this means that the use of SST approaches allows more freedom from the tenets of social studies of science such as the ones defined in the Strong Programme or Latour and Woolgar's ethnographic approach. The flexibility and possibility of inclusion of non-social factors also allows SST studies to delineate and explain a technological change in a less terminology-laden manner. Such an approach is relevant to this study because despite the use of SCOT approaches, the focus of the narrative is not just on

social factors but any additional influences that shaped broadband technologies are also considered.

When considered together as a school of thought, the use of SCOT and SST approaches has depended on the extent to which the theoretical explanation is central to the narrative. How the complexities of real-world politics, power struggle between groups and the privileges available to each group play out in the narrative, depends on the choice of SCOT/SST ideas employed. In this context, the different SCOT approaches have their own strengths. As Cozzens (1989) points out, Hughes' 'technology as a system' approach is considered more suitable to describe technological change in a historical analysis compared to Pinch, Bijker or Callon's approach. Pinch and Bijker's approach in social constructivism and Callon's approach in actor-network theory are deemed more suitable where a sociological analysis of the actors is required (Cozzens, 1989). Bijker and Pinch's social constructivism focuses on objects, artefacts such as the bicycle, Bakelite or fluorescent lamps. Bijker and Pinch examine the gradual convergence of the function and definition of what the technological artefact stands for. Hughes predominantly looks at large technological systems like the North Eastern Electric Supply Company (NESCO) in Britain, Rheinisch-Westfälisches Elektrizitätswerk (RWE) in Germany, and Pennsylvania Power & Light in America (Hughes, 1983). Hughes (1983) studies technological change in an industry-specific context, an approach that offers important insights to this thesis given its aim of examining the evolution of broadband technologies while at the same time considering the changes in the UK communications industry. Hughes' view of the technology as a

system is particularly relevant to the thesis as the discussion in section 3.6.1 and the narrative in chapters 4 to 7 will show.

The roots of Latour, Callon, and Law's approach in the actor-network theory can be traced back to Latour's use of a network as a unit of analysis in the ethnographic approach (Latour and Woolgar, 1979). As a result, the early association of the actor-network theory with the social constructionist approaches and thereby social studies of science is hardly surprising. However, in recent times, Latour (2005) has argued that putting social at the core of all explanations runs the risk of ignoring other important influences. Thus any study that puts social at the core of its explanation is termed the "*sociology of the social*" by Latour (2005, p.9; 35). Actor-network theory, he argues, does not prefer any causal explanation and is thus "*sociology of associations*" (Latour, 2005, p. 9; 35). This means, unlike Bijker and Pinch's social constructivism or Hughes' 'technology as a system' approach, the actor-network theory is more amenable to focus on the description of events and interactions within the actor-network rather than offer a causal understanding of the events. This is because actor-network theory breaks down the distinction between human actors and natural phenomena. Both are treated as elements in "*actor networks*" (Bijker, Hughes, and Pinch, 1987, p.4). An actor-network is defined simultaneously as an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what it is made of (Callon, 1987). Given the complete lack of distinction between human and non-human actors in the network (i.e. generalised symmetry) as part of the actor-network theory, non-human actors have the same kind of agency that human actors do. The result is that the actor-network theory is more abstract and using it to understand

the real-world situations is more difficult than the social constructivist or the 'technology as a system' approach.

For a significant part of the following discussion, the focus will be on how some of the concepts from social constructivism and Hughes' 'technology as a system' approach are relevant to understanding the events that resulted in the emergence of DSL as the most widely used broadband technology. The emphasis of this discussion is on the main premise of the SCOT approaches that technological change does not take place in an autonomous way. Although the various tenets of social constructivism and Hughes' 'technology as a system' approach are discussed and then used in chapters 4 to 7, their use is not intended to entirely explain the outcomes in relation to broadband technologies. These approaches are not meant to be employed as exact mechanisms that can explain the various stakeholders, their actions, prevailing market conditions, and the way in which broadband technologies were developed or deployed. The purpose is to essentially highlight how the main premise of the SCOT approaches i.e. the emphasis on non-determinism and the way SCOT studies challenge the triumphalist narrative, holds true when the evolution of broadband technologies in the UK is considered. In doing so, not only the manner in which these approaches draw from social studies of science is discussed but also the arguments against autonomy in relation to technological change are examined.

3.4.2 Understanding technological change from a social perspective

The premise of Bijker and Pinch's social constructivism is that social interaction between social groups and actors holds the key to how technologies develop.

Depending on the groups and actors involved, the technological change can occur in different ways. The possibility that technology, its changes and outcomes could have turned out differently enables social constructivism to argue against autonomy and the position that technological change takes place independent of social and cultural influences.

To establish the different ways in which technological change could have taken place, Bijker and Pinch rely on the concepts of interpretative flexibility, relevant social groups, and closure. Bijker (1995) presents the ideas about interpretative flexibility, relevant social groups, and closure in historical case studies of technologies such as bicycle, bakelite, and fluorescent lamp when these were new technologies (or more specifically technological artefacts in the context of how Bijker and Pinch define it). Through such case studies, he attempts to show how social effects bear on how technology emerges and how we understand it. Relevant social groups refer to the members or groups of members who share similar interpretations of the technology (i.e. the technological artefact). For example, in Bijker and Pinch's (1987) case study of the bicycle, the relevant social groups are young men, women, and older riders of the bicycle i.e. stakeholders in relation to the bicycle. The use of the word "relevant" is to indicate the importance of the social group in relation to the outcome of the technological changes. Each of the relevant social groups has its own interpretation of what the technology stands for and its function is. Interpretative flexibility indicates that the technology (the artefact) has more than one interpretation. Bijker and Pinch use the concept of interpretative flexibility in a context where technology is newly emerging, and no one is sure what its role is. In the example of the bicycle, the interpretations differ depending upon

whether the young men, women, or older riders use it. Young men see its purpose as a hardy, outdoor activity. For women and older riders the ease of use and utility takes priority. As a result, the design preferred by the relevant social groups also varies. Given the multiple interpretations of the technology, closure starts to take place when the interpretative flexibility diminishes with the multiple interpretations converging. The technology is said to have achieved closure when the relevant social groups agree on the interpretation and a consensus is reached about the function of technology. Thus in the example of the bicycle, Bijker and Pinch discuss how closure is achieved when the relevant social groups agree on its design with wheels of similar size and the use of pneumatic tyres along with its utility as a vehicle for riders of all ages.

With social constructivism Bijker and Pinch bring a number of themes from the social studies of science into the realm of studying technological changes and related outcomes. By focussing on how the relevant social groups see the technology while its function and interpretations vary, Bijker and Pinch aim to avoid an in-hindsight understanding of the outcome. Studying the outcome regardless of whether it explains the success or failure of a technology and conducting the analysis independent of the outcome, as done in social constructivism, draws from the tenet of symmetry in the Strong Programme. Gilbert and Mulkey's (1984) discussion on interpretative variability in relation to methods of discourse analysis is also an influence on Bijker and Pinch's formulation of interpretative flexibility. Gilbert and Mulkey suggest that in doing social studies of science, each version of events whether narrated by scientists or a sociologist needs to be treated on its own merit. Instead of trying to create a consensus-driven narrative, they argue, a better

approach is to allow each version of events to be filtered through interpretative variability. Bijker and Pinch extend this idea where different interpretations or understanding of technological changes can occur during a constant negotiation between the relevant social groups. Since the outcome of such a constant negotiation between the relevant social groups is not certain, different outcomes are also equally possible. As stated earlier, the possibility that different outcomes can occur strengthens arguments against technology having agency and being autonomous.

As the subsequent chapters 4 to 7 will cover, interpretative flexibility plays an important role in how broadband technologies evolved, the functions associated with the technologies and the extent to which the interpretations of the various social groups varied. In examining whether the changes taking place in relation to the broadband technologies would have happened regardless of other factors at work, interpretative flexibility is very relevant. With an extensive use of first-person interviews, Gilbert and Mulkey's formulation of interpretative variability during discourse analysis² is also very relevant for the narrative that unfolds in chapter 4 to 7.

² In plain terms, discourse analysis means the analysis of spoken word i.e. conversation, speech, or discussion. As set out by Gilbert and Mulkey (1984), the (then) prevalent method of using the most coherent and comprehensive version of described scientific events was unsatisfactory. They suggest paying more attention to the interpretative variability present among the participants and the need to understand each actor's voice so that different versions of the same event can be better understood. Thus according to Gilbert and Mulkey (1984), constructing a definitive account of events based on participants' discourse is difficult.

In contrast to the concept of interpretative flexibility, the concept of closure has limited relevance to this thesis. The artefacts studied by Bijker and Pinch in their social constructivist analysis (such as bicycles, Bakelite, and bulbs. See Bijker, 1995) tend to have achieved closure from the perspective of the relevant social groups involved. The difficulty for any study relying on social constructivism, as Gooday (1998) points out, is to identify when closure has taken place. As the subsequent discussion and history of broadband technologies shows, the function associated with various broadband technologies by the stakeholders has changed and continues to change. Thus a key difference in comparison to the technologies studied by Bijker and Pinch is that it is difficult to establish whether closure has taken place in relation to broadband technologies. Unlike the artefacts studied by Bijker and Pinch, it is also not possible to identify broadband technologies solely in terms of an artefact. Treating broadband simply as an object e.g. copper twisted pair or optical fibre cable would result in overlooking other aspects of the broadband technology. The network, equipment or exchanges that turn broadband into a high-bandwidth data connection in the last mile are equally important. Although the unit of analysis for this thesis will effectively be the technology in the last mile, it is important to consider broadband more in line with Hughes' 'technology as a system' approach (discussed in section 3.6) with multiple components that add up to a unified whole.

The difficulty of establishing whether closure has taken place in relation to broadband technologies points to the limitation of relying solely on social constructivism in relation to this thesis. The emphasis on "social" in constructionist studies has often resulted in a debate about the risk of such explanations lapsing

into socially deterministic analyses. This debate is explored in the sections 3.4.3 and 3.5.

3.4.3 The risk of social determinism

Much as the "social" part of social constructivism derives from social studies of science, the "construction" part originates from Berger and Luckmann's (1966) definition of the sociology of knowledge. Berger and Luckmann contend that knowledge as understood by human beings is in a decidedly social context. According to them, since the understanding of knowledge and any subject matter being studied or analysed is bound by its social context, it is thus a "social construct". Arguing that knowledge or any entity is a social construct allows Berger and Luckmann to have a more dynamic understanding and use of the entity and its eventual outcome. Bijker and Pinch's tenets of social constructivism advance this idea to studying technologies. In doing so, they attempt to ground the study of technology with the kind of empirical focus that Berger and Luckmann suggest is necessary to understand the outcome.

It is the emphasis on empirical focus that leads Berger and Luckmann to warn against social construction being used to prove or disprove "*socially produced distortions*" (1966, p. 24) i.e. social being the shorthand for explaining all outcomes. This warning is echoed by Latour (2005, p. 85; 127) by what he describes as the "*sociology of the social*". It also reflects part of the criticism levelled at the social construction of technology field where to counter technological determinism, SCOT and SST thinkers explain social as being the cause of all changes. Although the

emphasis on 'social' by SCOT and SST thinkers is part of their rejection of technological determinism, the risk of such social determinism has led Sismondo (2009) to distinguish between SCOT and SST tenets as radical and mild social constructionism respectively. Brey (1997) has a similar classification where mild constructionists in the SST tradition are considered willing to acknowledge that social may not be the main factor that leads to a technological change. The extent to which SCOT and SST research emphasises social influence has been at the heart of much of the criticism directed at it. The next section explores these criticisms and the alternative approaches that have emerged in response to such criticisms. Consideration of such alternative approaches is important to avoid the possibility of the triumph of DSL being interpreted simply as an outcome of "social" factors. As the various stakeholders (social groups) and their motivations (technological frames) in relation to broadband technologies are discussed in chapters 4 and 5, it is crucial to ensure that a reductionist narrative of the social sort is not created.

3.5 Accounting for politics, power struggle, and micro-political scenarios

Part of the problem with SCOT and SST, as Edgerton (1993) has pointed out, is the extent to which it derives from social studies of science. In arguing that science was influenced by its social context and that scientists were not always neutral and logical actors, social studies of science attempted to demythicise the hallowed turf of scientific work. According to Edgerton (1993), in relation to technology, this is not the revelation it is made out to be. He suggests that given the very nature of technology's interaction with human life and increasing use of technology,

technology has never been considered independent from daily life as science has been. Effectively, the insight that technology is socially influenced is not a huge addition to our knowledge about the workings of technology. In particular, the mild version of SST has been criticised for not saying anything original about the technologies it studies or explaining outcomes that are obvious.

Kirkpatrick (2008) suggests that "mild" social construction (whether in SCOT or SST) is likely to be dependent on the meaning assigned to technology by the humans associated with the social groups. In turn, there is a risk of social constructionist studies oversimplifying the understanding of technology and technological change via abstract terms. This possibility is elaborated by Buchanan's (1991) argument that SCOT is too terminology-laden. Being jargon-ridden and over-reliant on theory, he believes, is counter-productive to understanding technological change. A narrative history, Buchanan (1993 cited in Fox, 1996) points out, will be more useful for understanding technological change. Buchanan's position however is also not without flaws if Shapin's (1990) argument in relation to a narrative history of science is considered. Shapin (1990, p. 992) contends that *"The weakness of that account [relying on a narrative history of science or technology] is the attendant, and largely unacknowledged tendency to equate description with explanation, and to make out of a series of historical events a process which is its own explanation."* Although Shapin is not discussing the conventional histories of technology directly, his criticism is also equally applicable to them in addition to the narrative histories of technology such as Bray (1995; 2002) or Solymar (1999) as these offer description rather than explanation of the outcomes.

In a response to Buchanan's (1991) position, Law (1991) points out that the narrative history is hardly neutral itself. The strength of SCOT, he argues, is that the assumptions are clearly specified. In contrast, any assumptions about the nature of technology and the nature of history made by the narrative history are embedded without the same kind of clarity (Law, 1991). Effectively, the use of narrative history to solve the problems of a terminology-laden interpretation runs the risk of revisionism that was discussed earlier in the section 3.4.1 (see Jardine, 2011).

Latour (2005) describes "social" as having become a shorthand for lazy researchers to explain technological change making an assertion similar to Kirkpatrick (2008) about the drawbacks of SCOT/SST. Despite such assertions, reducing the understanding of technological change to only social context is hardly an intended outcome of the SCOT or SST tenets. Bijker (1987) has attempted to address this perceived limitation of SCOT through two concepts – technological frames and micro-political power strategies (see Bijker and Bijsterveld, 2000). Technological frames are defined as cognitive, social, and technical elements that guide the meaning and behaviour in relation to the technology (Bijker, 1995). The different social groups have varying degrees of inclusion in these technological frames and that subsequently leads to a negotiation between the relevant social groups involved. The strategies used by the social groups to get other groups to agree to their technological frame are called 'micro-political power strategies' (Bijker and Bijsterveld, 2000). The micro-political power strategies allow the social constructivist approach to explain the choices and decisions made by the relevant social groups. In Bijker and Bijsterveld's (2000) discussion on the role of women in Dutch public housing schemes, they employ both the concepts i.e. technological

frames and micro-political power strategies to show how the housing technology was socially constructed. They show how the women's committees supported varying technological frames and employed different micro-political power strategies to gain acceptance and subsequently exert influence more effectively on the housing plans in the Netherlands. Thus throughout the 1960s and 1970s the women's committees mostly supported the nuclear family house with fixed gender roles (i.e. a technological frame) with "*the housewife's experience card*" (i.e. a micro-political power strategy) (Bijker and Bijsterveld, 2000, p. 508). Starting with the 1980s and the changing socio-economic environment, the women's committees began to support houses for single mother families, childless couples, single elderly individuals (i.e. other technological frames) for which they used "*feminist arguments unrestrictedly*" (i.e. different micro-political power strategies) (Bijker and Bijsterveld, 2000, p. 508).

Bijker provides the concepts of technological frames and micro-political power strategies as tools to understand not only the intentions but also the outcome of technological changes as shaped by political struggle. Both these concepts are put to use in chapters 4, 5, and 6 to interpret the nature of interaction and the choices being made by various stakeholders (i.e. social groups according to social constructivism) in relation to broadband technologies. Particularly, the concept of a technological frame will be used to discuss the motivations and actions of the regulators, operators, or end-users (i.e. relevant social groups) in relation to broadband technologies (such as coaxial cable, ISDN, and B-ISDN). As the events from the 1980s and 1990s show, the various stakeholders involved including the UK government, the regulatory bodies, and the telecommunication companies

(amongst others) had different goals that influenced their choices. In case of the regulatory bodies, technology was far from being the main consideration. The operators and service providers were mainly driven by business priorities. Effectively, as the chapters 4, 5, and 6 will show, the evolution of broadband technologies provides a very different context for the concept of technological frames.

3.5.1 Neutral position on technology and politically insipid nature of pronouncements

Although Bijker's updates to the tenets of social constructivism address some of the criticisms related to the treatment of politics, it maintains an avowedly neutral position on pronouncements with regards to the merits and demerits of a technology (Pinch, 1996). This absence of any pronouncements about technologies being studied has led Langdon Winner (1993) to argue that SCOT is politically insipid. In his critique of the constructionist movement, "Opening the black box and finding it empty", Winner (1993) argues that SCOT's political neutrality hinders a better understanding of the society that is influencing the technological change. This charge has been countered by Pinch (1996) who asserts that SCOT's political neutrality is intentional and an attempt to avoid the old-guard thinking about technology. Addressing Winner's argument directly, Pinch (1996) contends that Winner's position is based on thinking about technology rooted in critical theory and Marxist ideas about technology and society.

Although Pinch (1996) argues that critical theory is an old-fashioned stance about technology, such a position overlooks Feenberg's (1991) updates in the form of the critical theory of technology. In contrast to SCOT's neutrality, Feenberg's update focuses on politics and the interaction between technology and society. Feenberg argues that technology and society simultaneously exert influence on each other, a position that finds a resonance in the concept of co-construction. With co-construction, society and technology are argued to co-construct the outcome rather than give into either technologically or socially determinist positions. This idea is explored in "How Users Matter: The Co-Construction of Users and Technologies" edited by Oudshoorn and Pinch (2003). Oudshoorn and Pinch look at how technology and the meaning and association of its function are constructed by the users of the technology when at the same time those developing and innovating the technology construct its meaning. By establishing that society and technology do not function in isolation from each other, Feenberg's position along with co-construction, provides a useful counter-point to the arguments that technology can have agency and dictates its outcomes independent of external influence. In addition to discussing how technology and society influence each other, Feenberg also suggests that technology and specific technological changes are often the means to achieve political and ideological goals. As the chapters 5, 6, and 7 cover, in light of the denationalisation of the UK communications industry, subsequent regulatory policies had an important influence on the outcome of various broadband technologies. In this context, as the next section explores, the way in which political decision-making shapes technological changes and outcome, turns out to be very relevant.

3.5.2 Understanding the extent to which politics influences technological outcomes

Feenberg (1991, 2002) examines the way in which prevailing political regimes influence technology adoption and deployment. Feenberg (1991) calls the resultant interconnectedness of technology and politics 'technical politics' in his writing on critical theory. This idea is strongly echoed in Gabrielle Hecht's (2001) case study of Commissariat à l'Énergie Atomique (CEA) and Électricité de France (EDF), two central organisations tasked with running nuclear power plants in different parts of France in post-World War II (WWII) era. Hecht shows how the use of nuclear technology and its implementation in the power plants was merely an instrument for fulfilling political aims of the organisations involved. In doing so, Hecht (2001) devises two terms – technopolitics and technopolitical regime to discuss two related and yet separate aspects of dealing with technology and the influence of politics. Hecht's (2001, p. 256) aim with these two ideas is to look at *"the strategic practice of designing or using technology to constitute, embody, or enact political goals the relationship between technology and politics"*. Of these, technopolitics involves technologies being used to fulfil political aims in much the same way Feenberg suggests technology is used to sustain the regime in power. The institutionalisation of such technopolitics results in a technopolitical regime. On a wider scale, such a regime consists of interconnected *"set of people, engineering and industrial practices, technological artefacts, political programs and institutional ideologies that act together to govern technological development and pursue technopolitics"* (Hecht, 2001, p. 257). As the narrative in chapters 5, 6, and 7 shows, it is this kind of regime of interconnected set of end-users, operators, government and regulatory policies,

and developments related to ISDN, B-ISDN, coaxial cable/HFC, optical fibre, and DSL technologies that has been at work in the UK – underlining the importance of Hecht's ideas to this thesis.

Feenberg and Hecht's formulations and their consideration to the interconnectedness of the various stakeholders and the multiple factors in understanding the technological changes are valuable in this study. The 'unintended consequences' of a technopolitical regime play a key part in the outcome. As the role of regulatory regimes, government policies, and the priorities of various operators involved is considered in chapters 5, 6, and 7, the extent to which the adoption and deployment of broadband technologies was shaped by unexpected events and how government policy influenced the cable and broadcasting industry becomes clearer. In this context, Kranzberg's (1986, p. 550) argument that "*Although technology might be a prime element in many public issues, nontechnical factors take precedence in technology-policy decisions*" is very pertinent. Although Kranzberg is mostly stating the role of nontechnical factors in a historical context, it highlights the manner in which technological change is influenced by factors that are not focussed on technology. Combined with the arguments against technological determinism, it is the historical perspective that will form one of the important parts of the narrative on the evolution of broadband technologies. The next section explores the way in which examining technological change in a historical context contributes to the discussion in chapters 4 to 7.

3.6 Focussing on a historical narrative of how technological changes occur

Allied to the social constructionist studies and social shaping of technology studies are the works of historians of technology. In contrast to social constructionists, the historians put less emphasis in disproving the autonomy of technology and are more focussed on the analysis of how the technological changes occur and lead to certain outcomes (see Douglas, 1990; Jardine, 2011 for further discussion). A prominent example of such a study of technology is Thomas P. Hughes' "Networks of Power" (1983). Hughes' approach and his formulation of 'technology as a system' can be traced back to some of his work much before the 1984 conference in University of Twente (see Hughes, 1962; 1966; 1976a; 1976b; 1979; 1981; 1983). After the conference, the 'technology as a system' approach can be seen to be much more aligned with the (then) emerging arguments about the influence of social factors on technology. Although Hughes remained a historian of technology, the inclusion of his 'technology as a system' approach in the wider set of social constructionist studies, reflects not only the increasing overlap between history and sociology of technology but also the shared goal of these disciplines in challenging the prevailing accounts about the agency and autonomy of technology. Hughes' ideas are particularly relevant to this thesis since unlike social constructivist studies, this is not just a case study about a new technology being formed. Aligned with the examination of the broadband technologies, this study is also a historical account of the UK communications industry. As a result, Hughes' (1983) analysis of the electricity industry and his 'technology as a system' approach offers important insights for the discussion in chapters 4 to 7.

3.6.1 Considering the technology as a system and the non-neutrality of technology

Hughes' (1987) 'technology as a system' approach is centred on the view of a technology not just as an artefact but as a continuously evolving large technological system (LTS) which has different components that interact and contribute to the development of the system. The components defined by Hughes are – physical artefacts, legislative artefacts, and organisations. Of these, physical artefacts are exemplified by the objects, tools, offices, and any physical networks connecting the objects e.g. *"turbogenerators, transformers, and transmission lines in electric light and power systems"* (Hughes, 1987, p. 51). The legislative artefacts are the rules for the governance of the system *"such as regulatory laws"* (Hughes, 1987, p. 51). The organisations are the companies or the governments that market or manage the system such as *"manufacturing firms, utility companies, and investment banks"* (Hughes, 1987, p. 51). Hughes thus sets up the components as a way of discussing the way in which the large technological system evolves due to the changes in the components and how that influences the system. Alain Gras' (1993; 1997 cited in Balbi, 2009) MST (Les macro-systèmes techniques in the original French) is quite similar to Hughes' approach in this respect. Gras identifies a large industrial object, a complex organisation that manages the communication flow, and a series of commercial entities that link supply and demand as part of his definition of MST. In doing so, Gras also focuses on the power relationships in the system. Hughes, in contrast, is more focussed on the nature of technological changes in the system (see Balbi, 2009 for a more detailed comparison of Hughes' LTS and Gras' MST). Hughes'

interest is in explaining or interpreting the outcomes associated with the technology rather than simply describing. This distinguishes his type of history (also Edgerton's approach – see the next section) from the 'narrative' history of technology advocated by Buchanan (1991) or the conventional history of technology in which description and narration are main purposes (see also Shapin's quote in section 3.5).

In order to explain the way in which the large technological system evolves, the key ideas within Hughes' 'technology as a system' approach are – reverse salients, critical problems, technological style, and momentum. Reverse salients, a term Hughes (1987) borrows from military terminology, refers to a situation where some components or parts of the system lag behind others in development. Intrinsically unsolvable, as reverse salients appear, the technological system eventually breaks down. It is only when the reverse salients are parsed into critical problems that they become solvable. The development of the technological system continues once the critical problems are resolved. The concept of reverse salients is of particular relevance in chapter 5 and 6 as part of the discussion on ISDN and B-ISDN and the issues that held back their deployment and adoption.

In addition to its use for analysing problems in a technological system, Hughes (1976b; 1987) also relies on the concept of reverse salients to show how technological systems do not evolve in a linear, predictable fashion. This non-linearity and unpredictability is further demonstrated by what Hughes refers to as technological style. Technological style refers to the regional and local differences in the deployment and adoption of technological systems and how these differences influence the outcome. With the concept of 'style', Hughes (1987) aims to show

technological changes vary according to a place and they are contingent upon the circumstances (see also Bijker, 1987). As the discussion in chapter 5 will show, BT's denationalisation and the subsequent liberalisation of the UK communications industry created a unique set of circumstances that have played an important part in the deployment of ISDN in the UK. Hughes' concept of 'technological style' proves very pertinent in discussing such a scenario.

However, despite an overall non-determinist position, one of the problematic aspects of Hughes' 'technology as a system' approach is how he defines momentum. With 'momentum', Hughes (1969; 1987) attempts to bridge the deterministic and non-deterministic positions. Hughes argues that the influence of technology is time-dependent. Thus early in its development, technology is influenced by the society and the environment in which it functions. As the technology matures, Hughes suggests, it begins to exert its influence on the society. This willingness to accept that technology, once it matures can function independently of its environment, marks Hughes as a soft-determinist (a charge Hughes seems to have accepted. See Aitken, 1990; Nye, 1984). Despite the soft-determinist position that the concept of 'momentum' argues, Hughes' approach is particularly suited to the kind of projects that he studies i.e. electrification in Germany, US and the UK in the early twentieth century (1983), development of large systems such as Semi-Automatic Ground Environment (SAGE), Atlas InterContinental Ballistic Missile (ICBM), and Advanced Research Projects Agency Network (ARPANET) in the post-WWII USA (Hughes, 1998) or biographies of Elmer Sperry (1971) or Edison (1976a). In each of these studies Hughes underlines the focus on the utility of the inventions and the technologies, the economic case for the technology, and the kind of methodical and

yet practical considerations that influenced the actions of the stakeholders. This has led Nye (1984) to suggest that Hughes' approach is far more applicable to early capitalistic systems and large infrastructure projects such as railways or electricity plants and may not be suitable for the kind of regimes that Soviet Russia (or the current day China) have operated in. In contrast to Nye's assertion, Jonathan Coopersmith (1992), in his study of electrification of Russia does not rule out the validity of Hughes' approach completely. He suggests that part of the inferences drawn by using Hughes' approach would be valid even with the old Soviet-style Communist system.

Unlike Bijker and Pinch, Hughes is primarily a historian and this is reflected in his focus on historical aspects and the concepts he uses despite the importance he gives to social factors. Such a blurring of boundaries between social studies of technology and the history of technology as exemplified by Hughes' studies, has led Kranzberg (1986; with Pursell Jr. 1967a; 1967b) to attempt to balance some of the recurring arguments about determinism and the role of social factors in relation to the history of technology. Kranzberg focuses mostly on the ways in which invention and innovation is shaped by unforeseen situations and circumstances (see Cutcliffe and Post, 1988 for a more detailed appraisal of Kranzberg's views on history of technology). Similar views can be seen in the works of Kranzberg's contemporaries such as Ferguson (1961; 1962) and Multhauf (1954; 1958; 1965a; 1965b). Their key contribution to the discipline of history of technology, Roland (1990, p. 163) suggests, is that they introduced "*organic, social, and externalist perspectives*" at a time when the prevailing culture was focused on deterministic, in-hindsight explanations that often attributed agency and autonomy to technology. Thus,

Roland (1990, p. 163) argues, Kranzberg, Ferguson, and Multhauf effectively challenged the existing "*Whiggish, mechanistic, internalist*" accounts of history of technology (see Mayr, 1990 for a more detailed discussion on what constitutes as Whiggish history).

However, despite the way in which Hughes' 'technology as a system' approach and the works of Kranzberg, Ferguson, and Multhauf enable externalist perspectives to be presented, in their work a lot of emphasis is placed on the invention and innovation phase of technological change. In this respect these approaches resemble social constructivism which has also been criticised for focussing too much on invention and innovation (see Pinch, 1996 about a related discussion). Edgerton (2006), one of the critics of the SCOT approaches, has tried to address this situation within the field of history of technology where a number of studies have overlooked the technology after it has been deployed. In his critique of social constructionist approach, Edgerton (1993) points out that it overlooks the role maintenance of technology plays in its evolution. By focusing on a use-based history of technology, Edgerton aims to shift the emphasis of understanding technology in a real-world context. As discussed in the next section, he does so without presenting a full-fledged theory or set of frameworks in the same manner as SCOT. Edgerton's approach highlights a gap in the more conventional studies within the history of technology. Given the importance of maintenance-driven innovation in relation to DSL broadband technologies, Edgerton's ideas are explored next.

3.6.2 The importance of how technology is used and maintained

Edgerton (2006) presents a historical account of technologies such as cars, planes, trains, and a host of other devices when the innovation activity is mostly over and the technology is primarily being maintained to continue its role. Although the reasons for the continued maintenance are equally likely to be political, economic or simply commercial, Edgerton's argument highlights the risk of ignoring a technology after it has been deployed. Edgerton suggests that the real history of technology is not just the popular history presented in the narrative of a heroic inventor, the story of invention or innovation where technology is discussed as though it were a succession of innovations. The real history, Edgerton argues, is about what happens to the technology once it is available in the real-world, how it is used and adapted to the environment in which it is rolled out. By ignoring maintenance as an activity, innovation and invention-centric studies of technological change also overlook a large part of a technology's life time (see Kline and Pinch, 1996; Pinch, 1996). As Edgerton (2006) points out, the outcome of any maintenance activity is far from predictable and results in the technology not being transferred in an orderly, predefined fashion. Instead, the technology and its function get adapted according to how it is used. Consider for example the way in which telephony networks originally designed for voice became adapted for data and cable networks were adapted to support broadband in addition to existing broadcasting capabilities. An example specific to broadband technologies is of how DSL broadband was developed for on-demand services but ended up getting used for Internet access. Seen from this perspective, broadband therefore is not an innovation as usually understood but a series of innovative adaptations of existing

systems. As the discussion in chapters 5, 6, and 7 will show, this is one of the reasons why the evolution of broadband technologies is more amenable to being understood with Hughes' 'technology as a system' approach rather than social constructivism.

Edgerton's ideas are often seen to differ significantly from the social constructionist and social shaping of technology studies. The contrarian nature of Edgerton's approach is summed up by Fara (2007, p. 622) who comments that "*Combining historical acumen with social commentary, Edgerton aims not only to reinterpret technology's past, but also to change its future.*" Hughes (2007) in his review of Edgerton's (2006) work "The shock of the old" argues that Edgerton's approach is markedly different due to its focus on use-based history in contrast to the more conventional histories that are concentrated on invention and innovation. As Pursell (2008, p. 237) points out, Edgerton "*attempts to undermine simplistic understandings of technology*" by focussing his investigation on "*technology in use*". This emphasis on the use and maintenance of technology as the chapters 6 and 7 show is important given the relevance of maintenance as an activity in relation to the DSL broadband technology.

By focussing on use-based history, Edgerton also discusses how the correlation between invention/innovation and economic growth is over-emphasised at the cost of ignoring the importance of maintenance as a key activity. If the studies of technological change are considered, this emphasis on economic growth and technological invention and innovation points to another important area of literature for the discussion in chapters 4 to 7 – studies that focus on the correlation

between economic factors and technological change. If the liberalisation of the UK communications industry starting from the 1980s and the influence of various market-orientated policies on the outcome of broadband technology deployment is considered, the discussion about the role of economic factors on technological change becomes pertinent. The following section focuses on such economic studies of technology and their relevance in relation to the way broadband technologies evolved.

3.7 The role of economic factors in relation to technological changes

The importance of economic factors in relation to technological changes is explored in Nelson and Winter's (1974) model of technology evolution. Nelson and Winter's model raises questions about two commonly cited forces that influence the outcome of technological change i.e. science/technology push and demand pull. The concepts of technology push and demand pull in turn originate from different perspectives about how technological change and the innovation that causes it, takes place. The arguments around science/technology-push come from the Schumpeterian tradition of economics. The arguments focused on demand-pull are based on Jacob Schmookler's formulation of how the markets work. In this context the next section examines the extent to which the supply and demand side forces are important to the way technological change takes place and how broadband technologies have evolved in the last mile. This is because as the discussion in chapters 5, 6, and 7 shows any understanding of the evolution of various broadband

technologies in the UK would need to take into consideration the economic impact of government policy, regulatory regime, and industry finances.

3.7.1 Defining push-pull factors in relation to technological change

Schumpeter's (1942) ideas, concern the role of monopolies and oligopolies as an efficient means of increasing innovation and achieving higher economic growth via an institutional push. In contrast to Schumpeterian push, Schmookler argues that innovation and technological change are spurred by demand (Schmookler, 1966). Although Schmookler's formulation does not rule out institutional push completely, a significant part of his argument centres on demand. Schmookler's and similar ideas are associated with 'demand pull' – a market force that is a catalyst for economic growth and the technological change that causes it.

However, Coombs et al (1987) argue that subscribing to either technology push or demand pull completely presents an inaccurate understanding of the role of economic factors in technological change. On the one hand, the critics of technology push have argued that it underestimates the role of pricing and economic conditions in the outcome of an innovation (Nemet, 2009). On the other hand, the criticism of the demand pull idea has often centred on its importance as an economic force (Rosenberg, 1974) and varying definitions of what constitutes demand itself (Mowery and Rosenberg, 1979; Kleinknecht and Verspagen, 1990). An additional school of thought is to highlight that push-pull forces are complementary and not mutually exclusive. As Arthur (2007) points out, push-pull factors not only contribute to the outcome, they also interact during the process. If the situation in

the UK communications industry in the late 1990s and early 2000s, as discussed in chapters 6 and 7 is considered, the deployment and adoption of broadband technologies was not simply a question of either a technology push by BT as an incumbent operator or a matter of sufficient end-user demand for high-bandwidth connectivity. The emergence of DSL was tied to a number of factors including the prevailing market conditions and cost considerations. Such a scenario is in line with Coombs et al's (1987) argument that technological change is a complex process in which both supply and demand play a key role depending on a variety of external factors. It is these perceived limitations of the technology push-demand pull ideas that are at the core of Freeman et al.'s (1982) aim to broaden the scope of Schumpeterian technology-push and Schmooklerian demand-pull.

Freeman et al (1982) attempt to put together the various factors i.e. the different stakeholders, their motivations, the influence on the markets and the resultant technological changes into a theory called 'New Technology System'. Such an approach discusses the ways in which economic growth is centred on how effectively the diffusion of technological changes is clustered, a position that finds an echo in David Edgerton's (2006) analysis of technological change and his arguments emphasising the importance of use-based history discussed earlier. Thus the conclusion presented is that the long-term significance of technologies is not driven by the superiority of the innovation or the nature of technological change alone. Instead, the social and political environment in which the technological change operates combined with "market-based" economic activity is seen as a key influencer in the direction of technological change (Coombs et al, 1987). Coombs et. al. thus posit that the interconnectedness of technology with social and economic

factors has a significant influence on the outcome of technological change. When the conditions that governed the initial selection and subsequent consolidation of DSL are considered in chapter 6 and 7, the relevance of this kind of interconnectedness becomes clearer. This interconnectedness is also a key consideration as the supply-demand side shifts in the markets, their influence on technological change and in particular, the bandwagon effect and its importance in relation to broadband technologies (specifically DSL) as examined in the next section.

3.7.2 Economic disequilibrium and the interaction of supply-demand sides

As defined by Leibenstein (1950), the bandwagon effect in microeconomics refers to the situation where the benefits of a product or service derived by an end-user increase relative to the number of end-users who use the product or service. Such an accumulation of end-users creates a strong demand for the product or service and influences the supply-side significantly. The bandwagon effect is one of the three complementary effects in the theory of demand along with the Snob effect (which focuses on the exclusivity of a product/service driving the demand) and the Veblen effect (which focuses on the increase in the pricing of a product/service driving the demand) (Leibenstein, 1950). The bandwagon effect is manifested in two types of outcomes. When the first type of outcome, network externalities takes place, the benefits available to end-users increase or multiply as more end-users use the same product or service. Network externalities are associated with the demand-side of the equation in the bandwagon effect. With the second type of outcome i.e.

complementary bandwagon effect, the supply of the product or service grows to cater to the cumulative demand for complementary products or services that develop due to the bandwagon effect. In contrast to the network externalities, the complementary bandwagon effects are associated with the supply-side of the bandwagon effect. Both, network externalities and complementary bandwagon effects can be seen at work in relation to DSL as the discussion in chapter 7 will show in detail.

Rohlfs (1974; 2001), in particular, has examined the bandwagon effect in detail in relation to the telecommunications industry and the adoption of technologies in relation to telecommunications. Rohlfs (1974; 2001) discusses how subject to supply and demand side constraints the deployment of a technology can deliver benefits to end-users that result in increased demand and further accelerate the deployment of technology. As the discussion in chapter 7 will show, Rohlfs' views in relation to the bandwagon effect and the telecommunications industry offer important insight in relation to DSL broadband deployment and adoption.

However, an important part of the argument presented by the theory of demand and the bandwagon effect is that the end-user demand is not just driven by the pricing of products or services but also by their value and quality. This argument is underlined by the events in the 2000s where technical merits and pricing were just two of the factors that influenced the end-user demand and the deployment of broadband technologies in addition to the role of the regulatory, financial, and governmental decision-making. Nelson and Winter (1974; 1977), and Dosi (1982; 1984a; 1984b) have attempted to address some of this complexity of supply-demand

side interaction by highlighting how the decision-making of the various stakeholders operates within a lack of equilibrium. In this context Nelson and Winter (1977, p. 49; 52) devise the term "*selection environment*" to describe a competitive market with various stakeholders in which the "*relative use of different technologies changes over time*" (p. 61). The relevance of such a selection environment, Coombs et al, (1987, p. 120) argue, is that "*different motivations, rewards and criteria for success*" influence the outcome. The result as Coombs et al (1987) discuss is "imperfect competition" due to the imbalance in the skills, resources, and finances available to various industries, organisations, and stakeholders. The outcome of technological change as a result of this lack of equilibrium is far from predictable. As the discussion in chapters 6 and 7 will show, similar uncertainty and lack of equilibrium in the UK market played an important part in the initial selection of DSL as a broadband technology.

The subsequent narrative in chapters 4 to 7 will establish that the development, deployment, and adoption of broadband was contingent on a number of factors working in combination with each other. To allow the events to be examined in their historical context and as a corrective to creating either social, technologically or economically deterministic narrative, a number of factors need to be taken into consideration. For this reason, the next section considers the role of historical factors and the way in which technological change is influenced by a prior sequence of events. In order to do so, the concept of path dependence as put forward by David (1985) and Arthur (1989; 1990) is discussed in detail. The relevance of the concept of path dependence in relation to the capital intensive nature of the communications industry is also considered as part of the following discussion.

3.8 Historical contingency and the systemic nature of the communications industry

Path dependence is a concept in the fields of history, economics, and social sciences that refers to an outcome at the end of a long run of events. As Liebowitz and Margolis (2000, p. 981) point out - "*path dependence means that where we go next depends not only on where we are now, but also upon where we have been.*" The key idea behind path dependence is that even a minor initial advantage (such as early market entry or lower cost) or a few random shocks along the way (such as unexpected end-user choices, unforeseen market changes, or emergence of disruptive innovations) for a technology, product, or service can result in irreversible influences on the market (David, 1985; Arthur, 1989). Depending on the importance of the starting point for the sequence of events, the extent to which outcomes are irreversible, and the influence on market conditions, the nature of path dependence at work can vary significantly (Liebowitz and Margolis, 1995). Despite the variations though, the overall focus of using path dependence as a concept remains on explaining the outcomes in their historical context.

Given its emphasis on historical sequence of events to explain an outcome, the use of path dependence to say "history matters", has been criticised as a form of by historical determinism (see Thelen, 1999). Page (2006) in particular, has argued that the use of path dependence to say "history matters" has dulled its value. However despite the use of path dependence to emphasise historical events and the way in

which the concept of path dependence has been employed in various disciplines³, it was originally formulated by David (1985) and Arthur (1989; 1990) to discuss technology adoption (Stack and Gartland, 2003). It is in this context of technology adoption that this literature survey mostly focuses on the use of path dependence. Given the role of multiple factors in the evolution of broadband technologies, the concept of path dependence is very relevant for the analyses of social, economic, political, and technological factors in chapters 4 to 7. Before proceeding to that part of discussion it would be pertinent to consider how David and Arthur have presented the idea of path dependence.

David (1985) examines path dependence in relation to the prevalence of QWERTY keyboards. David (1985; 1997) focuses on how historical contingency contributed to QWERTY keyboard becoming popular. The way in which the use of QWERTY keyboard displaced other alternatives once it was popular, is also analysed in the same case study. Arthur's (1990) best-known case study of path dependence is about the Video Home System (VHS) vs. Betamax battle for Video Cassette Recorder (VCR) formats. Arthur shows how once the number of consumers using VHS players grew, it led to diminishing returns on Betamax as an investment for the consumers. Thus Arthur discusses the way in which technology adoption depends on its historical context. Similar to David, Arthur (1989; 1990) positions path dependence as an economic theory and explores how technology adoption is influenced by a specific sequence of events being at work. The outcome of innovation and

³ Path dependence has been used in a number of disciplines amongst which economics (see David, 1997), historical sociology (see Mahoney, 2000), and political science (see Pierson, 2000) are notable examples. For a more detailed discussion on how the field of studies related to path dependence has grown, see Magnusson and Ottosson (2009).

technological change is thus argued to be unpredictable and dependent on the various stakeholders at work at different points of time during its history. Arthur (1990) introduces the idea of 'small events' which he suggests can alter the outcome of technological changes and thus lead to unexpected results in terms of deployment and subsequent use of a technology i.e. tilt the competitive balance. David (2007), on the other hand, presents a 'theory of framing conditions' as part of which he discusses how once a technology has been adopted, it can create barriers to reversing the selection of technology and make switching to other technologies difficult. Both Arthur (1989; 1990; 1996) and David (1985; 1997; 2007) discuss how once a technology has been adopted, its use can grow at the expense of other similar and sometimes even better technologies. As the discussion in chapters 6 and 7 will show, in the context of selection of DSL and the growth in DSL adoption, the concepts of small events and framing conditions prove to be relevant.

Despite the criticism from Liebowitz and Margolis (1990; 1995), who argue that the use of path dependence as done by David (1985) and Arthur (1989; 1990) does not conclusively explain any of the outcomes it covers, it has become an oft-used concept to understand the role historical contingency plays in the outcomes. In relation to this thesis the concept is useful because as Rosenberg (1994) argues, path dependence uniquely amplifies the systemic nature of communications industry and the role of government policy in analysing the outcome of technological change. The capital intensive nature of the industry places unique constraints in relation to technology deployment and adoption since as Rosenberg (1994, p. 205) points out " ... *This is particularly true in telecommunications where future investments must remain compatible with the currently chosen system, as capital in*

telecommunications is unusually long-lived." Thus the two causes of path dependence that Page (2006) elaborates i.e. increasing returns and lock-in, are particularly relevant where investment is dependent on prevailing circumstances and made with a view to long-term goals. As the discussion in chapters 6 and 7 will show, in an increasingly competitive market the operators' decisions vis-à-vis investments in broadband technologies were strongly influenced by returns possible on investment – a situation in which the concepts of increasing returns and lock-in offer important insights.

In addition to the causes of path dependence such as increasing returns and lock-in, given its emphasis on historical causality, path dependence is also relevant to highlight how the nexus of various events, stakeholders, and decision-makers contributed to the way broadband technologies were deployed, implemented, and adopted in the UK. As the events that led to the current market share of broadband technologies in the last mile are discussed in chapters 4 to 7, the narrative will overlap with various disciplinary boundaries i.e. the history of technology, sociology of technology, and economic studies of technological change that have been explored in this literature survey. The multi-disciplinary relevance of path dependence allows a socially aware, historically contingent, and contextually-focused explanation to be offered.

Not only does the narrative presented in chapters 4 to 7 cover the very recent history of communications industry in the UK, but it also does so by considering the socio-economic, political context in which the evolution of broadband technologies took place. In each of these chapters, the various events that shaped the selection

and consolidation of DSL are examined against a range of theoretical perspectives surveyed in this chapter. In the end, chapter 8 provides the conclusions on the various narrative threads and theoretical approaches covered. Before beginning the thesis narrative however, the next section summarises the findings of this literature survey and the gap in current research that this thesis targets.

3.9 Summary

This chapter has surveyed the various themes within the fields of history and sociology of technology. The nature of existing research in relation to technological change and its outcomes has been discussed against a range of theoretical concepts. The discussion has included an examination of the early determinist tradition of writing on science and technology, the emergence of social studies of science/scientific knowledge, and the way in which both these approaches influenced various studies in relation to technological change such as social shaping of technology and social construction of technology approaches. The works of Hughes and Edgerton who are primarily historians of technology and the extent to which it contributes to and challenges the ideas within sociology of technology have also been covered. This analysis has been combined with a survey of literature in relation to the economic studies of technological change, the interdisciplinary approach of path dependence, and various narrative studies in relation to the communications industry. Balbi (2009), although he does not present a historical narrative and focuses only on the theoretical ideas relevant to presenting a history of communications makes very similar choices. He identifies social constructivism, Hughes' 'technology as a system' approach', and path dependence as the most

relevant theoretical ideas. Although Balbi is not focussed on a specific aspect or technology of the communications industry (such as broadband technologies as in this thesis) and arrives at his conclusions differently, the similarity of the choices is noteworthy.

The literature survey has shown that despite significant research, a study combining an understanding of technological change and the communications industry as part of a historical, socio-economic narrative is currently not available. The currently available literature has tended to focus either on specific aspects of technological change or on economic, regulatory perspectives in relation to the communications industry. The result has been various analyses discussing technology from an artefact-based view or non-deterministic narratives in the social constructionist/social shaping tradition. Although articles on technological change and the shifting landscape of the communications industry are available, such accounts are mostly conventional, internalist narratives and do not attempt to deliver theoretical insights. When the changes in the communications industry in light of the liberalisation and denationalisation of the industry, improvements in signal processing and digitisation, and the convergence of voice, data, and video services are considered, a study examining the way in which socio-economic, political, regulatory, and technological factors influence technology development, deployment, and adoption is not currently available. Such a situation points to a gap in relation to studies providing a causal explanation of the outcome of technological changes in the communications industry with consideration to the myriad factors that influence them.

In order to reflect the influence of these multiple factors, the discussion in chapters 4 to 7 chooses to employ a number of approaches surveyed here. The narrative in these chapters will rely on blurring the boundaries between economic, social, and historical studies of technological changes when attempting to relate the various theoretical concepts in a practical context. The aim is not to use these approaches as a way to explaining every facet of the various events and outcomes. The following chapters not only cover the way in which these ideas can be applied in the context of an increasingly liberalised UK communications market but also show the limitations of some of the theoretical ideas in relation to the development and deployment of broadband technologies. As stated earlier, these ideas are not intended to be exact mechanisms to understand the outcomes associated with the evolution of broadband technologies. The focus is on underlining the extent to which the eventual result in terms of the emergence and consolidation of DSL as a broadband technology was dependent on multiple influences and hence not a result shaped by either technological autonomy or because DSL was an inherently better or superior technology to the alternatives available.

The aim of the narrative and the theoretical discussion presented in chapters 4 to 7 is not only to address a gap in the current literature in terms of understanding the way broadband technologies have evolved but also to combine such an analysis with a historical account of the communications industry in the UK from 1960s onwards. An additional intent of such a narrative is to present how the evolution of broadband technologies is not just a matter of the physical artefacts in the last mile, the networks or the exchanges but how it has taken place in a systemic context. In doing so, the thesis examines the extent to which the evolution of broadband

technologies in the UK has been contingent upon the role of socio-economic, political, regulatory, and technological factors.

4 Datal, early digitisation, and "wideband" connectivity

4.1 Introduction

An important advancement that influenced the way broadband technologies evolved in the UK originated in the 1960s. Pulse Code Modulation (PCM), although it had been conceived in the 1930s, finally became a practical possibility due to the improvements in transistor technology. With the use of PCM becoming practical, the introduction of digital electronic equipment began in the existing telephone network. As a result, starting with the 1960s, the data transmission capacity of the existing copper network (i.e. PSTN) continued to improve. The use of the PSTN to transmit data would turn out to be very relevant to the way broadband connectivity was delivered in the following years.

This period of introduction of digital electronic equipment was overseen by the rule of the British Post Office (hereafter "Post Office") which at the start of the 1960s was a government department. By the end of 1960s, it had gained a measure of independence by becoming a public sector corporation i.e. a legal entity created by government charter and owned by the government. Its evolution as an organisation took a further important turn when by the end of 1970s the postal and telecommunications operations were separated as a prelude to the creation of British Telecom. Throughout this period of the Post Office's monopoly in the 1960s and 1970s, it experimented with a number of technologies intended to not only lower costs of transmission but also deliver wider variety of high data-rate services such as television broadcasting and Videotex. The key attribute of these services was

their requirement for higher data rates to carry the signals. As the story in this chapter reveals, this led to trials of a number of transmission technologies such as satellites, millimetre waveguides, and the early experiments on optical fibre technology.

The narrative in this chapter explores the public monopoly status of the Post Office and its influence on the choices and decisions being made in relation to innovations in relation to the various high data-rate services and transmission technologies under consideration at that time. This discussion is underpinned by the theoretical ideas of Hughes' 'technology as a system' approach combined with Pinch and Bijker's formulation of social constructivism.

4.2 Digitisation and the emergence of the data services

In the early 1960s, the Post Office began to modernise its exchanges with the purpose of not only reducing its dependence on manual operations but also to cater to what it perceived to be growing demand for telephony services¹. Since most of the Post Office exchanges were analogue at this stage, a programme of converting its exchanges to full electronic operation and "*automatisation*" through the use of digital signals was begun (BPO, 1962, p. 17).

¹ The emphasis on moving away from electro-mechanical exchanges to automatic ones is a recurring theme in the Post Office reports during the 1960s. Apart from annually reporting on the number of exchanges converted, the Post Office also talks "*about a quicker, more efficient and cheaper service and an impressive economy in staff.*" (BPO, 1962, p. 17).

A key part of this digitisation effort was the pulse code modulation technique developed by a Post Office engineer Alec Reeves in 1937 (Bray, 1995). Despite a long period of gestation, once it became practical in the 1960s, PCM was to form a key block of the transmission technology in the following decades and influence decisions about broadband technologies. Ian Millward, then an apprentice engineer working in one of the Post Office exchanges during the 1970s, describes the importance of PCM in the following quote:

Even then, in mid to late 1970s, we [the Post Office] were starting with the first PCM systems - 24 channel and 30 channel. The 30 channel is still the 2 Mbit building block of everything that goes on now.

Source: Ian Millward, Unpublished interview conducted by the author.

Cambridge, 16 January 2012

PCM would also go on to play a key role in the way the Post Office would cater to the demand for data services from 1960s onwards. However, although data services (in the form of telex) had begun in the 1950s and gained currency during the 1960s, telephony services continued to account for a large majority of the Post Office revenue throughout the 1960s and 1970s².

² Although the Postal services showed a profit of £1M in 1961-62, apart from 1965-66, 1966-67 and 1967-68, it ran at losses. In contrast, the telecommunications service delivered increasing profits. In 1961-62, the telecommunications service had a profit of £20.2M. Apart from averaging profits in the range of £30-35M throughout the 1960s, the profits had grown to £50.1M by 1968-69. See BPO (1969a) for further details.

4.2.1 PCM becomes practical

One of the main attributes of PCM was that it enabled several conversations to be carried simultaneously on two pairs of wires (BPO, 1965)³. This would improve the capacity of the existing Post Office networks significantly and also enabled it to provide a higher capacity data service. At this stage of the narrative, the higher capacity available due to PCM was not directly associated with any plans for offering or delivering data services. The use of PCM was focussed at building capacity in the trunk (now called core) network⁴. As the 1960s progressed, the Post Office grew increasingly confident of its PCM trials. At the end of 1967, the Post Office had begun to envisage the use of PCM in a nationally integrated transmission and switching system which handled telephony, data, facsimile, and even television (BPO, 1967). By the start of 1970s, PCM was a key part of the Post Office "automatisation" strategy. The Post Office had initiated studies to develop higher capacity systems that could handle 100 to 500 Mbit per second (BPO, 1969b; 1970).

³ PCM enabled digital systems to achieve a near-complete immunity to noise, interference, and nonlinear distortion. With PCM -

- Different types of signals such as voice, data, facsimile, and television could be accommodated without mutual interference on a pair of wires, a coaxial or optical fibre cable, or microwave carrier.
- Digital signals could be stored without loss of quality from repeated use at the same time offering advantages of low cost, reliability, and small size.

See Bray (1995) for a more detailed discussion on PCM and its attributes.

⁴ As described in "Understanding Telecommunications Networks" by Andy Valdar (2006), the core network provides links between relatively small numbers of network nodes, typically spread across the whole country. These network nodes are points in the national network where bundles of circuits, serving telephony, private circuits, data services, etc., are entered onto the required transmission links. In contrast, access network provides a link between each end-user (referred to as the 'subscriber') and their serving node in the network. In a PSTN, the copper or 'local loop' network is overlaid with a variety of transmission systems such as, transverse-screen copper, optical fibre, terrestrial microwave radio, or satellite microwave radio. See Valdar (2006) for more details.

PCM would also be a crucial technology in the delivery of narrowband services that preceded the early broadband technology. The use of PCM to build capacity in the trunk (core) network combined with the introduction of digital electronic equipment meant that a digital core was in place by the time technologies such as ISDN and DSL were considered as a means of delivering high-data-rate transmission via the existing access infrastructure.

Around the same time as the PCM trials began, the Post Office introduced a data service named Datel (short for Data Telephone) that enabled data to be sent over telephone and telegraph circuits (The UK Post Office, 1975). As the demand for better bandwidths grew, the Post Office introduced a number of variants with higher bandwidths. Typical uses for the various Datel services were related to data transmission for ticket reservations, stock control, payroll, time-sharing of computer bureau operations, and direct on-line access to computers for bank branches (The UK Post Office, 1975). Although the introductory Datel service offered 100 bits per second in 1964, by 1968, the Post Office had developed the capability to deliver data transmission rates up to 48 kbit/s through new data modems (BPO, 1969a). Two years later, this "wideband" capacity became operational in July 1970. This use of the term "wideband" to describe additional capacity introduced the notion of a higher, wider bandwidth⁵ being used for data transmission. It was also indicative of a new class of service related to data transmission at higher capacities being established in addition to telephony services

⁵ The term "wideband" would have had a somewhat different connotation based on whether analogue or digital transmission was taking place. In relation to analogue transmission, "wideband" meant wide analogue bandwidth and high bandwidth would indicate the use of high data rates. In case of digital transmission, the availability of higher or wider bandwidth essentially meant the same thing as both allowed more data to be transmitted.

– an early interpretation of "broadband" technology at work⁶. In all likelihood, this term was the precursor to the term "broadband" which began to be used in the 1980s to indicate more bandwidth being available for data transfer.

4.2.2 Shift in the focus of the digitisation activity

The Post Office research throughout the 1970s focussed on developing an all-electronic next generation digital transmission system with improved performance⁷, ease of manufacture, maintenance, and overall cost effectiveness (BPO, 1975). This work took the form of a range of exchange switching systems named 'System X' with

⁶ Malcolm Taylor, a veteran of the telecommunications industry and someone who witnessed a number of the events being described in this chapter first-hand, provides further context for the use of term wideband in his interview. He points out that:

Going back to the 1980s and 1990s, we used the term wideband for relatively low-speed data services i.e. more than 64kbit/s which was the voice-band. We used to do multiples of 64kbit/s. We were talking about wideband services then around 128 - 256kbit/s ...

Source: Malcolm Taylor, Unpublished interview conducted by the author. London, 27 March 2012

Although the term "wideband" precedes "broadband", its use was not very widespread partly owing to the fact that data services were mostly used by businesses. The term appears sporadically until mid-1980s in relation to connections providing higher bandwidth capacity than telephony service connections. With the introduction of the term "broadband", the use of the term "wideband" largely went out of circulation.

⁷ The performance improvements offered by 'System X' were derived from features such as (Bray, 2002) -

- The use of stored programme control based on data control and computer techniques for administrative functions such as maintenance, recording call charges, and collecting traffic data.
- Integrated digital transmission and switching in core and access network.
- Provision of non-voice services such as facsimile, data, Prestel, and audio/video conference facilities.

an emphasis on digital, microelectronic, and software techniques. Despite Post Office claims about the superior nature of the 'System X' technology however, Sir Bryan Carsberg, who would later become the first Director-General of Telecommunications, has argued that the solution being put in place was far from perfect and had significant limitations. In the following quote he is referring to the telecommunications operations of the Post Office as British Telecom (as it would eventually become known after being split from the postal operations):

British Telecom had been working with manufacturers, particularly GEC [General Electric Company] and Plessey on a new digital system called "System X". That was, as so [often] happens with national monopolised industries, an over-engineered system. They used to say it was a gold-plated system. It was running late and it had design problems. This meant Britain was rather lagging in digital technology.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London, 27 March 2012

Despite the limitations of the 'System X' programme however, the Post Office continued to see an increased demand for data services. In response the Post Office also continued to trial a number of technologies to build the transmission capacity required to handle the increased demand. Throughout the 1970s, the number of terminals for the data transmission system 'Datel' grew by an average of 18-22

percent every year and growth of Telex lines averaged about 10 percent per year⁸. By early 1972, the Post Office introduced a new data service named Dataplex that enabled remote users of time-sharing computer bureaux to access computers via PSTN at local call rates (BPO, 1972; The UK Post Office, 1975). The Dataplex service showed an early convergence of computing and telecommunications at work. An outcome of this growth in data services was the investments made by the Post Office in relation to the equipment. By early 1976, the Post Office introduced a miniature modem that fitted under a telephone for a Datel service (Datel 200 in this case, offering bandwidth of 200 bit/s. See BPO, 1976). By the end of 1970s, new modems were delivering bandwidth of 9600 bit/s for a Datel service and a 1200 bit/s full duplex service⁹ (BPO/BT, 1981). The development of these modems can be seen as a precursor to the modems eventually used for dial-up (narrowband) services to connect to the Internet/Web in the 1990s.

During this time in the 1960s and the 1970s, the data services being provided i.e. Datel and Dataplex were mostly aimed at businesses. This emphasis on delivering data services with increasing bandwidths to businesses was to shape a number of decisions and strategies of communications service providers as data usage became more mainstream. This emphasis would also influence the thinking at the Post Office first and then later when it became British Telecom. Despite the growth in demand for data services by business end-users, the viability of data services to

⁸ The Post Office had around 15000 Datel terminals at the end of 1970-71 (BPO, 1971). By the end of 1976-77, the number of Datel terminals had grown to 43100 with a year-on-year growth averaging 18-22% (BPO, 1977). In comparison, the Inland telex lines stood at 32900 in 1970-71 and had an average year-on-year growth of 10% to reach 90000 lines by 1980-81 (BPO, 1971; 1981).

⁹ A telecommunications service is considered to be full duplex when in a point-to-point connection signal can be transmitted in both directions at any given time.

consumers remained under question for a significant duration until the mid-1990s as the discussion in chapter 6 will explore in detail. The outcome was that the Post Office attempted to define and create a consumer market for data services. The efforts of the Post Office to create a home computer information system resulted in a Videotex¹⁰ system named "Prestel" (Bray, 2002). Seen in some quarters as an analogue precursor to the Internet/Web, the Prestel system provides a case study of how a monopoly such as the Post Office functioned in relation to delivering data-centric services to consumer end-users. Unlike Datel or Dataplex, the Prestel system attempted to provide an end-to-end experience with a specially designed terminal. In addition, the Prestel system provided a range of services (described in the next section) that were designed for consumption and information dissemination, and not just limited to the transmission of data from one end-user to another (see Fedida and Malik, 1979). The focus of the Prestel system on the consumer end-users, as explored in the next section, distinguished it further from both Datel and Dataplex services.

¹⁰ Videotex (more specifically interactive Videotex) is the generic name used to describe end-user information systems developed by a number of Postal, Telegraph, and Telephone companies (PTTs) starting in the late 1970s (Mayntz and Schneider, 1988). The Videotex systems were characterised by the use of a computer-like terminal attached to a keyboard at the end-user's side. The information displayed on the end-user terminal was usually delivered through a centralised database hosted by the PTT. Although largely text-orientated, the Videotex systems were also capable of delivering graphics (including images) to the end-users. Examples of the most well-known Videotex systems are Prestel (UK), Télétel (France) and Bildschirmtext (West Germany) (Mayntz and Schneider, 1988). In the UK, the Videotex system Prestel was initially described as a Viewdata system (Fedida and Malik, 1979; Bray 1995).

4.2.3 The Prestel system – the British Videotex implementation

In the mid-1970s, the Post Office began work on "Viewdata" (more commonly referred to as Videotex or specifically Interactive Videotex outside the UK), a data retrieval display service designed to operate over existing telephone network (BPO, 1975). The early pilot trial of Viewdata began in January 1976. The Post Office planned a market trial in 1978. To this end, the Post Office arranged with suppliers of information and television industry for modified Television (TV) receivers to be available (Mayntz and Schneider, 1988). The "Viewdata" service was named as "Prestel" and the Post Office had decided to spend £23M for its development and promotion as the world's first computer-based information system linking telephone and television (BPO, 1978). By September 1979, the full public service for the Prestel system was launched in London. The Post Office planned further expansion by opening four customer access centres in London in the second half of 1979. By early 1980, the first batch of provincial centres were scheduled to be opened in Manchester and Birmingham (Bright, 1979). By the end of the financial year 1979-80, the Prestel system had become operational nationwide and was available in other UK cities.

The Post Office considered the Prestel system an important achievement and worked to commercialise the Prestel design in other markets including Western Europe and North America. With sales of the Prestel system to telecommunication administrators in West Germany, Netherlands and Switzerland and licence agreement for USA market, the Post Office expected to take world lead in the

Videotex services market (BPO, 1979). By early 1981, the Prestel system was also sold to Belgium and Italy. The Post Office / British Telecom had begun participation in the market trial of "Prestel International" for the world's first international Videotex service (BPO/BT, 1981). The Post Office however was not alone in its efforts to push for an interactive Videotex system. Similar push for a Videotex system was made in France in the form of Télétel¹¹, a programme which turned out to be the most successful Videotex implementation in the world¹².

The Prestel system enabled the Post Office to retain complete end-to-end control of the system. Despite this though, the Prestel system aimed to create a price-competitive market that would provide the terminals to the end-users. This was in contrast to the more successful Télétel system in France as part of which terminals were freely distributed to the end-users. Although the Post Office envisaged Prestel as a service for residential end-users, until the trial and launch of the Prestel system, the data services had been mostly aimed at business end-users. Unlike the Datel or Dataplex services, the Prestel system did not just provide a data connection to the residential end-users. With the Prestel system (and similar Videotex systems) the

¹¹ Although it is more popularly known as Minitel, the name of the French Videotex system was actually Télétel. Minitel was the name of the display terminal distributed as part of the system. See Carey and Elton (2009).

¹² Unlike its German and British counterparts, Télétel, the French Videotex system was extremely successful and resulted in close to 5M end-users by early 1990s. The success of Télétel is often attributed to the fact that the French telecom agency distributed Minitel, the terminal, free-of-cost to end-users resulting in economies of scale which other systems failed to achieve (Feenberg, 1992). Although Carey and Elton (2009) have pointed to the financial success of the Télétel system never being fully ascertained, in terms of end-user adoption (10M by 2009) and number of services offered (several thousands), it is arguably the most successful system. Télétel continued to function throughout the 1990s and the 2000s. It was finally shutdown on June 30, 2012 (Chrisafis, 2012). In contrast, most other Videotex systems including Prestel were shut down by early 1990s.

Post Office also attempted to create a business model on the basis of which services such as telephone directory, weather reports, travel reservations, and home-banking (amongst others) would become available to the end-users (Bray, 1995). The thinking and effort behind the Prestel system showed that the Post Office was looking to expand telephony revenue and chose to invest in a residential data service (Fedida and Malik, 1979). Despite its enthusiasm, the Post Office and later BT adopted a relatively cautious approach towards the rollout of a data service for residential end-users such as the Prestel system as chapter 5 will explore. Such an approach also foreshadows the uncertainty about viability of broadband services during the 2000s that chapter 7 will cover in detail.

Although the Post Office was using the existing telephone network for the Prestel system, during 1970s the Post Office had begun to explore alternatives for technologies that would extend the capabilities of the existing copper PSTN. A number of these technologies were being considered with a view towards building higher data capacities. However, there was no clear indication at this stage of what the future services would look like or what form of data services would emerge. The uncertainty about possible revenues and the end-user adoption for services other than telephony was reflected in the different types of data services such as Datel, Dataplex, and the Prestel system aimed at various end-users being rolled out by the Post Office. At this stage of the narrative, the introduction of services was aligned with the digitisation of the network undertaken by the Post Office. Since the aim of digitisation was mainly to deliver more efficient and lower cost telephony, the extent of importance attached by the Post Office to any of the data services such as Datel or Dataplex was unclear. As the next section explores, the investments being

made by the Post Office in the various transmission technologies highlighted the different aims and purposes at work in relation to the services being offered.

4.3 The improvements in transmission technologies

As part of its digitisation effort, the Post Office was also investigating various transmission technologies to upgrade its network infrastructure. As a result, throughout the 1960s and 1970s the Post Office conducted trials with a number of technologies such as millimetre waveguides, optical fibre, coaxial cable, and satellites. Of these, apart from satellites, the other technologies were possible means to improve the existing fixed-line network capabilities. Satellites and coaxial cable, as the section 4.3.2 explores, were key to the Post Office forays into international telephony service provision. With regard to its UK infrastructure, the technologies in specific contention were – millimetre waveguides and optical fibre cables.

In both cases, the choices made by the Post Office were dictated by the expected use for the technologies which was primarily to boost the transmission capacity in inland trunk communications (i.e. core network in today's parlance). For this purpose, the Post Office collaborated with the industry and universities to conduct research on millimetre waveguides and optical fibres (see Bray, 2002 for some of the specifics of the research done by the Post Office and later British Telecom in this context). The actual use of these technologies and the manner in which their deployment would take place, were not decided and their intended use changed depending on the priorities of the Post Office and the nature of its requirements during the 1960s and 1970s.

4.3.1 Building high-bandwidth capacity - millimetre waveguides and optical communications

In 1967 the Post Office with the University College London built an experimental one-mile long millimetre waveguide at Martlesham Heath, near Ipswich (BPO, 1967). With its initial trials producing encouraging results, in 1969 the Post Office estimated that simultaneous transmission of 300,000 telephone conversations or 300 television channels was possible through a specially constructed copper tube of two inch diameter through millimetre waveguides (BPO, 1969a). Despite the Post Office's early inclination towards it, at this stage of events, it was not clear whether millimetre waveguide would prevail over optical fibre as a technology of choice (see Solymar, 1999; Hecht, 1999 for an engaging discussion on the race between millimetre waveguide and optical fibre). Prof. Andy Valdar, then working at the Post Office recounts the Post Office approach to the deployment of millimetre waveguides in the following quote:

They [the Post Office] did actually build a waveguide route from Martlesham to Cambridge (I think). It proved to be impractical. It [millimetre waveguide] was designed not at all for access. It was designed entirely for linking exchanges i.e. high-capacity links between exchanges. It would be able to carry all traffic - TV, broadcast, private circuit, and PSTN. There was almost no data in those days. At the time of making the decision, there was no question of looking at it other than merits of the technology [as far as the Post Office was concerned].

Source: Andy Valdar, Unpublished interview conducted by the author.

London, 18 April 2012

Although the early trials were considered satisfactory, millimetre waveguides were not pursued as a serious alternative for building high-capacity networks by the Post Office. By 1963, Standard Telecommunications Laboratories (STL) working in conjunction with the Post Office Research Laboratories had suggested that millimetre waveguides would prove unsuitable for the UK conditions. Alec Reeves, known for his invention of PCM, considered millimetre waveguides unsuitable for the densely structured network in the UK. In his view, millimetre waveguides needed a lot of room to bury pipes with large-radius curves which made them impractical for the UK (see Hecht, 1999 for a more in-depth discussion on the Post Office approach to millimetre waveguides). Prof. David Payne, whose work at the University of Southampton has involved extensive research with optical fibre technologies, elaborates this in the following quote:

If you look back at the solution, the prime solution in the 1960s that was Hoi waveguide, the microwave. How could have that ever succeeded? On paper, it is a very wonderful piece of physics. Very high bandwidth - multi gigahertz. But it was the precision, the cost and the straightness [that was the problem]. Its bend radius was in kilometres. Everybody thought we could put it next to motorways and so on. If you look at those solutions, you realise how desperate we were [to figure out a way to deliver high-bandwidth connectivity].

Source: David Payne, Unpublished interview conducted by the author.
Milton Keynes, 29 March 2012

These drawbacks effectively meant that it was difficult to implement millimetre waveguides on a significant stretch of a network in the UK. As a result, despite the trials and an early interest, millimetre waveguides did not get deployed in the UK.

During this time, when trials were being conducted for the millimetre waveguide technology, in autumn 1965, Charles Kao along with George Hockham, working at STL, had suggested that light could be used to carry communications signals through a glass fibre i.e. fibre optic communications was practical (Hecht, 1999). In July 1966 Kao and Hockham published their findings in the *Proceedings of Institution of Electrical Engineers* (IEE) outlining their proposal on glass fibres and optical communications (Kao and Hockham, 1986). The paper identified that glass fibres with loss below 20 decibels per kilometre would be suitable for carrying communications signals (Faltas, 1988). As Prof. John Midwinter, who headed a

research group for optical fibre within the Post Office recalls, the Post Office evinced an early interest in the nascent optical fibre technology:

The [optical fibre] project started about 1966 when Charles Kao first made the proposal [for single mode fibre]. The Post Office research centre latched onto it and thought it was very exciting and managed to free up some money to start an internal programme and I think to partly fund the STL programme. So they [the Post Office] were in it from 1966.

Source: John Midwinter, Unpublished interview conducted by the author.
Milton Keynes, 23 December 2011

Despite the early interest though, it was not until the 1970s that the optical fibre technology offered practical possibilities to the Post Office. This is reflected in the following quote by Prof. John Midwinter, where he is referring to a demonstration in 1977 that showed optical fibre to be a viable technology:

It was in 1975 that the technology had advanced to a point where we [the researchers] began to believe that you [as an operator] could actually realistically think about pulling a fibre cable into a duct and expect it still to work. It was the 1977 presentation when we actually did it for the first time. That [presentation] caused shockwaves around the company [the Post Office]. Suddenly people started to take it [the potential of optical fibre] seriously. My own research group started the research - seriously looking at single mode technology which is what Kao had originally proposed. It [single mode fibre]

had been deemed too difficult to deploy in the field [in the early stages of the research]. We began to realise that it [single mode fibre] was actually deployable and offered huge potential operational advantages.

Source: John Midwinter, Unpublished interview conducted by the author.
Milton Keynes, 23 December 2011

By early 1978, the Post Office had introduced an optical fibre link carrying telephone calls in the form of pulses of light in public service. This link was installed over a distance of 13 km between Martlesham Heath and Ipswich first. A second cable was installed between Martlesham Heath and Kesgrave Exchange for a distance of 5 km at the same time (BPO, 1978). The same year, experiments reduced optical fibre loss to as low as 3.5 dB/km indicating a good potential to produce high capacity digital systems in future. Based on this evidence and results from its trials, the Post Office ordered thirty-four optical fibre systems on 15 routes to be delivered at the end of 1980 and planned to install 3600km of fibre in due course. By September 1980, the optical transmission system between Brownhills and Walsall became one of the first production standard systems of its kind in Europe. On the strength of its initial optical system installation, British Telecom¹³ then planned to introduce 6000 km of fibre in the trunk network in the next decade (BPO/BT, 1981). As Prof. John Midwinter states:

¹³ By this time, the telecommunications operations of the Post Office had been split from the postal operations to create British Telecom. This is covered in detail in section 4.4.

[...] it was in 1983 that BT made a decision that it would only install single mode fibre on its long-haul network then on. That was a real first. They [BT] were ahead of anybody in the world in doing that.

Source: John Midwinter, Unpublished interview conducted by the author.

Milton Keynes, 23 December 2011

Despite the extent of Post Office efforts with millimetre waveguides and optical fibre cables, it also considered technologies such as microwave radio, coaxial cable, and satellites during this time. In particular, coaxial cable and satellites had a clearer utility than optical fibre when it came to real-world deployment. As the next section discusses, coaxial cable and satellite networks were deemed important in relation to international communications (including international telephony and data transmission). This also meant that in contrast to millimetre waveguide and optical fibre technology, both coaxial cable and satellites were not primarily aimed at building capacity in the trunk (core) network.

4.3.2 The role of international communications – coaxial cable and satellite telephony

The investments made by the Post Office in relation to coaxial cable as a technology were largely part of its exploration of a number of technologies and approaches for carrying different types of traffic. Given the success of the coaxial cable technology in the Trans-Atlantic Telecommunications submarine cable system (TAT) with the USA, it had become the technology of choice for a number of networks that

delivered international communications (more specifically international telephony). The success of coaxial cable technology not only showed its viability for long-distance communications but also showed that the cable networks had the required durability. Given the higher capacity of the coaxial cable networks compared to the existing copper-based PSTN¹⁴, coaxial cable was also a credible alternative when it came to carrying data at high-capacity links.

Despite such advantages however, the choice of coaxial cable for international communications was not so obvious itself. Before submarine cable systems became the most common medium for international communications, the Post Office had relied on microwave radio links. However, with coaxial cable holding up better than expected, the Post Office focussed its microwave radio operations within UK initially on connecting large cities such as London, Birmingham, and Manchester at the start of 1960s. By 1963, the Post Office began building a nation-wide network of microwave radio relay stations to handle increasing demand for trunk circuits (i.e. core network). Part of this capacity was also intended for distributing television channels. The Post Office planned this system to be capable of carrying hundreds of simultaneous conversations (BPO, 1964). An important attribute of microwave radio was that it had a lot of capacity to carry data over a short distance. The result, as Prof. Andy Valdar points out, was that it remained a relatively niche technology:

¹⁴ The maximum data rate possible on the single copper twisted pair used in the PSTN was 64 kbit/s at that time. The traditional coaxial cable (used in television) networks had an analogue bandwidth of 370 MHz (Goleniewski, Wilson Jarrett, 2006) and a high signal to noise ratio, so was capable of data rates up to 52 Mbit/s. The maximum data rate possible on a communication channel is defined by the Shannon-Hartley theorem based on analogue bandwidth of the channel, average signal power over the bandwidth, and the average noise or interference over the bandwidth (Dunlop and Smith, 1984).

The microwave radio was used for local ends for private circuits. That was 90 GHz microwave radio. It was 2 Mbit and 8 Mbit local ends for private circuits. [...] It was used for business and not for residential customers.

It is still used around the city [of London]. There are still a lot of point-to-point microwave dishes on rooftops. It tends to be used by the business community and it is mostly used for data centres, between buildings and not for local ends.

Source: Andy Valdar, Unpublished interview conducted by the author.
London, 18 April 2012

In addition to the use of microwave radio in the UK, a key alternative to the coaxial cable systems for international communications at this stage were satellites for international telephony. The Post Office created an experimental satellite communications ground station at Goonhilly, Cornwall in 1961 which became fully operational as a ground station around 1963 (BPO, 1962). These early satellite systems were initially intended to safeguard against potential submarine cable system failures (Bray, 1995). Despite this modest beginning, the Post Office continued to invest in the ground station at Cornwall with the intention of becoming a major operator in a worldwide system of communications satellites by the 1970s. The importance attached by the Post Office to satellite communications can be gauged by the extent to which it invested and participated in various satellite communications initiatives.

To begin with, the Post Office was part of the INTELSAT (INternational TELEcommunications SATellite) consortium of 56 member nations for satellite services across the Pacific and Atlantic oceans (BPO, 1967). Through its participation in the INTELSAT consortium, the Post Office could provide telephony, data, and facsimile services to its customers via a satellite connection. Given the high cost of satellite connectivity though, delivering telephony, data, and facsimile services via satellite was mostly targeted at business end-users. The Post Office became the second largest shareholder of the International telecommunications satellite organisation, a successor to the INTELSAT consortium in February 1973 (BPO, 1973). By 1975, the satellite communications service had been expanded to three aerials at Goonhilly Downs, Cornwall with a new earth station commissioned at Madley, Herefordshire in 1979. The Post Office also continued to participate in worldwide satellite communications with a major financial share in a European Communications Satellite System i.e. International Maritime Satellite Organisation (INMARSAT) during 1978-79.

The Post Office's approach was to keep its options open vis-à-vis different technologies and chose to not commit to a single technology too early. The various technologies under consideration, the nature of trials being made by the Post Office, and the significant length of time over which technologies were being trialled indicate a cautious approach towards making investments in technologies. The Post Office decisions were driven by a combination of engineering merit and the intended use of the technologies. Given the pros and cons of each of the technologies, as the next section explores, the outcome was far from certain.

4.3.3 Different but overlapping uses for the transmission technologies

In the 1960s and 1970s, most of the Post Office research in relation to optical fibres was aimed at improving efficiency of the existing networks and reducing costs of operation. Prof. John Midwinter, who headed one of the Post Office research groups on optical fibre sheds further light on the aim with which initial optical fibre investment and trials were carried out. In the following quote he is observing the status of optical fibre studies by the end of his tenure in 1984, a part of the story which is covered in more detail in the next chapter:

[...] the justification for fibre transmission initially was to save money on transmission i.e. that these [fibre transmission] systems would be cheaper than coaxial cable. That was the justification for the research project. In 1984 when I left, we [the research group in the Post Office/BT working on optical fibre technologies] did an economic study, an internal study that had been published for the benefit of people in the BT headquarters. It showed pretty conclusively that even by then, in 1984, the research cost for the project in the company had been recouped in the savings in transmission by switching to optical. It was not driven by thinking that we would have to cope with huge capacity. It was driven by cost-effectiveness for the ordinary, plain old telephone network.

Source: John Midwinter, Unpublished interview conducted by the author.

Milton Keynes, 23 December 2011

Prof. Midwinter's comment highlights that optical fibre technology was not conceived to cater to a demand for huge data capacity or high-bandwidth

connectivity in the first instance. The initial ambitions behind the research and trials for optical fibre technology were relatively modest and driven by the need to lower costs for telephony services. Given that data connectivity was almost exclusively used by businesses and there was no discernible residential end-user demand for services other than telephony, this is hardly surprising. In comparison, coaxial cable and satellite technologies had a very different intended use. When compared to a submarine cable system based on coaxial cable, satellite networks were perceived to have a number of advantages in relation to international communications (Bray, 1995). Apart from the initial cost of launching a satellite, satellite telephony did not require the kind of infrastructure investment that coaxial cable needed. Unlike coaxial cable, the maintenance requirements for satellite-based communications were far less frequent. Although fixing a satellite was costly, the occurrence of breakage was expected to be on the lower side (Bray, 2002). Satellites also made the rollout of a service for a wider region far quicker than a cable-based network which was (and remains) labour-intensive.

However, like other wireless systems, satellite systems also had limitations in relation to the traffic they could handle. Satellite systems were (and remain) ideal for broadcasting. For two-way communications however, handling upstream traffic remained an issue for satellite systems. As it turned out, the delays in transmitting traffic via satellite during international communications meant that once optical fibre technology was sufficiently developed to deliver high-capacity, high-reliability connectivity at much lower cost, it became the preferred technology for carrying traffic for international communications in the long run (Hecht, 1999).

An important part of these developments is that each technology was intended for different and at times overlapping uses. Optical fibre, a technology now synonymous with high bandwidth transmission was primarily considered for delivering cost efficiency. Millimetre waveguides were mainly positioned to build large capacity in the trunk network (BPO, 1967, 1969a). Reliable as coaxial cable had proven itself, along with optical fibre it was not yet seriously considered for use in the last mile or in parts of the access network¹⁵. Given the high costs of launching satellites, although satellite telephony was gaining importance, it was not being pursued for general purpose telephony. This meant that satellite telephony was mostly a fail-safe option for international communications at this stage. Each of the technologies had its own advantages and disadvantages when it came to specific usage scenario whether international communications or provision of high-bandwidth. Coaxial cable may have been proven reliable for submarine cable systems, but laying it required significant investment of resources. Promising as optical fibre technology was, it was yet to be proven capable for large-scale deployments. Although in the long run millimetre waveguides were ruled out due to not being fit for deployment in the UK, millimetre waveguide technology was a serious frontrunner when it came to providing high-bandwidth capacity in the trunk (core) network.

These various technologies, their trials and deployments indicate the extent to which the outcome was unclear – not only in relation to the nature of services being

¹⁵ That neither coaxial cable nor optical fibre was being extensively used in the access network was also due to limited revenue potential of service other than telephony at this stage. It could be argued that the existing copper network in the last mile was perfectly adequate for the purposes of telephony. The additional capacity available with coaxial cable or optical fibre did not have a strong enough case to justify replacing the copper in the last mile.

offered but also the potential of these technologies. Factors apart from the technical attributes of these technologies such as the cost of deployment and their real-world use influenced the selection of the technologies. In hindsight, optical fibre may seem like a clear choice for carrying high-capacity traffic. However it was not until late 1970s that optical fibre cables durable enough for submarine cable systems were developed¹⁶ (Solyman, 1999). This meant that, until then, coaxial cable and satellites were more proven alternatives for such a purpose. That the outcome was also dependent on additional factors becomes clearer as the next section discusses the role of the Post Office monopoly and its effect on the UK telecommunications industry. The changes in the late 1970s that shaped the Post Office monopoly on telecommunications services and the following liberalisation of the telecommunications market are also considered at length.

4.4 The monopoly of the British Post Office

In relation to the UK telecommunications industry, the Post Office was responsible for the end-to-end nature of the telephony services in the UK during the 1960s and the 1970s. The entire set of innovations, technological changes, and activities in the UK telecommunications market were driven by the Post Office. Throughout the 1960s the Post Office was a department in the UK government. The perceived

¹⁶ Although optical fibre cable had become a viable option for submarine cable systems in the late 1970s, its actual use in submarine cable systems did not happen until late 1980s. TAT-8, deployed in 1988, was the first instance of optical fibre cable (instead of coaxial cable) being used to carry international communications traffic in a submarine cable system. It was constructed by a consortium of companies that included AT&T Corporation, France Telecom, and British Telecom. See BT (1984; 1988a) for further details on TAT-8.

inefficiency of such a structure played a key part in the changes made to the Post Office and more specifically the telecommunications operations in the late 1970s.

The Post Office was the largest employer in UK and in one of the most capital intensive sectors. While the telecommunications division remained mostly profitable, it was faced with continued growth in demand for services. To fulfil this demand, the Post Office was reliant on suppliers who were bound by exclusive long term contracts, and delays in delivering equipment and provision of telephone lines were routine. This lack of competition meant that supply of exchange equipment mostly lagged behind demand and in 1966-67, the waiting list grew to 115,000 end-users (BPO, 1967). In addition, the postal division, due to its labour intensive nature, continued to make losses with profits visible only after periodic tariff increases¹⁷.

The end-users, whether residential or business, had little say or choice in relation to the services offered by the Post Office or their pricing. As a public sector monopoly, the considerations of cost and return on investment had limited relevance to the Post Office since its remit was to focus on the provision of postal and telephony services as a public service.

Sensing the need for better efficiency and more accountability, on August 3, 1966, *"the Government decided to take the Post Office out of the Civil Service and make it a public corporation"* (BPO, 1967, p. 5) which happened on October 1, 1969 (BPO,

¹⁷ Starting with 1962-63, the Post Office income on its postal operations delivered losses. By financial year 1964-65 the losses had grown to £19.6M. With the charges for postal services revised, the postal services delivered profits for the next three years (1965-66, 1966-67 and 1967-68). This revival however was short-lived as the postal operations delivered losses again from 1968-69 (losses of £5.8M). See BPO (1969a) for further details.

1970). This was expected to pave way for the modernisation and faster functioning that the Post Office needed. The UK government however put restrictions on the new corporation's tariff pricing. This meant it was not until mid-1970s that the Post Office would function independently.

4.4.1 The political and ideological shift to liberalisation

The inefficiencies of the monopoly as perceived by the UK government shaped the transition of the Post Office from civil service to a nationalised corporate entity in the late 1960s. The aim of improving the UK communications infrastructure and addressing the demand for telephony services effectively also drove some of the subsequent changes to the Post Office. The Post Office operations were reviewed by a committee headed by Professor Charles Carter for two years starting from 1975 to 1977 (BPO, 1978). The main recommendation of this review committee was that the Postal and telecommunications services should be split. As a result, by the end of financial year 1977-1978, the division of postal and telecommunications operations became imminent. Finally in October 1981, British Telecom broke away from the Post Office and became a separate corporation (BPO/BT, 1981).

A number of these changes in the late 1970s were tied to a deeper political and ideological shift within the UK government particularly as a result of the 1979 election. When the Margaret Thatcher led Conservative party came to power in 1979, the functioning of state-owned "natural" monopolies such as the Post Office, telecommunications, and the utilities industries (i.e. water, electricity, and gas) began to be scrutinised as part of a government policy. In a policy of economic

liberalism claimed to deliver Britain's industries back to British people (see Meek, 2012 for a detailed discussion on the Thatcher Government's policies of liberalisation, particularly in relation to the electricity industry), the Thatcher government focussed on market-led competition. As Sir Bryan Carsberg, who would go on to become the first Director-General of Telecommunications points out, the approach taken was to disband the nationalised monopolies:

A lot of the important assets were owned by the government at that time including British Telecom. The feeling was that if you subject them to free market pressure, they will operate more efficiently. I am sure that was part of it [the reason]. Keith Joseph, one of the early members of Margaret Thatcher's cabinet was a strong advocate of privatisation.

Source: Bryan Carsberg, Unpublished interview conducted by the author.
London. 27 March 2012

One of the first industries to be denationalised and opened to competition was telecommunications. The introduction of competition and market-led economics not only changed the functioning of British Telecom (which had been separated from the Post Office by then) but also altered many decision-making processes including ones that affected technological changes and their outcomes. Aside from the ideological purpose of promoting market-led competition however, the subsequent denationalisation of British Telecom was also in part influenced by the political agenda of the UK government. Malcolm Taylor, then working with Cable & Wireless, discusses one of the main reasons that led to a push for competition

within telephony. In the following text, he is referring to the break-up of AT&T in the USA and how that influenced the thinking in the UK:

When the UK government changed in 1979, the new prime minister, Margaret Thatcher said, if the US could do this, we ought to look at the same thing. It was very interesting because at Cable & Wireless, at the same time, we were very aware because of having to switch traffic. London was a very big centre for switching telecoms traffic around the world. There were others. Basically, at that time the French were investing public money in digitising the French public telecoms network. There was concern that the city of London was not being served by the Post Office telecoms and the government didn't feel it could invest enough money to address the explosion of communications needs.

Margaret Thatcher, on the back of what was happening in America and what was happening in France, particularly didn't want to risk losing the financial services sector to Paris. [She] basically said can we introduce a form of competition in the UK which really happened around 1980-1981. There was a guy called Michael Beesley, Prof. Beesley of London Business School who produced a report for the government. In fact, I worked with Michael on a number of things which basically said - yes, there is probably room for competition.

Source: Malcolm Taylor, Unpublished interview conducted by the author.

London, 27 March 2012

Sir Bryan Carsberg discusses an additional important aspect of the push for denationalisation – an ongoing concern about the power of the trade unions:

There were some very bad disruptions in late 1970s which disrupted national economic activity. Telecoms trade unions were in a very strong position because you had BT, a monopoly supplier with very strong trade unions. The government feared that the trade union could hold the country to ransom really. The thought was that if we introduce a second telecommunications network then that will reduce the power of the trade unions in BT. In order to do that you have to have a fair arrangement for competition between the two and the feeling was that you couldn't have a fair competition between a private and a state-owned company for various reasons. That was an additional impetus for privatisation.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London, 27 March 2012

Consequently a liberalisation-focused, market-orientated approach was pursued not only by the subsequent UK governments but also across a number of regulatory bodies that were introduced in the communications industry starting in the 1980s¹⁸. Under the new British Telecommunications act 1984, the Secretary of State could license competitors to BT. As a result, in line with the policy of focussing on market

¹⁸ By the mid-to-end 1980s, the UK had a number of regulatory bodies for the communications industry, each catering to separate segments of the market. For telecommunications (primarily telephony) operations, the regulator was the Office of Telecommunications (OfTel). For the cable industry, the UK government had created the Cable Authority (CA). For wireless, radio transmission, the regulatory body in charge was the Radiocommunications Agency (RA).

competition, the use of existing Post Office telecommunications network and licensing of parallel network was permitted to newly licensed operators. The result of BT's privatisation and continued focus on competition would not only influence the innovation activity but also the nature of investments made in the communications services, the transmission technologies, and within the marketplace. The consequences of the British Telecommunications act would be of further importance when BT planned to revitalise its networks through the introduction of optical fibre in the 1980s.

4.5 Discussion and Conclusions

In the period covered in this chapter, the major technical innovation was the digitisation of the network and conversion of the exchanges to electronic systems. The focus was on lowering cost of network operations and building capacity in the core network. Although the Post Office continued to invest in data services such as Datel, Dataplex, and Prestel, these were mostly niche services compared to telephony services. Aside from Prestel, the data services were mostly aimed at businesses. At this stage telephony was still dominant and the commercial viability of delivering data services to residential end-users was also open to question. As a result, the investments in various transmission technologies such as millimetre waveguide and optical fibre were influenced by the priorities of the Post Office in relation to telephony and digitisation of networks rather than any requirements for delivering high-bandwidth data services, particularly if the residential end-users are considered.

Hughes' 'technology as a system' approach offers two concepts that are useful to understanding the context in this chapter. The first is Hughes' definition of a large technological system in terms of: physical artefacts, legislative artefacts, and organisations. The second concept is reverse salients through which Hughes discusses failures and bottlenecks faced by such a system. Both these concepts and their relevance to the evolution of broadband technologies are considered in section 4.5.1. This discussion is coupled with an analysis of the various stakeholders and their motivations in the form of relevant social groups as defined in Bijker and Pinch's social constructivism in section 4.5.2.

4.5.1 Telecommunications as a large technological system

Using Hughes' 'technology as a system' approach if the UK communications industry is considered as a large technological system, the various components in such a system can be identified in the context of the narrative presented in this chapter. Although these components evolve significantly during the story narrated in chapter 5, 6, and 7, these components interact and shape the system particularly in light of digitisation of the network.

The physical artefacts are accounted by the transmission network in place in the form of PSTN, and telex networks. This would include not only technologies such as optical fibre, coaxial cable, copper, satellites in the core and access network but also the exchanges, and the equipment in the exchanges, the network, and the end-user premises. Thus although in relation to broadband, as defined in chapter 2, the technology in the last mile assumes higher importance for the end-user, taking a

systemic view, the transmission network including the exchanges and cabinets in the local area of the end-user also need to be taken into consideration. Such a systemic view is important since it was the digitisation of the transmission network in the core/trunk started in the 1960s that paved the way for higher capacity transmission that formed the building blocks of the current day broadband technologies.

Legislative artefacts are the rules for the governance of the system such as 'the regulatory laws' in Hughes' formulation. Since the Post Office functioned as a public-sector monopoly throughout the 1960s and 1970s, at this stage of the story, in the absence of a separate regulatory set-up, the most visible legislative artefact is the Post Office's public service remit to provide postal, telegraphy, and telecommunications services to the UK tax payers. As defined by Hughes, the organisations are companies that market and maintain the system. Due to the nature of the monopoly prevalent in the UK, in the context of this chapter, the organisations can be identified by the Post Office, the equipment manufacturers, and government departments that oversaw the function of the Post Office until the end of the 1960s. As the story covers the denationalisation of British Telecom in the early 1980s, with the creation of regulatory bodies such as the Office of Telecommunications (OfTel), not only do the number of organisations in the system increase but the legislative artefacts and their influence on the system also becomes more visible in the discussion in chapters 5, 6, and 7.

The one important aspect of the narrative that the Hughes' 'technology as a system' approach does not directly address is the importance of services in the

telecommunications industry. Unlike the systems that Hughes' studies cover, the telecommunications system can deliver multiple services over the same network. This capability is particularly important if the incremental growth in demand for high data-rate services is considered. As chapters 5, 6, and 7 cover, broadband technologies such as optical fibre and DSL are associated with high bandwidth capabilities related to delivering data-centric services such as the Internet and video-on-demand. Although the focus of the Post Office operations during the period covered in this chapter was mostly on telephony services, the use of Hughes' 'technology as a system' approach does not enable the emergence of high data-rate services such as video-on-demand and the Internet/Web to be directly addressed. This importance of services to the telecommunications system is highlighted further in chapters 5, 6, and 7.

Another important tenet of Hughes' 'technology as a system' approach and one that will also form part of the discussion in chapters 5 and 6 is the concept of reverse salients. Reverse salients, as explained in chapter 3 (section 3.6.1), are essentially unsolvable problems due to which the development or deployment of a technology comes to a halt. It is only when the reverse salients are successfully parsed into critical problems, which are solvable, that the development or deployment of the technology resumes again. If the narrative in the 1960s and 1970s is considered, a number of the transmission technologies in the fray came across reverse salients. In the case of technologies such as millimetre waveguides and satellites such reverse salients meant that they did not develop as long-term alternatives for building transmission capacity.

Millimetre waveguides, despite a successful trial, were rejected as a long-term solution for the UK due to the kind of deployment requirement the technology imposed as section 4.3.1 stated. Effectively faced with a reverse salient i.e. the unsuitability of millimetre waveguides for deployment in the UK geography, the result was that the pursuit of millimetre waveguides was dropped in the favour of optical fibre cable. The problems related to satellites being not very suitable for upstream transmission and resulting delays in transmission could also not be solved – essentially creating reverse salients that resulted in satellites being a niche solution.

4.5.2 Understanding the stakeholders and their motivations

Having considered the 'technology as a system' approach to analyse the nature of events at work, it would also be important to consider the various stakeholders and their approach to technologies providing high data-rate connectivity. In this context, Bijker and Pinch's (1987) formulation of social constructivism could prove useful to gain additional insight into the events in the 1960s and 1970s. As discussed in chapter 3 (section 3.4.1, 3.4.2), the key pillar of social constructivist ideas is that technology is socially constructed and such a social construction is an ongoing process of negotiation between various stakeholders i.e. relevant social groups. Although at this stage of the narrative the concept of high data-rate connectivity as it is currently associated with broadband technologies did not exist, different social groups and their technological frames (i.e. cognitive, social, and technical elements that guide the meaning and behaviour in relation to the technology) can be discerned.

At this stage of the narrative, the relevant social groups that can be identified are – the Post Office, the UK government, the equipment manufacturers and suppliers to the Post Office, and the end-users. The Post Office functioned as a public-sector monopoly and made all the decisions related to the product, services, or infrastructure investments. The other relevant social groups such as the end-users and the equipment manufacturers and suppliers to the Post Office had limited influence on the technological choices being made by the Post Office vis-à-vis technologies such as optical fibre or millimetre waveguides. The Post Office offered services such as Datel and Dataplex for businesses and planned to deliver interactive Videotex services combining data and video to residential end-users. The term 'wideband' was used sporadically and the potential of such connectivity (whether commercial or technological) was unclear. High data-rate connectivity had limited commercial viability to the extent that the focus of Post Office activity was almost entirely on telephony services.

In light of the Post Office's monopoly, the provision of 'wideband' connectivity was mostly influenced by the Post Office's decision-making. The Post Office's approach to the 'wideband' connectivity was that of end-to-end ownership of the products, services, and the transmission technologies used to deliver such wideband connectivity. Since other relevant social groups whether the end-users or equipment manufacturers had very little influence on how the Post Office functioned, the aforementioned approach of end-to-end ownership was the de-facto dominant technological frame in the context of the narrative presented in this chapter. This does not mean that the other relevant social groups (end-users or equipment

manufacturers) did not have technological frames of their own, but that the nature of monopoly limited the extent to which they could influence the Post Office's technological frame.

As the next chapter explores, due to the denationalisation of BT, the UK communications industry underwent a number of changes that had important ramifications for the deployment of broadband technologies. In the more liberalised UK communications market of the 1980s and 1990s, not only did additional relevant social groups emerge but the technological frames also diverged significantly. With the monopoly of the Post Office no longer applicable, other relevant social groups (whether non-BT operators, end-users or regulatory bodies) would play an important part in the way the function and meaning of broadband was shaped. As the discussion in chapters 5, 6, and 7 shows, the industry-wide change in the UK i.e. the systemic context of it, is crucial to understanding the way broadband technologies evolved in the UK.

5 Denationalisation of BT, cable franchise allocation, and the quest for "killer application"

5.1 Introduction

The 1980s marked the transition of British Telecom from a public sector monopoly to a denationalised company with competition in the form of Mercury Communications, and opening up of the cable industry for multi-channel transmission. Accompanying the denationalisation, the UK government appointed a regulator for each industry. For the telecommunications industry, the Office of telecommunications (OfTel) was created along with a Director-General of Telecommunications; and the cable industry had the Cable Authority (CA) to oversee its functioning. The main function of the regulatory bodies was to promote competition and regulate prices. To achieve effective competition, a number of restrictions were placed on BT to limit its market dominance. Investment in the cable industry was encouraged by allocation of cable franchises as regional monopolies. However, the allocation of cable franchises as regional monopolies resulted in fragmented and uncoordinated network deployment, without any unique selling proposition to monetise it.

The discussion in this chapter will show how the changed orientation of BT as a private sector company played an important part with its investments in new technologies such as ISDN and optical fibre increasingly weighed against possible returns on the investment. ISDN in particular, remained a niche solution due to

BT's focus on deploying ISDN to business end-users. By the end of the 1980s, Broadband ISDN (B-ISDN) was being proposed to overcome the perceived limitations of ISDN. At the same time, a solution to deliver higher bandwidths over the copper twisted loop was being developed. Relatively unheralded compared to ISDN, optical fibre, or B-ISDN, it was called High-bit-rate Digital Subscriber Line (HDSL).

The theoretical analyses in this chapter draw from social constructivism, Hughes' 'technology as a system' approach, the insights offered by Hecht's concept of technopolitical regime, and path dependence.

5.2 1980s and the changing face of UK telecommunications industry

The policy of liberalisation mooted by the Conservative administration under Margaret Thatcher in 1979-80, gathered further pace at the start of the 1980s. A number of previously nationalised industries such as electricity, gas, water, and telecommunications¹ were set to be privatised² (Parker, 1991). The first one to be liberalised was the telecommunications industry (Rutter et al, 2012). Since the intention was to create a competitive market, the UK government did not want BT to be turned into a private monopoly instead of a public one. In order to end BT's monopoly position, the British government licensed a competitor to British

¹ See Parker (2009, 2012) and Veljanovski (1987) for a more detailed history of the privatisation in the UK.

² Although the sale of publicly owned assets is generally described as "denationalisation", in the UK the term "privatisation" was used by the government. As Rutter et. al. (2012, p. 1) describe, the term privatisation "*gained favour simply through the lack of a better alternative*" and because denationalisation "*did not sound positive enough*".

Telecom. This was Mercury Communications (hereafter "Mercury"), a newly created company owned by a consortium of Cable & Wireless, British Petroleum, and Barclays Mercantile Bank (Mercury Communications Press Office, 1992). The creation of Mercury ended the monopoly in telephony and data that British Telecom had enjoyed prior to its denationalisation³.

Along with the privatisation of BT and introduction of Mercury, the British Government also created a regulatory body for telecommunications industry in the form of the Office of Telecommunications (OfTel). Sir Bryan Carsberg, who was appointed as the first Director-General of Telecommunications recalls OfTel's original goals, the conditions under which it was created, its method of working, and priorities in the quote below:

OfTel was set up because you can't have a monopoly [being broken up] without a regulator [being appointed]. Our duties were all sorts of supervisory things like price control and so on. A very important duty was also to promote competition. My duties [as a director-general] were set up as an act of parliament. The regulatory system was quite unusual in those days. It was a very British model which the other countries didn't ever follow. The regulatory

³ The British Telecom monopoly applied to all areas of the UK except Kingston-upon-Hull. When the various municipal telephone systems licensed under the Telegraph Act 1899 were gradually absorbed into the Post Office telephone department in the early 20th century, the Hull City Council chose to renew its licence in 1914 and remained the only municipally owned telephone corporation in the UK. Kingston-upon-Hull was thus the only area in the UK which was not served by BT, before and after its privatisation. See KCom (2011). Effectively, the creation of Mercury ended BT's monopoly in all areas except Kingston-upon-Hull where BT had no footprint. Given the unique nature of Kingston Communication's (i.e. KCom's) monopoly and the small regional footprint of its operations, it is not considered at great length in this thesis.

duties and responsibilities were vested in one individual who held a statutory appointment. That was me in case of telecoms. Oftel was there to support but there was no commission. It was just one individual exercising [various] regulatory functions. [...] [As the Director-General of Telecommunications] One reported to parliamentary committees but parliamentary committees had no power to instruct on how to do/not do something. You obviously listen to parliamentary committees but the power is in your hands as a regulator.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London. 27 March 2012

In order to promote competition and regulate prices, the approach adopted by Oftel quite early on was of controlling BT's earnings via a formula based on the Retail Price Index (RPI). Known as RPI-X⁴, the aim was that BT's prices should decrease by X% in line with the rate of inflation (measured by the RPI). It was agreed with BT that Oftel would periodically revise the value of X. To start with, BT's prices were fixed at RPI - 3.5% and subsequently revised to RPI - 7% (Oftel, 2003a). The RPI-X formula would go on to play a key part in the decisions made by not only BT but also its competitors in relation to investments in high-bandwidth technologies such as optical fibre as chapter 6 will explore in detail. In the following quote, Sir Bryan Carsberg explains the thinking behind the policy of price control:

⁴ The policy of price control was based on the recommendations of the 1983 report "Regulation of British Telecommunications' Profitability" authored by Stephen Littlechild. See Cave (2003), Littlechild (2003), and Stern (2003) for a discussion on the policy of price control.

Competition for fixed-line was limited to those two [BT and Mercury Communications] for seven years under what was called the duopoly policy. [...] This meant that there was limited competition in the early stages. [...] So a heavy burden fell on direct regulation to make British Telecom more efficient. Price control was a part of that. We had RPI-X price control regime. One increased X each time it was reviewed in order to put more pressure on them [BT].

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London. 27 March 2012

Sir Bryan Carsberg's quote highlights the extent to which direct regulatory measures were relied upon to make British Telecom more efficient. The use of the RPI-X formula and the increase in the value of X with successive iterations to put more pressure on BT is a key example of such a regulatory approach. In addition to the introduction of price controls, Oftel also focused on encouraging infrastructure investment on part of BT's competitors. Termed 'infrastructure competition', the aim of Oftel policy was to create alternative infrastructures to BT's fixed-line network and enable more choices for the end-users. Infrastructure competition was thus intended to foster competition by reducing the dependence of end-users and non-BT operators on BT's fixed-line network for last mile access connectivity. As Sir Bryan Carsberg explains in the following quote, the policy of infrastructure competition was also tied to the goal of improving BT's efficiency:

In my book, a great deal of the emphasis was on getting British Telecom to become more efficient. I thought that some infrastructure competition was necessary to make it happen. If they [BT] were confident that there would not be any infrastructure competition or at least in the foreseeable future, they would have been much more relaxed in what they did with their network.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London. 27 March 2012

An additional regulatory goal, Sir Bryan Carsberg states, was of accelerating introduction of new technologies:

I always used to say monopolies can afford to wait to introduce new technologies. They have spent a lot on the investment they have already. They try to get the most out of it. If they have a competitor who might introduce the new technology, they have to worry about that. They can't afford to wait any more. That was the important reason for infrastructure competition. We had it through Mercury. We eventually had it through some urban networks. The cable television system was an important aspect of infrastructure competition, which could have been developed beyond where it was. This meant British Telecom was faced with a threat.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London. 27 March 2012

As a result of the emphasis on infrastructure competition, BT's competitors i.e. Mercury Communications and the cable operators were required to build their own network infrastructure as part of the licence requirements. Mercury had to build its own network capacity to a deadline, and for this it chose a 'figure of 8' network connecting the major cities of the UK (at an early stage these cities were - Birmingham, Manchester, Leeds, Nottingham, Milton Keynes, London, and Bristol. See Mercury Communications Press Office, 1992). However, although Mercury built an optical fibre core network, for the last mile access, Mercury mostly relied on BT for connectivity via interconnect agreements⁵ (Mercury Communications Press Office, 1992).

Additional competition to BT was encouraged by removing the restrictions on the cable industry. Although cable distribution systems for television and radio signals had been in operation in the UK since 1951, until the end of 1983, with the exception of a few pilot systems, all cabled distribution systems had been authorised to relay only the programmes of the British Broadcasting Corporation (BBC) and from 1955 those of Independent Television Authority (ITA), later the Independent Broadcasting Authority (IBA) (see Dutton and Blumler, 1988 for a concise history of cable systems in the UK until 1980s). With the Cable and Broadcasting Act 1984, the UK government not only established the Cable Authority (CA) but also started granting the first multi-channel cable franchises in November 1983 (see VOA, n.d.

⁵ Interconnect agreements refer to the financial + technical terms and conditions under which BT allowed non-BT operators access to its network in the local loop (the last mile). As part of its privatisation, BT was required to provide connectivity to its access network to the non-BT operators. Given the sheer cost and scale of building an access network with a UK-wide national footprint, the interconnect agreements were a practical necessity for the non-BT operators in order to establish their operations.

for more details) Although BT was allowed to bid for cable franchises, it could only do so under stringent regulatory restrictions as the next section will discuss.

As competition was being introduced in the form of Mercury and the cable franchises, BT had continued to invest in the digitisation of the exchanges and upgrades to its transmission network. BT's continued interest in building better capacity than its existing copper-line networks allowed can be witnessed via its participation and interest in industry-led initiatives such as ISDN, Research in Advanced Communication in Europe (RACE), and Advanced Communications Technology and Services (ACTS). Before considering BT's approach to technologies such as ISDN and optical fibre, the next section discusses the cable franchise allocation, subsequent growth in the cable industry, and the emergence of coaxial cable/HFC network as an alternative to the BT-owned PSTN.

5.3 Cable Authority (CA) and the cable franchise allocation

Appointed by the UK government, the CA was authorised to decide which bidder would get the licence to be a cable operator in the franchise areas. Within a franchise area, the successful bidder would be a monopoly cable operator. Trevor Smale, a regulatory advisor to the cable industry during this time, describes the process by which the licensing took place in the following quote:

Basically at that time, anybody who wanted a licence could go to the Cable Authority and request a licence for area of their choosing. [...] But the focus was very much on quality and diversity of programming the operator was intending

to provide. There was some attention paid to ensure that the programming would be local in nature and support educational programming.

Source: Trevor Smale, Unpublished interview conducted by the author.

Milton Keynes, 11 April 2012

As part of the Cable and Broadcasting Act 1984, the cable operators were required to comply with the provisions of the Prescribed Diffusion Services order which contained a number of technical requirements regarding the capacity of the cable network and the way these cables would be laid. One of the key requirements was that the network needed to have the ability to carry 16 video channels of 8 MHz simultaneously in addition to the system being capable of delivering reception to 10,000 or more dwelling houses at the same time (see VOA, n.d.; Fox, 1990 for a discussion of the technical requirements for laying the cable networks). As the narrative in chapter 6 will show, such a stringent requirement on the required capacity of the cable networks proved important when the end-user demand for high-bandwidth connectivity grew starting in the 1990s.

5.3.1 Restrictions on BT

To ensure that the cable industry developed as a strong enough alternative to BT, restrictions were placed on BT. As Sir Bryan Carsberg recalls, these restrictions were put in place to ensure that BT did not extend its existing market position within telephony services into cable television and broadcasting services:

Part of the original idea was that the cable television companies would be given the advantage of integrating television and telecommunications, to give them economies of scope to reduce their overall cost per unit. British Telecom would be denied that. British Telecom was not allowed to carry television on their main network. The field was deliberately tilted towards the cable companies in order to help them overcome BT's entrenched position in the marketplace.

Source: Bryan Carsberg, Unpublished interview conducted by the author.
London, 27 March 2012

The restrictions on carrying television on BT's main network would play a key part in relation to BT's decision-making with regard to investments in optical fibre technologies, as section 5.4.1 will discuss in detail. Although British Telecom was prevented from competing with cable operators through the embargo on its delivering broadcast content, it was allowed a limited presence in the cable industry. British Telecom was initially allowed to bid for up to a maximum of 1/3rd of the cable franchises, and it could bid for cable franchises only through subsidiary or associate companies⁶ (BT, 1992). Since BT (1986, p. 13) perceived "*entertainment and information services to the home as an important part of an increasing telecommunications market*", it participated in the launch of three new "broadband" cable TV schemes in Aberdeen, Coventry and Westminster along with the acquisition of a company Swindon Cable. By 1987-88, BT even had a branded cable network TV service called "BT Vision" operating in Swindon (see BT, 1988a; 1988b). Despite BT's claims that the "BT Vision" service was well placed to remain a leader

⁶ Similar restrictions were in place to prevent BT from investing in mobile communications except through subsidiary or associate companies (BT, 1993a).

in cable and satellite industry (BT, 1988a), BT's investment in the cable operations was short-lived. BT exited the cable television market in 1990-91 as a result a review of its non-core activities⁷ (BT, 1991).

Despite the perceived threat of the cable industry to BT's market dominance, the cable operators were faced with a number of issues in relation to running the regional franchises, partly exacerbated by the way the bidding operators had rolled out their networks. In Dutton and Blumler's (1988) assessment of the development of cable development in Britain by late 1980s, they describe an industry struggling with a number of problems:

By 1987, only about 1.2 million households were passed by cable plant, and only about 190,000 households were connected, resulting in a penetration rate of about 16 percent of households passed. This amounted to less than 2 percent of all television households (Dutton, Rogers and Jun, 1987). Moreover, early market research on subscribers to cable systems created a "down-market" image of the consumer of cable services. This malaise hit programmers as well. Companies set up to provide programming for cable systems were reporting heavy losses and were paying increased attention to other outlets, such as satellite services, as a more promising market (The Times, 9 April 1986).

Source: Dutton and Blumler (1988, p. 288)

⁷ Although BT exited the cable television market in 1990-91, it continued to state its displeasure about the regulatory policy that barred it from delivering television on its main network. Part of this displeasure was due to the fact that some of the cable operators had US-based Bell regional companies as investors and hence, according to BT, benefitted from foreign investment derived from monopoly profits (see BT, 1991; ITC, 1997).

The problems with "programming" (i.e. developing local content) and lack of penetration were two of the key problems faced by the cable operators. Combined with the cable operators' initial lack of interest in telephony services, each of these problems would play a key part in how the cable infrastructure developed as a competitor to BT's copper-line network. The next section examines these difficulties along with the impact it had on the cable infrastructure being built by the cable operators.

5.3.2 The difficulties faced by the cable operators

Not only did the cable operators not pursue telephony seriously at an early stage, but the policy of cable franchise allocation as regional monopolies also meant that the cable industry was fragmented right from the beginning. This fragmentation significantly influenced the cable operators' capability to develop as a competition to BT. Sir Bryan Carsberg, the first Director-General of Telecommunications, although he was not involved in the cable franchise allocation, discusses the prevailing Oftel perspective in the quote below:

In Oftel, we certainly came to believe quite quickly that it would have been better to have bigger franchises. We [Oftel would have] encouraged the development of bigger franchises. Maybe what we [the regulatory bodies and the UK government] should have done is to divide the UK into 3 regions or something like that and then tender each third as a whole.

The honest truth is that cable television was slow to develop a challenge. Slow partly because it was a very expensive business to build it out. They were constantly running behind their mileposts, behind their targets for expanding their networks. There wasn't a very strong incentive for customers to buy into cable television because the off-air coverage was good and in any case, it [cable network] was slow getting to them [i.e. the end-users].

Source: Bryan Carsberg, Unpublished interview conducted by the author.
London, 27 March 2012

Prof. Martin Cave, a noted regulatory economist, and an expert on the functioning of the network industries (such as telecommunications and utilities), states the impact the fragmentation of the cable industry had on the investors, including a number of US-based telcos who had invested in the UK cable companies:

Originally, as you know, it [cable industry] was very fragmented. And that made it hard for it [the cable industry] to market its product and to develop. The returns for the original investors, particularly US telephone companies were rather disappointing. The impact of the cable companies on the telecoms market was really fairly limited. They managed to attract some telephone customers but not a very large number.

Source: Martin Cave, Unpublished interview conducted by the author.
Milton Keynes, 02 April 2012

Trevor Smale, then a regulatory advisor to the cable industry, mentions another important aspect relevant to the actual deployment of the cable infrastructure, which resulted in lower returns for the cable operators despite heavy investments⁸. This was the requirement about the laying of cables as part of the licence obligations set by the CA:

I was not privy to policy making decisions at that time but I certainly think it is highly likely that people went to the US model originally and sought to try and replicate that in the UK. One of the big differences in the UK right from the start was that in the US cable operators were able to sling their wires from telegraph poles and put them overhead. In the UK, the policy from an environmental point was that the cable operators had to dig up roads and bury their cables. That was a significant difference to the way the industry worked in the US. From an environment and aesthetic point of view, one can understand why the cable had to be buried but that was a significant factor as well i.e. the cost of digging up roads and building cable networks.

I can see from the outset that the US was the model but I think that was flawed for the UK. The additional burden of digging up roads to bury cables was incredibly costly. It ultimately played a part in cable companies going to Chapter 11 bankruptcies.

⁸ A number of wide ranging estimates have been made about the extent of investment that was made into building the cable network infrastructure. Malcolm Taylor worked in the cable industry throughout the 1990s and the 2000s and suggests that the costs were as high as £12B (see chapter 6 for more details).

Source: Trevor Smale, Unpublished interview conducted by the author.

Milton Keynes, 11 April 2012

The problems faced by cable companies in relation to rolling out the networks can be further evidenced by the manner in which the cable companies renegotiated their licence requirements. As mentioned by Sir Bryan Carsberg in a quote above, the operators were constantly running behind the milestones set by the Cable Authority. Richard Feasey, then working with a cable franchise owned by United Artists (a US-based investor), mentions one of the main reasons why these delays were commonplace, in the quote below:

The other key thing was the renegotiation of construction milestones which I was very closely involved in. The cable companies never met their original commitments in terms of how quickly they were expected to rollout the networks. It turned out that half the areas we thought we were going to build in were middle class areas where nobody wanted [the services]. So we ended up building other areas which the government hadn't anticipated.

Source: Richard Feasey, Unpublished interview conducted by the author.

Milton Keynes, 26 April 2012

An additional problem faced by cable operators in line with the Prescribed Diffusion Services order 1986 was that of generating and delivering content that distinguished their services from each other and the terrestrial broadcasters (as mentioned in section 5.3.1 as part of the discussion on developing local content). As part of their

licences, the cable operators were obligated to carry the terrestrial signals in addition to their own offerings (Dutton, 1987 cited in Dutton and Blumler, 1988). Fox (1990) has pointed out that for a significant part of the late 1980s some of the cable operators did not have any content other than the terrestrial television channels. This had a detrimental effect on the selling proposition of the cable operators since the content was available via a terrestrial signal and hence resulted in the cable system being perceived as not offering any significant advantages (Cable was perceived as being "down-market". See the quote from Dutton and Blumler, 1988 in section 5.3.1). As Richard Feasey points out in the following quote, the cable TV content was not seen to add any value amongst key end-user demographics:

... and one [important factor] that the Americans [i.e. the US-based investors] underestimated is the fundamental position of the BBC and free-to-air television in the UK. The assumption [on part of the US-based investors] was that people would self-evidently want to buy pay-TV in the UK. The Americans simply did not understand - how much attachment there is, particularly amongst high-value customers i.e. the [British] middle-class households to the BBC and free terrestrial television and how reluctant they would be to migrate.

Source: Richard Feasey, Unpublished interview conducted by the author.
Milton Keynes, 26 April 2012

As a result of the lack of content and lower end-user adoption, although the cable operators had built significant network capacity due to the requirements of the Prescribed Diffusion Services order, the cable operators had no immediate use for

the excess capacity. As the events in the late 1990s would show (see chapter 6) however, this excess capacity provided an early advantage in relation to broadband provision via cable modems.

An important factor that compounded the problems faced by the cable operators was their licence obligations to deliver localised, regional content. The scale of problems faced by the cable operators specifically in relation to delivering localised content are encapsulated by Richard Feasey's account of his time at United Artists (which had a cable franchise in Croydon):

The original idea was really that cable TV's main justification was that there would be demand for very localised TV content. That was the reason for having Croydon Cable, Newcastle Cable and so on. When I joined, we had obligations as United Artists to build a TV studio in Croydon. We were so desperate for local content that I used to go and occasionally appear on it and no one was watching it.

Source: Richard Feasey, Unpublished interview conducted by the author.
Milton Keynes, 26 April 2012

Due to the problems of fragmentation, the high cost of cable network deployment, the down-market image of cable TV services, and the inability to meet their licence obligations related to network rollouts, not only had the cable industry failed to emerge as a competitor to BT, but it was also struggling for financial solvency. Looming over these difficulties was the possibility of the duopoly review in 1991 and

the market being further liberalised. The outcome was that by the end of 1980s, the cable industry in the UK had begun to show signs of consolidation i.e. merger. Throughout this time, along with its forays into cable industry, BT had also made a significant effort in relation to building capacity in its core and access network. BT's efforts were focussed not only in relation to investments in transmission technologies such as ISDN and optical fibre, but also in relation to services such as Prestel and a "killer application" that would deliver returns against such an investment.

5.4 Changes in BT's strategy after denationalisation in relation to the investments in ISDN and optical fibre

During the early 1980s, prior to its denationalisation, the British Telecom operations had begun to be influenced by the new competition policy and its impending privatisation⁹. An example of BT's changing priorities is the way in which the Prestel system, which was launched with much fanfare in 1979, was handled during the early 1980s and particularly after BT's denationalisation (in contrast with the investment and deployment of the Télétel system under France Telecom, a public sector monopoly. See Feenberg, 1992). Although the BT annual report in 1985-86 declared that the Prestel system had achieved its first full year of profit (BT, 1986),

⁹ By early 1982, with Mercury being granted a licence, it was apparent that the market would be liberalised. BT's foreknowledge of the impending denationalisation can be understood from its annual reports in the years 1981-82 and 1982-83 (see BT, 1982). By early 1983, BT managed to reduce its waiting list to 2,560, its lowest level for more than 25 years (BT, 1983). It is arguable that such expedient disposal of the waiting list was motivated by ensuring that as many end-users as possible had BT's subscription before competition was introduced.

beyond that point the Prestel system hardly sees a mention in the BT annual reports. This is because when it became obvious that the Prestel system was unlikely to succeed commercially, no further significant investment was made either in the form of the servers which would host the "pages" or the terminals which were to be distributed to the end-users (see Mayntz and Schneider, 1988). No longer a public-sector monopoly, BT's focus was increasingly on profit-making in line with its prerogative as a private company¹⁰. Although the British government had retained golden shares¹¹ as a minority owner, by late 1980s, it had begun to contemplate diluting its ownership of BT. The failure of the Prestel system had also led to questions over the viability of services other than telephony for the consumer end-users. In the subsequent years BT's approach in relation to investing in technology to deliver high-bandwidth connectivity to residential end-users is decidedly cautious as the discussion in chapter 7 will show. This caution is highlighted by the continued attempts by the BT and other incumbent telcos to find a "killer application". Of particular note is the failure of AT&T's Picturephone service in the USA during the 1970s (see Lipartito, 2003; Noll, 1992; Rohlfs, 2001 for further detailed discussion on the failure of the Picturephone). As a result of the way in which the Picturephone service failed in the USA, the telcos wanted to ensure that the elusive "killer application" would not only guarantee an additional revenue stream but also open up the consumer end-user segment to additional services over

¹⁰ BT's intent was *"to develop British Telecom into a top class information technology business operating around the world"* (BT, 1985, p. 5).

¹¹ The term "golden share" refers to the stake the British government retained while denationalising a number of the network industries such as water, gas, electricity, and telecommunications. These shares were retained as part of a strategy to execute the denationalisation in a phased manner. In case of BT, the UK government retained a minority share at 49.8% to begin with (BT, 1984). By the time the remaining shares were sold off in 1993-94, the UK Government stood to earn £3B by conservative estimates (BT, 1994a, 1994b, 1994c).

the network. As discussed in the next sections, this search for a "killer application" combined with BT's phased denationalisation had a significant influence on its investments in relation to optical fibre and ISDN.

5.4.1 Optical fibre in the core network

As noted in chapter 4, BT had already begun to strengthen capacity in its core network via optical fibre in the late 1970s. With the introduction of competition in the form of Mercury and in view of Mercury's efforts to build its own optical fibre core network right from the beginning (C&W, 1984; 1985; 1986), BT's efforts in relation to optical fibre became more significant. BT's strategy was also influenced by its efforts in relation to the "X-Stream" set of services¹². The X-Stream services were being designed to operate on optical fibre cables (called "Lightlines") to provide fast and high capacity links to carry voice, data, and video at different bandwidths (BT, 1984). By early 1984, BT had deployed an optical fibre network for the City of London through which customers could be provided with videoconferencing, point-to-point video transmission, high-bandwidth data links, and services for bulk distribution of information (BT, 1984). BT's efforts to deliver X-Stream services and the perceived importance of non-voice services in its plans for optical fibre are indicative of a wider trend in the industry to introduce non-voice services and generate new revenue streams throughout the 1970s and 1980s¹³.

¹² The X-Stream set of services were termed so due to the nomenclature followed by BT in their branding i.e. KiloStream, MegaStream, Packet SwitchStream, SatStream, and VideoStream referring to the different bandwidths and services offered. For a concise description of X-Stream services specific to BT's data networks, see King (1998).

¹³ The intention to expand into non-voice services was one of the main reasons behind the Picturephone initiative by AT&T in the USA during 1970s. See Noll (1992) for an analysis of AT&T's

Despite BT's interest in the X-stream services and their potential for delivering voice, data, and video over optical fibre cables, BT's deployment of optical fibre in the access network (as opposed to the core network) remained limited to one-off trials such as its deployment of small fibre optic switched star system called "Fibrelevision" to 18 homes in Milton Keynes (BT, 1983; West and Firnberg, 1987 cited in Dutton and Blumler, 1988). Once the restrictions on delivering television over its main network were in place, BT's official position remained that in the absence of the ability to deliver premium content, installing optical fibre in the access network was not a commercially viable proposition (BT, 1991. See chapter 6, section 6.4.7). Sir Bryan Carsberg, who was the Director-General of Telecommunications during this time when the UK government imposed these restrictions on BT, suggests that by allowing BT to bid for up to one-third of cable franchises, this limitation was compensated for. In the quote below, he elaborates on the restrictions BT was subject to carrying television on its main network, and the extent to which this restriction played a part in BT's optical fibre rollout. His scepticism about the actual importance attached by BT to a television broadcasting capability is relevant given that BT exited the cable television business by 1990-91 citing unfavourable economics of operation (BT, 1991):

I am very doubtful about it [that BT would have rolled out optical fibre if it was allowed to carry television on its main network]. British Telecom was allowed to have cable television networks - just under a separate licence. They had

approach and the reasons for Picturephone's failure. Brotman (1980) discusses the introduction of teletext and Videotex services and the ways in which competition and investment can be encouraged for such non-voice services.

[owned] some [cable franchises]. [...] They would have had a de facto monopoly in the areas where they had cable television franchise. I told British Telecom at one time that they could have up to a third of the cable television licences.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London, 27 March 2012

In the following quote, Sir Bryan Carsberg explains the reasons why the restrictions on carrying television remained for a long time¹⁴. He also comments on the decision to restrict BT from delivering television on its main network and the implications of the decision in terms of its position as a former monopoly:

The power to grant them [BT] permission to carry television over the main licence was not mine. That was something the government reserved. I could have advised the government to do it [i.e. allow BT to run television]. It seemed to me that the idea of letting them [BT] have their own cable television franchises was quite sufficient to allow them to develop. I viewed that [restriction on carrying TV over main network] as a bit of an excuse [on BT's part] quite honestly. I think if they [BT] had really wanted to [deliver broadcast television services], they could have made good progress that way [i.e. by owning cable franchises]. They could have set themselves up for further steps in the future - not to regain the whole monopoly but to get a big piece of the action [through the cable television business]. Given the history [of BT as a

¹⁴ The restrictions on BT were amended to allow delivery of video-on-demand in 1993. The restrictions on delivering television/broadcast services remained in place until 1999. These developments are discussed in further detail in chapter 6.

monopoly] and the way it looked then, when people [like BT] want to restore the monopoly, you [as a regulator] start running away [from such a prospect].

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London, 27 March 2012

On the one hand, Sir Bryan Carsberg's explanation reflects the extent to which the regulators (Ofcom and CA) and the UK Government were wary of allowing BT's advantageous position in telephony services to be extended into other market segments such as television. On the other hand, unlike BT's approach to rolling out optical fibre in the 1970s (when it functioned as part of the Post Office), BT's position on optical fibre deployment after denationalisation was aligned with its changed focus as a privatised company. That is to say as a public-sector monopoly, the Post Office's decisions were not dictated by achieving commercial returns on investments in technologies such as optical fibre alone but by other considerations such as fulfilling its public service remit, providing telephony services to residential and business end-users in the UK, increasing efficiency of operations and lowering transmission costs (see chapter 4, section 4.3.3). The profit motive played a limited part in the decisions of the Post Office since it functioned to deliver a service to the tax-payers¹⁵.

With the introduction of competition in the form of Mercury and the cable operators, BT could only lose market share and revenue (since it started with 100%

¹⁵ The Post Office's focus on public service was a reflection of its position as a public sector entity. The lack of emphasis on profit-making during the Post Office days or on part of BT prior to its denationalisation was arguably not specific to the organisation itself.

ownership of the market). The result was an increased interest in technologies and services which could deliver additional revenue. Although BT perceived the business case for optical fibre to be non-viable due to the constraints on carrying broadcast television, it continued to pursue the capability to deliver non-voice services. In this context, ISDN was a potentially important development since it was intended to be a platform capable of delivering integrated services in the form of voice, data, and video¹⁶ (see David and Steinmueller, 1990 for a discussion on the standards "movement" behind ISDN, its intended purposes, and possible outcomes related to its adoption). The next two sections cover how, given these expectations, the development and deployment of ISDN turned out.

5.4.2 ISDN and the digitisation of access network

The ISDN set of standards, protocols, and technologies were developed by the CCITT and the European Telecommunications Standards Institute (ETSI). Although the term 'ISDN' had been first created as early as 1971, *"it took about 15 to 20 years before the ISDN concept received full international attention at the CCITT"* (Kano et al, 1991, p. 118). It was only at the end of 1984 that the I-Series Recommendations were approved by the CCITT Plenary Assembly and printed as part of the CCITT "Red Book" (see Decina and Scace, 1986). The long gestation period is not only indicative of the lengthy development cycles followed at the CCITT but also the extent of ambition associated with the concept of ISDN. Prof. John Cioffi, whose

¹⁶ The development and the outcome of ISDN is a subject matter of study in itself. Not only was ISDN a mammoth standards movement, it was a result of collaboration between up to 140 countries at the CCITT/ITU. Its commercial failure was due to multiple factors, of which technical reasons were a small part. This thesis mostly focuses on ISDN deployment in the UK and how related outcomes are relevant in relation to the eventual market share of broadband technologies.

work with Discrete MultiTone (DMT) modulation would play a key part in the development of DSL broadband technologies in the 1990s (more on this in chapter 6), explains the early approach and intention behind ISDN in the quote below:

I remember a meeting from 1979 about ISDN (when it wasn't even called ISDN). What they [the telcos and the standards-making bodies i.e. CCITT/ITU and ETSI] were trying to do at that time was to create an all-digital network worldwide. [...] The aim [with ISDN] was to carry the voice transmission digitally end-to-end. However, there wasn't really a need to transmit voice digitally. [...] It [ISDN] didn't really have any applications that could take advantage of this digitisation.

Source: John Cioffi, Unpublished interview conducted by the author. Milton Keynes, 15 December 2011

Thus the aim with ISDN was to extend the Integrated Digital Network (IDN) capability in the core network from the local exchange down to the end-user to allow a digital interface to be offered to the end-users (Valdar, 2006). As highlighted in Prof. Cioffi's quote above, despite the capabilities ISDN offered, throughout the 1980s, the lack of applications and services that effectively utilised this additional capacity and justified the expense of investing in it, held back the deployment of ISDN. As a result, the extent to which ISDN would lead to additional revenue-making opportunities getting created for the telecom operators remained unknown. Despite the expectations associated with ISDN and concerted effort put into it by

CCITT/ITU¹⁷, the aforementioned lack of services / applications played an important part in the limited adoption of ISDN. A change of approach to infrastructure investment in the newly privatised BT's priorities also played a key part in how ISDN was deployed in the UK as the next section explores.

5.4.3 The problems with ISDN deployment

One of the main reasons for the delay in the adoption of ISDN by telcos such as BT was that it required the telephony network and the local loop¹⁸ to be made digital. Such digitisation was considered important by the telcos because it not only provided a cost-effective multiplexing and transmission technique but also greatly improved the quality and clarity of circuits providing immediate benefits to the telephone users in the form of improved clarity of voice transmission, lack of background noise, and the ability to mix different types of services due to digital conveyance for both voice and data (Valdar, 2006). As a result of the requirement to install the digital local loop, the deployment of ISDN faced a number of practical difficulties (Starr et al, 1999) -

- While the digitisation of the core telephone network was relatively inexpensive due to the economies of scale involved, converting local loop to become digital was a labour intensive and expensive process.

¹⁷ Haslam (1994) states estimates related to ISDN deployment where within ten years (i.e. by 2004) 28M channels or half of all business exchange lines in Europe were expected to be connected to ISDN. A European Commission paper produced in December 1993 on the European economy recommended the building of a Europe-wide ISDN initiative at the cost of European Currency Unit (ECU) 15B. See Haslam (1994) for more details.

¹⁸ The local loop, also called the "last mile" is the length of the network from the end-user premises to the nearest cabinet or local exchange. See Valdar (2006).

- The conversion of local loop involved replacement of the end-user front-end equipment at the local exchange which was time consuming.
- Even with the core network becoming digital and the local loop remaining analogue, the quality and reliability of voice transmission had greatly improved. In addition, supplementary services such as caller ID and call waiting that were part of ISDN recommendation had become possible without the local loop being converted.

Effectively, with very limited demand for data services from the residential end-users, the adoption of ISDN lagged behind expectations of CCITT/ITU. Although digital voice offered better quality and clarity over analogue voice, the telcos were not certain whether end-users would be willing to pay for the additional costs of implementing a digital local loop. The absence of any revenue-making application/services meant that ISDN was often facetiously labelled as "Innovation Subscribers Don't Need" (see Newstead, 1986).

Prof. John O'Reilly, the chairperson of UK's Network Interoperability Consultative Committee (NICC) for the Office of Communications (Ofcom) and the telecommunications industry, and a former Principal Research Fellow with BT, discusses the extent to which digital voice was central to ISDN's selling proposition and the intended uses of ISDN in the quote below:

The implementation of digital voice in ISDN meant although it was intended for other services, not much use was being made of such capabilities. In

addition the analogue to digital to analogue conversion process used for voice in ISDN was arguably making an inefficient use of bandwidth. ...

Source: John O'Reilly, Unpublished interview conducted by the author.

Cranfield, 22 December 2011

An additional factor that influenced ISDN deployment in the UK significantly was BT's focus on business end-users in relation to ISDN. BT's approach is reminiscent of its focus on delivering Datel and Dataplex services to business end-users during the Post Office days as chapter 4 discussed. Kevin Foster, the Head of Access Platform Innovation at BT, who was involved with BT's efforts in relation to ISDN standardisation and deployment, highlights the extent to which business end-users were a priority for BT. In the following quote, he contrasts BT's focus on businesses with that of Deutsche Telekom which strongly pushed ISDN to residential end-users:

It is down to the way ISDN was marketed and used. Deutsche Telekom were in sync with the strategy that their voice provision was to be transferred to digital instead of remaining analogue. BT also has a number of ISDN lines for data purposes, linking PBX [Private Branch eXchange]. It [ISDN] has been a business kind of an application rather than a mass-market residential service. It did have a residential application with services like 'Home highway' with voice and data access.

Source: Kevin Foster, Unpublished interview conducted by the author.

Ipswich, 19 January 2012

The reference to 'Home Highway' in Kevin Foster's quote is particularly relevant if the fate of ISDN for the UK residential end-users is considered. BT's approach in relation to the 'Home Highway' product reflects its continued uncertainty about whether demand existed for data connectivity on the part of residential end-users. The failure of the Prestel system, which was intended as a data service for residential end-users, was also an important factor in BT's strategy. In contrast to the ISDN service for business end-users, Home Highway not only saw limited rollout but also suffered from lack of end-user adoption. This commercial failure of ISDN in the residential end-user / consumer segment of the market would play a key part in relation to BT's forays into delivering high-bandwidth connectivity in the 1990s as the discussion in chapter 6 will show. David Brown, the former Head of Schema, a noted telecoms consultancy, discusses the outcome of the Home Highway service

(implemented with the 2B+D¹⁹ interface) in the quote below. He reiterates the issue of ISDN being overly reliant on digital voice as a selling proposition:

There was a realisation in BT that Home highway wouldn't hack it. [...] The problem with ISDN was in terms of how it attempted to deliver the voice channel. [...] There is no need for digital voice as it was done in 2B+D [i.e. 2 Bearer channels and 1 Delta channel as implemented with ISDN]. [...] 2B+D looked at making voice channel digital that meant Home Highway did not take off.

Source: David Brown, Unpublished interview conducted by the author. Hemel Hempstead, 13 December 2011

In addition to the lack of viable applications and services, the comparison of the UK and German markets in relation to ISDN adoption highlights an important difference in the way Deutsche Telekom and British Telecom handled the commercial prospects of ISDN as a technology²⁰. Deutsche Telekom, during the

¹⁹ 2B+D (also 2B1D or Basic Rate Interface) refers to an ISDN channel consisting of two 64 kbit/s "bearer" (B) channels and one 16 kbit/s "delta" (D) channel, giving a total data rate of 144 kbps. The B channels are used for voice or user data hence the bandwidth of 128 kbit/s. The 16 kbit/s D channel is used for control and signalling.

²⁰ The difference in the extent to which the adoption of ISDN differed in Germany and the UK can be understood by following numbers (Starr et al, 1999) -

Country	1994 BRI lines	1996 BRI lines
Germany	428,000	2,000,000
United Kingdom	75,000 *	200,000

Table 5.1 - ISDN adoption in Germany and the UK (* Extrapolated numbers)

1980s remained a nationalised telecommunications monopoly and did not have the same obligations as BT, a private company²¹. Gavin Young, former Board Director at Broadband Forum, worked with Kevin Foster in the early high-bandwidth connectivity trials at BT and adds further to this discussion on the relatively less adoption of ISDN in the UK:

It is interesting that in Germany, ISDN became ubiquitous. Almost every phone in Germany was connected to ISDN. Where as in the UK, most people had an analogue phone and ISDN was predominantly for businesses whether basic rate or primary rate. In Germany, ISDN was on mass consumer scale. A lot of that is down to pricing and how the product is positioned.

Source: Gavin Young, Unpublished interview conducted by the author.
London, 01 February 2012

Thus, the absence of ISDN adoption by residential end-users in the UK can also be attributed to the fact BT pushed ISDN mostly for business end-users. Unlike Deutsche Telekom, BT's choices were significantly influenced by the commercial returns possible and hence BT chose to not push ISDN to residential end-users.

Although the numbers are extrapolated for the UK, the difference represents the extent to which the approach taken by Deutsche Telekom and BT made a difference in end-user adoption.

²¹ Haslam (1994) states that Germany and France even had their own national version of ISDN. In line with a Memorandum of Understanding (MoU) signed by 17 countries in the Europe (including the UK) in 1986, a standardised Euro-ISDN was launched at the end of 1993. German and French carriers launched a Euro-ISDN service in late 1993 only to comply with the MoU. The extent of German and French national carriers' push for ISDN can be understood by the fact that between them France and Germany accounted for more 99% of the basic rate connections in Europe based on non-Euro-ISDNs as of 1993. See Haslam (1994) for more details.

Despite specifically targeting business end-users however, in part due to the requirements of installing digital loop and also due to its limited bandwidth capabilities (of 128 kbit/s), a number of businesses which required higher rate data services were catered through T₁ and E₁ transmission systems. The T₁ and E₁ transmission systems could deliver bandwidth of 1.554 Mbit/s and 2.048 Mbit/s respectively. In contrast to ISDN, the key advantage of the T₁ and E₁ transmission systems was that they operated over existing telephone lines²².

5.4.4 The demand for improvements to ISDN

With the experience of T₁ and E₁ lines behind them, BT and incumbent telcos in other countries began to realise that the bandwidth delivered by the existing ISDN standard would not suffice for the intended services for use of data and video (including video-conferencing features plus Videotex services) (Starr et al, 1999). This perception heightened further with the telcos' increased interest in delivering entertainment video through a telephony network for which the bandwidth of 128 kbit/s delivered by ISDN were deemed insufficient (Ayanoglu and Akar, 2003). To BT (and other incumbent telcos), delivering entertainment video was an important way to counter the threat of cable operators. All these events contributed to a

²² T₁ and E₁ transmission systems were originally intended to connect the local exchanges in the core network. These systems operated over existing telephone lines and were intended to increase the number of telephone calls that could be made over the existing telephone lines. The T₁ transmission system was used in US, Japan, and Korea. The E₁ transmission system was used in Europe and despite the similarity in its naming with the T₁, the systems were not entirely compatible. Despite the capability to re-use the existing telephone lines, T₁/E₁ transmission systems were expensive to install. This meant that the telcos relied on T₁/E₁ lines to address a relatively smaller section of end-users mostly focussing on businesses (Starr et al, 1999). See Andrews (2011) for a more detailed history of the early T₁ transmission system.

clamour for ISDN to be capable of delivering such high bandwidths (and be future proof). Part of this clamour was due to the lengthy process and the speed with which standards-making progressed at CCITT/ITU in relation to ISDN (Knight, 1992). In the following quote, Prof. John O'Reilly discusses the role of the length of development cycles followed for ISDN and the effect it had on ISDN deployment by telcos:

My impression is that ISDN was a good idea, probably ahead of its time and then eventually took too long [to develop]. It was locked into CCITT standards making with 4 year cycles - an incredibly long drawn out process for making standards and incompatible with the data world and where telecom industry was going.

Source: John O'Reilly, Unpublished interview conducted by the author.
Cranfield, 22 December 2011

Kevin Foster has echoed the above comment about the extent to which the process followed for ISDN development was incompatible with the trends in the industry. In the quote below, he talks about the pros and cons of the approach by the CCITT/ITU:

Another factor is that rapid advancement of technology at that time meant that the traditionally long depreciation periods were shrinking. There was a kind of change of worlds and the alternative, better, faster, and cheaper technology was just somehow beyond the ISDN development. We applied the

same principles as ISDN to some of these new developments. It didn't obsolete ISDN completely but technology relentlessly marched on. ISDN did have a window of opportunity but it was just a question of where it was situated in the change from the analogue world to the digital world.

Source: Kevin Foster, Unpublished interview conducted by the author.
Ipswich, 19 January 2012

As an outcome of the perceived limitations of ISDN and its limited adoption in the real-world, the standardisation work on B-ISDN was initiated by Broad-Band Task Group (BBTG) of the CCITT at beginning of 1985-1988 study period (Kano et. al., 1991). CCITT responded to the increased demand for higher bandwidth in 1988 by issuing a set of Recommendations for ISDN, under the general name of "broadband aspects of ISDN" (see Ayanoglu and Akar, 2003 for a detailed discussion on the process under which the Broadband ISDN i.e. B-ISDN specifications were developed). This use of the word "broadband" marked the beginning of the term "broadband" being used more widely. It also marked the association of the term "broadband" with the capability to deliver multiple services – voice and non-voice through high-capacity transmission technologies (Byrne et al, 1991).

However, as the events in the 1990s will show, an unforeseen development within data communications and computing would have a disruptive influence on the way the development of B-ISDN and further progress of related standards for integrated services took place. It was a project called the Advanced Research Projects Agency Network (ARPANET) which had been initiated with very modest goals as part of a

stealth project by the US Department of Defense. Although a significant portion of the events related to B-ISDN, ATM, and ARPANET took place in the 1990s and hence will be covered in chapter 6, the next section focuses on the events in late 1980s specific to B-ISDN, ATM, and the goals with which these technologies were designed.

5.4.5 B-ISDN, ATM, and the ambition of a multi-service network

Intended to overcome the perceived limitations of ISDN (including bandwidth capacity), a key driver for B-ISDN was the ability to deliver a high-bandwidth "killer application" and generate an important revenue stream, which by the end of 1980s had become a key priority for not only BT (and incumbent telcos in other countries) but also cable operators²³. David Brown, the former Head of Schema, a noted telecoms consultancy, points out the extent to which such a high-bandwidth capability was prioritised in relation to B-ISDN as part of the EU RACE programme:

²³ This trend for high-bandwidth applications and services is reflected in a number of industry and institutional initiatives such as Integrated Multi-Service Communication Network (IMCN), RACE, and ACTS. IMCN was *"was not about better ways of getting a signal from A to B but about networks supporting a wide range of services, including those not yet thought of"* (IEEE ComSoc, 2012, p. 123). RACE was intended *"to investigate all aspects of the integrated broad-band communication network (IBCN)"* (Mogensen et al, 1989, p. 1715).

In the EU RACE programme, Broadband ISDN was stated as a target. There was though no specific association with a technology. The focus was on specific services that are digital and fast - interactive entertainment, remote collaboration, streaming, Video-On-Demand, and a basket of things like that.

Source: David Brown, Unpublished interview conducted by the author.
Hemel Hempstead, 13 December 2011

The aim of a network capable of delivering multiple services is echoed by Prof. Andy Valdar, who during his 30 year tenure at BT took part in a number of initiatives related to network strategy and planning, and development of international standards such as B-ISDN. In his quote below, he outlines the approach behind B-ISDN:

A primary driver for ATM was to develop what looked like a Broadband ISDN. [...] ISDN is essentially putting data over circuit-switched telephone network. It was recognised that this would always be a limitation. Because ISDN means you are stuck with telephony tariffs. [...] Just like the ISDN means integrated services digital network, ATM really is multi-service network. [...] So you would deal with real-time applications, non-real-time applications, high and low speeds including voice and video.

Source: Andy Valdar, Unpublished interview conducted by the author.
London, 18 April 2012

This contrast between B-ISDN and ISDN (which had begun to be called narrowband ISDN or Basic-Rate ISDN i.e. BR-ISDN retrospectively) is also mentioned by Prof. Laurie Cuthbert of Queen Mary University of London (QMUL) and co-author of the book "ATM: the broadband telecommunications solution". He suggests that video capabilities were a key part of the B-ISDN specification:

Narrowband ISDN was never really in consideration for video except may be video telephones. It was Broadband ISDN powered by ATM that was considered for Video-On-Demand. Nobody actually knows killer applications. For Broadband ISDN, the killer application was identified as video.

Source: Laurie Cuthbert, Unpublished interview conducted by the author.
London, 13 February 2012

Although the developments related to B-ISDN had begun in the late 1980s, it was not until early 1990s, that the specifications including those of ATM, which formed the backbone of B-ISDN, were considered ready for deployment. These key developments related to B-ISDN and ATM will be covered in chapter 6. In relation to how the broadband technologies evolved, during the same time as B-ISDN was being developed, a key breakthrough was taking place. Despite the extensive efforts being made on B-ISDN, the perceived limitations of ISDN had led a group of researchers to consider other alternatives to improving the initial ISDN specification (or more specifically BR-ISDN). A key effort amongst these was a way to use the existing copper twisted pair to deliver data. Similar to B-ISDN, the capability to deliver video (specifically video-on-demand) formed a key part this effort on part of

the various researchers. Relatively unheralded, this effort would be known as High-bit-rate Digital Subscriber Line (HDSL).

5.5 The early iterations of DSL

The early concept definition of HDSL was developed in late 1986 at AT&T Bell Laboratories and Bellcore. Subsequently prototype HDSL systems appeared in 1989. HDSL transceivers were built on the BR-ISDN designs and promised peak rates of 1.5 and 2 Mbit/s.

Apart from the better bandwidth compared to ISDN (which delivered 128 kbit/s full duplex), HDSL had other advantages compared to technologies such as T₁/E₁ lines. These were as follows (Starr et al, 1999) –

- HDSL eliminated the need for repeaters (to boost transmission signal) which were required for T₁/E₁ lines and added to the T₁/E₁ installation costs. HDSL did not need a repeater on 95% of the lines.
- HDSL could be installed as a plug-and-play transmission system and could quickly provide up to 1.5 to 2 Mbit/s over most existing copper lines.
- HDSL caused less crosstalk compared to T₁ / E₁ lines and hence less data loss.
- The annual maintenance costs of HDSL lines were lower than for T₁/E₁ lines because HDSL lines had fewer repeaters to fail, superior transmission robustness, and improved diagnostic capabilities (i.e. the capability to detect and locate faults in the copper line).

The extent to which HDSL owed its origins to ISDN is highlighted by David Brown's summary of how DSL differed from ISDN:

[...] In the end, DSL didn't get labelled as ISDN although it worked on some of the same principles. ISDN as a concept continued with DSL - which did it better. The problem with ISDN was in terms of how it attempted to deliver the voice channel. With DSL, the voice channel is still analogue.

Source: David Brown, Unpublished interview conducted by the author.
Hemel Hempstead, 13 December 2011

However, despite of all these advantages, HDSL was restricted by its peak rates of 1.5 to 2 Mbit/s. Similar to ISDN, HDSL also enabled symmetric traffic i.e. the same bandwidth to be delivered upstream and downstream. The pursuit of better bandwidth meant that Asymmetric Digital Subscriber Line (ADSL) which promised peak rates close to 7 Mbit/s for downstream traffic, was being developed in parallel to HDSL. As the discussion in chapter 6 will show, the use of asymmetry, the availability of more bandwidth for downstream traffic, and the improvement in the data rates that ADSL could deliver, would play an important role in relation to the emergence of DSL as a broadband technology. The earliest conceptual definition of ADSL originated in the work of J. W. Lechleider and others at Bellcore in 1989 (Cioffi, 2011). Early ADSL development happened at Stanford University²⁴ and AT&T Bell Labs in 1990.

²⁴ It was at Stanford University that Prof. John Cioffi initiated some of his pioneering work on DMT which would go onto play a key part in the development of the early ADSL modems. See Cioffi (2011).

At this stage of DSL development, in comparison with coaxial cable, optical fibre, and B-ISDN, the bandwidth offered by copper-based HDSL was significantly lower. As a result, not only was copper twisted pair considered inadequate in relation to high bandwidth connectivity but any long-term investment was expected to be in optical fibre technologies. Kevin Foster, who worked on BT's behalf on a number of key specifications related to ISDN and DSL, recalls how copper twisted pair was perceived in some sections of the industry at that time:

... I remember being told by a colleague that this [the work on BR-ISDN] was the last transmission problem, and when this problem had been solved you [had] better get away from copper and DSL and move onto fibre because there was no future in copper.

Source: Kevin Foster, Unpublished interview conducted by the author.
Ipswich, 19 January 2012

Despite the perceived limitations of copper twisted pair though, the most important contribution of HDSL was that for the first time since late 1970s, the copper twisted pair was in contention to carry something other than voice traffic²⁵. As the events in the 1990s show, this previously unforeseen, unpredicted capability to carry non-voice traffic on copper twisted pair would have a significant effect on the evolution of broadband technologies in the UK.

²⁵ The important difference as explained by David Brown was that unlike ISDN, DSL did not require extensive rewiring in the last mile and DSL also left the use of analogue voice unchanged.

5.6 Discussion and Conclusions

This chapter shows the extent to which political and economic factors related to denationalisation, competition, and regulation had technological consequences for the communications industry (subsequent chapters will continue to demonstrate this effect). Although even during the 1980s the term "broadband" was not part of mainstream usage, the idea of using additional bandwidth to deliver services such as television, video-conferencing, and video-on-demand had taken hold. In particular, with the denationalisation of BT and introduction of competition in the form of Mercury and the cable operators, each of these stakeholders was attempting to grow revenue through various means. For cable operators, the opportunity to grow their market share was incentivised through the capability to bundle telephony and television services. For BT, it was in the form of extending into other emerging market segments such as broadcasting services and video-on-demand. Mercury, for its part, was attempting to minimise investment by focussing on building a 'figure of 8' core network and relying on BT for the last mile access.

Underlying these different motivations and strategies on the part of BT and other operators was the regulatory focus on creating a competitive market for the UK communications industry via infrastructure competition and price control. Mercury and the cable operators had licence obligations to build a required network capacity within a specific timeframe. The aim of the regulatory policies was not only to create pressure on BT to become more efficient but also to accelerate investments in new technologies. Despite the regulatory pressure though, BT's investment in new technology was fairly cautious. BT's deployment of optical fibre was restricted to core network and its push for ISDN was mostly limited to business end-users. In

order to encourage cable operators to invest in infrastructure and limit BT from extending its market dominance of telephony, BT was not allowed to carry television on its main network. Such restriction meant that BT's approach to investments in technologies such as ISDN and optical fibre was revised, citing inability to recoup its investments. Despite the incentives, by the end of the 1980s, the cable industry was significantly fragmented due to the nature of franchise allocation signalling a need for consolidation.

The differing priorities of the various stakeholders combined with the difficulties in the development and deployment of ISDN indicate that not only was the concept of broadband unclear, the use that would be made of such broadband capacity was also an unknown. The use of social constructivist ideas enables an understanding of the different contexts in which high-bandwidth capacity was being considered. The way in which different services such as video-on-demand were considered to be potentially revenue-generating streams is also covered as part of the analysis. Hughes' (1987) 'technology as a system' approach offers an opportunity to understand the various interactions between the operators (including BT), regulatory bodies, and the developments related to technologies such as ISDN. In addition, as the discussion in chapter 4 presented, the concept of reverse salients offers insights in relation to understanding the difficulties in the development and deployment of ISDN. This discussion is then rounded off with an analysis of the role of regulatory policies such as infrastructure competition and price controls in relation to technologies such as ISDN, coaxial cable and optical fibre. Hecht's (2001) concept of technopolitical regime is considered to understand the role of such

historical decision-making by the various stakeholders including regulators and operators.

5.6.1 More stakeholders and different interpretations of high-bandwidth connectivity

With the denationalisation of BT, not only did the existing relevant social groups (i.e. various stakeholders involved in shaping the function and meaning of technology) undergo a change but new relevant social groups emerged. Among the relevant social groups identified in chapter 4, the Post Office telecommunications division was superseded by BT. The new relevant social groups that emerged were – the regulatory bodies i.e. Oftel, CA, and the non-BT operators i.e. Mercury and the cable operators. Although BT would remain the dominant operator in the UK for a long duration of time, the Post Office's approach of end-to-end ownership of products, services, and technologies did not carry the same weight given the regulatory push for competition and liberalisation. Thus the influence of the Post Office's technological frame (i.e. cognitive, social, and technical elements that guide the meaning and behaviour in relation to the technology) also lessened significantly. The regulators and the non-BT operators had different views about the nature of products, services, and technologies they wanted to implement. As the events in this chapter show, relevant social groups such as BT, Mercury, and cable operators were attempting to define what the high-bandwidth connectivity could do. Each of these relevant social groups had different and yet somewhat overlapping technological frames about broadband connectivity. In consequence, although broadband was not

yet a clearly defined concept, efforts to decide how it could be implemented and what it could do were already underway.

Since what broadband connectivity would do or how it could be accomplished was undecided, the technological frames of the relevant social groups were not entirely focussed on broadband connectivity, but shaped by the context in which the UK communications industry was changing. In relation to the events covered in this chapter, the technological frames of the various relevant social groups can be understood as follows -

- The regulators' (Ofcom and CA) technological frame was about accelerating investment in new technologies and encouraging infrastructure investment via a competitive market mechanism.
- BT's choices with regard to optical fibre and ISDN deployment indicate that it was attempting to grow additional revenue streams by expanding into broadcast television and video services. BT's technological frame for high-bandwidth connectivity was thus about delivering broadcast television services.
- The cable operators' technological frame was focused on building network capacity in line with their licence obligations, bundling television and telephony services, and delivering unique content in addition to the terrestrial broadcast television content.
- Mercury's immediate focus was on building core network capacity based on optical fibre technology and relying on interconnection with BT's access network in order to achieve coverage.
- No longer restricted to one operator, the end-users' focus was on pricing of

services, particularly telephony services and the prospect of dual-play of television and telephony services in areas with cable franchises operating. At this stage of the narrative, the end-users' interest in non-voice services such as interactive Videotex or video-on-demand was limited partly because these services were not available on widespread basis.

In addition to the differing technological frames, the relevant social groups were also attempting to determine what the high-bandwidth connectivity could do or the kind of services that could be used to monetise such connectivity. In consequence, interpretative flexibility (i.e. different interpretations about the function and meaning of technology) was apparent in the varied notions of high-bandwidth connectivity. The pursuit of non-voice services such as interactive Videotex, video conferencing, and towards the late 1980s, video-on-demand services suggests that different interpretations of what the broadband connectivity would be used for were in circulation. The telcos and cable operators, although in search of non-voice services that would create new revenue streams, did not have a clear idea about the kind of high-bandwidth service that would find acceptance from residential end-users. Although the most commonly expected use of the high-bandwidth capacity was in the form of delivering video over the network either via video-conferencing or video-on-demand, the viability of such uses was far from confirmed. Videotex systems such as Prestel were intended to generate additional revenue streams by combining information systems with video capabilities. Such efforts show significant variation in the meaning and context for high-bandwidth connectivity within the operators themselves.

In addition to the services, the way in which broadband connectivity could be implemented was also not entirely decided. Although the cable industry was focussed on coaxial cable/ HFC-based solutions, for BT or Mercury, the possible choices were ISDN or optical fibre. However as the uncertainty over the nature of high-bandwidth services shows, the selection of coaxial cable, ISDN, or optical fibre was only a part of what would determine broadband connectivity. The fact that deciding the function and meaning of broadband was not restricted to an artefact (specifically a physical artefact) highlights the extent to which the context for broadband evolution differs from Bijker and Pinch's case studies. This context was systemic given that an entire industry was undergoing a complex transformation in light of BT's denationalisation. The next section discusses this transformation in the UK communications industry and its implications for broadband technologies in detail.

5.6.2 Introduction of competition and regulatory bodies

In contrast to the social constructivist ideas which emphasise the meaning of technology being constructed via negotiation between various relevant social groups, Hughes' (1987) 'technology as a system' approach offers a different way to understand the interaction between various stakeholders. In the 1980s, the three components of a large technological system as specified in Hughes' 'technology as a system' approach i.e. physical artefacts, legislative artefacts, and organisations become more distinct with the denationalisation of BT and creation of regulatory bodies such as Oftel and CA. Based on Hughes' definition and in context of the events discussed in this chapter, these components can be identified as follows -

- The 'physical artefacts' in the telecommunications system are accounted by the networks, the various transmission technologies, exchanges, and equipment in the exchanges and end-user premises.
- The 'legislative artefacts' i.e. the rules of governance for the system become distinctive with the formation of the regulatory bodies. With specific reference to the narrative in this chapter, the government policy of denationalisation and regulatory policies of infrastructure competition and price control can be identified as the legislative artefacts.
- The 'organisations' i.e. the companies that maintain and market the system according to Hughes, can also be distinguished better with the introduction of competition and creation of the regulatory bodies. Thus BT, Mercury, cable operators, Oftel, and CA can be identified as the organisations in the telecommunications system.

As the events in the 1980s show, each of these components evolved significantly, adding further complexity to the large technological system for telecommunications that the analysis in chapter 4 covered. This section covers the way in which these components contributed to the changes to the large technological system for telecommunications and the influence these components had in relation to the development and deployment of broadband technologies.

An important change to the system was the increased role of 'legislative artefacts' in the form of the regulatory measures implemented by Oftel and CA. Their pursuit of infrastructure competition as a means of encouraging new technologies in the transmission network played a key part in the way choices were made in relation to

coaxial cable and optical fibre by the cable operators and BT respectively. Considered as a component in the telecommunications system, the role of the regulatory policies in influencing choices with regard to technologies aligns with Hughes' definition of the legislative artefacts. The different priorities on part of the legislative artefacts i.e. the policies of the British government and the regulatory measures pursued by Oftel and CA compared to those of the organisations such as BT, Mercury and cable operators also provide useful pointers to the way a large technological system such as telecommunications is subject to socio-economic, political factors.

Consider for example, the way in which the emphasis on restricting BT in order to foster competition shaped BT's position in relation to investment in optical fibre, a physical artefact in Hughes' 'technology as a system' approach. Policy decisions related to infrastructure competition (i.e. a legislative artefact) were important in the deployment of optical fibre (i.e. a physical artefact) with BT seeking to reduce its costs and thus deploying optical fibre mostly in the core network. Thus the legislative artefact that restricted BT from carrying broadcasting services over its main network provided BT a reason to limit its optical fibre investment in the access network. The other important regulatory policy i.e. price control (another legislative artefact) would also play a similar role in the way the organisations including BT and cable operators made decisions with regard to infrastructure investment and upgrades throughout the 1990s as the events in chapter 6 will show. The long-term influence of these regulatory policies as the legislative artefacts will be discussed in chapter 7 when the events in the 2000s are considered.

Although the development of ISDN (i.e. a physical artefact) had started in the 1970s, at the early stages of development, it was intended to deploy an ubiquitous digital network on the part of all the participating telcos, almost all of whom were monopolies. Beginning with BT's denationalisation (and subsequent denationalisations in Western Europe by the 1990s), the purpose of building such a network had begun to be increasingly tied with the commercial returns it would deliver. This change of approach is reflected in the way the newly denationalised BT's deployment of ISDN was mostly restricted to business end-users. In contrast, Deutsche Telekom, functioning as a public sector monopoly and unencumbered by similar commercial considerations, chose to deploy ISDN as a matter of public service. The different outcomes underline the extent to which choices being made with regard to technological change were influenced by non-technological factors. The changed priorities of BT as an organisation were an important factor. The influence of non-technological factors is visible in BT's decisions regarding the roll out of optical fibre or the way the cable operators had to renegotiate their licence obligations. The prospect of not making any financial returns on infrastructure investments influenced the choices being made by BT and the cable operators in relation to introducing technological change significantly. In each of these situations, the technology and its outcome was dependent on socio-economic reasons and regulatory decisions rather than only the technological attributes. The different outcomes of ISDN in Germany and the UK also echo Hughes' concept of technological style in which he argues that region-specific influences shape deployment and adoption of technologies. Not only was the deployment of ISDN contingent upon the different strategies adopted by BT and Deutsche Telekom in relation to residential end-users, it also depended on the different priorities of a

privatised BT when compared to those of Deutsche Telekom which was a public-sector monopoly.

The outcome of ISDN and the difficulties in its adoption also furthers the analysis presented in chapter 4 in relation to Hughes' concept of reverse salients. As explained in chapter 4, when faced with unsolvable problems i.e. reverse salients, the development and deployment of technologies halts. In relation to ISDN, the reverse salient was that it could only deliver 128 kbit/s bandwidth. Although intended to be capable of delivering voice, data, and video in an integrated manner, by the time ISDN was ready, its bandwidth capability of 128 kbit/s was deemed insufficient for the industry's requirements, particularly for delivering video-based services. This, in turn, led to the pursuit of Broadband ISDN which chapter 6 will cover in detail.

Most importantly however, the commercial failure of ISDN was not entirely due to the reverse salient imposed by its limited bandwidth capabilities. The telcos lacked commercially viable services other than digital voice that justified the investment in ISDN. In the case of a privatised company like BT, the lack of revenue-generating services meant that ISDN remained a niche solution targeted at businesses. As Kevin Foster points out in section 5.4.3, as a result of the pace at which other technological changes were taking place, ISDN development missed the window of opportunity in the transition from analogue to digital transmission. The commercial failure of ISDN is thus a reflection of the constraints of the system and the prevailing circumstances in the communications industry not just a question of its limited bandwidth capabilities. ISDN struggled to get adopted despite the scale of

effort and investment that went into it. Such an outcome highlights the extent to which services were important in relation to the commercial prospects of such broadband technologies. The importance of services in relation to the technological choices being made is further underlined in chapters 6 and 7 which discuss the emergence of DSL and the extent to which DSL addressed the need to deliver a specific set of services.

An additional and important aspect of the narrative in this chapter is the influence of regulatory policies on the choices being made by BT and other operators. The intentions behind denationalisation whether relying on competition to encourage investment, increasing efficiency of the incumbent, lowering prices for the end-users, or reducing the power of the trade unions, highlight the way in which economic and political choices were important in shaping the UK communications industry and the choices made by the various stakeholders. As Gabrielle Hecht (2001) argues in "Technologies of Power: Essays in Honor of Thomas Parke Hughes and Agatha Chipley Hughes", decisions about technology are often influenced by socio-economic and political considerations. The next section considers Hecht's argument and the extent to which the regulatory policies influenced the outcome of not only ISDN but also the way in which BT and cable operators approached other technological deployments.

5.6.3 The influence of regulatory policies on technology deployment

Although intended to accelerate the introduction of new technologies, the main goal of the policy of infrastructure competition was to reduce BT's market

dominance and also to increase the efficiency of its operations. Similar thinking was also at work in relation to the decision to allocate cable franchises as regional monopolies in order to foster more competition to BT. The decision with regard to the Prescribed Diffusion Services order 1986, allowing cable operators to bundle telephony and television, and the extent of technical requirements it imposed were intended to ensure that an alternative to BT's copper-line infrastructure would develop. The aim was to reduce the market dependence on BT for telephony and the last mile access. In each of these cases, although technological attributes were a key element of the choices the regulators were making, the driving force were political considerations related to reducing BT's market power. This situation offers parallels to Hecht's (2001) study of post-war France and how the design decisions being made in relation to nuclear power plants by Électricité de France (EDF) and Commissariat à l'Énergie Atomique (CEA) were in fact dictated by ideological considerations of the labour unions and political parties. As Hecht (2001) highlights, the outcome showed the extent to which technologies were dependent on non-technological factors.

If the decisions made by BT in relation to ISDN, or the deployment of excess capacity by cable operators are considered, their choices were influenced by financial returns and legal obligations respectively. Oftel's policy of accelerating innovation was not tied to a specific technology but the overall goal of increasing the competitive pressure on BT. The regulatory policy would similarly influence a number of choices made in relation to broadband technologies such as optical fibre and DSL throughout the 1990s and the 2000s as the narrative in chapter 6 and 7 will show.

The role of regulatory policy and the decisions being made by the operators in response to it also strengthens the argument about the extent to which the deployment of broadband technologies has been historically contingent. Although in the 1980s the services and transmission technologies that would bear on the broadband landscape two decades later were unknown or unclear, the denationalisation of BT and introduction of competition had irreversibly introduced the considerations of recouping investment costs and delivering returns to the communications market. Such considerations contributed to a sequence of events in the 1990s related to BT's changed priorities in relation to its UK infrastructure, the problems faced by cable operators that slowed down the cable network deployment, and unforeseen developments related to the emergence of the Internet into mainstream consciousness. As the narrative and discussion in chapter 6 will cover, the outcome at the end of 1990s further highlights the role of historical causality and the path dependent nature of the outcome in the choices about broadband technologies.

6 Golden shares, global ambitions, and the emergence of the Internet/Web

6.1 Introduction

As a result of the duopoly review in 1991, the duopoly of BT and Mercury was ended and the UK markets were further liberalised. After being fully privatised in 1994, BT citing the constraints on investments in television/broadcast services, increasingly chose to focus on investments outside the UK. Meanwhile, the cable industry faced stiff competition with the emergence of British Sky Broadcasting (BSkyB) and its satellite broadcasting platform. The difficulty of competing with BT on the telephony front and Sky on the television front drove the cable industry to economise through consolidation. Despite significant consolidation however, even by the end of the 1990s, the cable industry was still beset by problems of fragmentation and incompatibility of standards, and struggling to maintain viability.

Video-on-demand services failed to materialise by late 1990s, but the unforeseen demand for Internet/Web soon began to outstrip the capabilities of the dial-up/narrowband connections. At the same time, with the growth in adoption of personal computers, proliferation of local area networks (LANs), and the Internet, Ethernet and Internet protocol had proven to be cost-effective and efficient means of delivering large amounts of traffic. Compared to the deployment costs of ATM, IP-based networks provided a number of short-term advantages. Given the economies of scale offered by IP technologies, the possibility of B-ISDN/ATM being

deployed on a wide scale faded despite its capabilities to deliver high-bandwidth connectivity. As a result of the regulatory pressure and increased government emphasis on high-bandwidth Internet/Web access, DSL emerged as the most suitable interim technology for BT which was facing a financial crisis by the year 1999-2000.

Although the 1990s are notable for the growth in mobile communications, particularly the 2G/GSM networks, mobile systems are outside the scope of the thesis and, fixed-line connectivity is the focus of discussion in this chapter. The theoretical analyses in this chapter draw from social constructivism, path dependence, Hughes' 'technology as a system' approach, and the concept of 'imperfect competition'.

6.2 The duopoly review and a more market-driven regulatory approach

The duopoly review of Mercury and BT's operations took place in 1991. At the conclusion of the duopoly review, the UK market was completely opened up to competition¹ (see Pye et al, 1991 for an analysis of the consultation process for the duopoly). Thereafter, Oftel (2003d, p. 4) focussed "*on interconnection to BT's ubiquitous network, policing of anti-competitive behaviour and removal of barriers to entry*". The cable operators no longer needed permission from the Director-General

¹ This was decided after the Oftel consultation for the BT-Mercury duopoly in 1991-92 and a discussion on opening up the market for further investment - "Competition and Choice: Telecommunications Policy for the 1990s"

of Telecommunications to deliver telephony services. However, despite the opening up of the competition and the absence of constraints on non-BT operators, some of the restrictions on BT remained. Apart from the price caps, BT continued to be restricted from delivering television/broadcasting services on its main network. Although this restriction was modified to allow the delivery of on-demand services in 1993 (BT, 1994a), for a significant part of the 1990s (until 1999), BT was prohibited from delivering television content (BT, 2000b).

Such policy measures influenced not only the investment decisions made by BT but also the investments made in the cable infrastructure. Two of the most influential policies that affected BT and the cable industry were infrastructure competition and price regulation via the RPI-X formula. Both these policies influenced the investments in the cable industry and the choices made by BT regarding technologies such as coaxial cable and optical fibre. Before discussing the decisions by BT and the cable industry regarding transmission technologies, the influence of the regulatory policies is discussed in the next sections.

6.2.1 Infrastructure competition

The Oftel review 1984 – 2003 (2003d, p. 3) specifies that *"Oftel's early focus was on infrastructure competition on the assumption that a choice of infrastructures would generate competition in service provision without regulation."* Sir Bryan Carsberg, the first Director-General of Telecommunications, offers his views on how the policy of infrastructure competition eventually turned out:

I did believe in infrastructure competition and I wanted to see it develop. At the same time, I didn't expect it to go very far. I didn't expect there to be lots of competitors because the economics were against it. If you look at the number of companies that built their own network in city areas, I am surprised of the extent [to which] it [the infrastructure investment] went to actually.

Source: Bryan Carsberg, Unpublished interview conducted by the author.

London, 27 March 2012

As Sir Bryan Carsberg states, the economics of the business were against infrastructure competition being sustained in the long-term. Combined with the policy of price control, the influence of infrastructure competition was far-ranging in terms of not only the infrastructure built but also the way in which competition to BT developed. As discussed in chapter 5, BT's main competition within telephony i.e. Mercury mostly focussed on building its own core network and relied on BT for last mile access through interconnect agreements. In line with the Prescribed Diffusion Services order 1986, the cable operators were also required to build network capacity against specific timelines (see the discussion in chapter 5). However, as Malcolm Taylor, then working with the cable industry describes, it was not sustainable to keep building infrastructure without commercial returns. He is referring to the money spent on additional cable franchise allocations done in the early 1990s by the Independent Television Commission (ITC) in the following quote (see ITC, 1997):

The operators spent quite a lot of money to capture exclusive rights for that [franchise] area back in early 1990s but had those rights only for six or seven years. They bid a lot of money but they also had licence obligations to build to 80% of the homes in the area within a seven year period. So everybody was pouring money into construction and not earning a great deal of money in return. It all comes back to the sustainability question. At what stage do you stop spending money and start to try to earn it?

Source: Malcolm Taylor, Unpublished interview conducted by the author.

London, 27 March 2012

The lack of returns, as mentioned by Malcolm Taylor above, would play a key part in the way cable modem-based connectivity evolved as a broadband technology which is explored in section 6.3.3. However, perhaps the most notable example of a company that struggled in the light of the regulatory policies of infrastructure competition and price control combined with technological problems is Ionica, a wireless services operator. Ionica was founded in 1992 with the intent to provide a nation-wide alternative to BT in the residential and small business market. Ionica's business proposition was to rely on wireless access to achieve high market penetration at a low cost (£30 per home for wireless vs. £200 per home for cable). Launched in 1996 in the East Anglia region, Ionica managed to achieve only 62,000 subscribers by 1998 and entered administration by October 1998. The result was that all of its subscribers were transferred to BT by early 1999 (see Haine, 2010 for more details about Ionica's technical approach and its outcome). Malcolm Taylor, working in the cable industry throughout this time, sums up Ionica's failure and

analyses it in the context of the policy of infrastructure competition. In the excerpt below, he is also talking about the limitations of what Ionica tried to do via wireless technologies:

It [Ionica] was part of the government and Oftel's desire to have infrastructure competition. The director general of Oftel at that period was a guy called Don Cruickshank who said every home should have a choice of 3 infrastructures. Ionica was really welcomed and supported. [The problem with Ionica was] A - The technology was a little bit ahead of its time. They were trying to introduce a technology that wasn't really working. And [B] it didn't have scale.

Source: Malcolm Taylor, Unpublished interview conducted by the author.
London, 27 March 2012

The lack of scale that Malcolm Taylor mentions above also played a key part in the way the cable industry struggled (as section 6.3 explores). An additional problem for Ionica, cable operators, and other non-BT operators however was the pricing of services. Prof. William Webb, former head of Research & Development (R&D) at the Office of Communications (Ofcom, the successor to Oftel), makes the following comment about Ionica, pricing of its services, and its business model:

Ionica's business case was based on then existing BT pricing. This meant that as soon as BT lowered prices, Ionica's business case became unsustainable. Similar initiatives in terms of delivering wireless to the home have generally not taken off.

Source: William Webb, Unpublished interview conducted by the author.
Cambridge, 19 December 2011

The example of Ionica shows some of the problems of trying to create a market based on competing infrastructures. The high cost of installing infrastructure can usually only be justified by generating revenue at a sufficiently high rate. In the absence of revenue that can offset the cost of investment, the operator's business becomes highly vulnerable. As a result, a market based on new, competing infrastructures with high-level of redundancy is difficult to sustain in the long-term as witnessed in the problems faced by Ionica and the cable operators.

6.2.2 Price regulation via RPI-X

Prof. William Webb's comment in the last section about the influence of BT's pricing on BT's competitors relates to the other key regulatory policy i.e. price control which also had significant influence on infrastructure investment. The aim of price regulation was to control the prices that BT would charge its competitors as part of interconnect agreements and also its end-users. The purpose was to not only avoid BT's misuse of its monopoly position (either excessive profits by overcharging its end-users or driving its competitors out of market by predatory pricing), but also

to ensure that the end-users had the services at the best possible price (Cave, 2003; Stern, 2003). Despite the best of regulatory intentions though, the policy of price regulation had an impact on the way competition developed. Although Prof. William Webb refers to Ofcom in the following quote, the argument is equally applicable to the policies of Ofcom's predecessors whether Oftel, CA, RA, or ITC:

Ofcom tried to protect companies against BT's lowering of prices that could put such companies [i.e. Mercury or Ionica] out of business. [This has meant that] Although the prices have lowered significantly, in general the competition is mostly centred on ISP level [i.e. focused on service provision rather than network operations]. This means to a certain extent near-monopoly prevails in the last mile provision.

Source: William Webb, Unpublished interview conducted by the author.
Cambridge, 19 December 2011

Prof. William Webb's comment about pricing brings into focus the extent to which infrastructure investments were influenced by the RPI-X price regulation. Malcolm Taylor, then working with the cable industry, discusses how the cable industry approached the issue of pricing their telephony services:

[...] In essence, cable's original business models were - we'll be cheaper than BT for telecoms services at least by 25% and in parallel with that we'll launch all the multi-channel television services containing paid services as well as the free services. ...

Source: Malcolm Taylor, Unpublished interview conducted by the author.
London, 27 March 2012

Effectively, every time the value of X was increased by Oftel (it rose from an initial 3.5 to 7) and BT's prices were cut, the prices were also cut by the cable operators because they couldn't risk being more expensive than BT. Thus, although the RPI-X price regulation did not directly apply to the cable industry or non-BT operators², it had an unforeseen effect on their pricing and revenue margins. As a result, combined with a lack of unique selling proposition (for content), competition from British Sky Broadcasting (BSkyB), and limited revenue from telephony services, the cable industry struggled for financial viability. As a result, not only did the investment in the cable infrastructure slow down but also in order to build economies of scale, a significant amount of consolidation took place in the cable industry. These problems in the cable industry and their impact on the investments in coaxial cable infrastructure are discussed in the next section.

² An exception to this was Mercury Communications' international telephony business. By 1994-95, Mercury was considered to have enough share of the international telephony traffic to impact the end-user prices and was thus price regulated (see Oftel, 1995).

6.3 *Fragmentation and consolidation in the cable industry*

As covered in chapter 5, the cable industry was significantly fragmented by the end of 1980s and, despite the investment by US-based investors, had struggled for financial viability (see section 5.3.2, quote by Prof. Martin Cave). This extent of fragmentation and the resulting lack of economies of scale played an important part in the way coaxial cable infrastructure shaped up throughout the 1990s. Apart from the licence obligations, the cable operators had failed to build on the original promise of delivering regional content. An additional difficulty was posed by the emergence of satellite broadcasting in the form of BSkyB Corporation.

6.3.1 Margin squeeze on telephony and television services

BSkyB itself was created from the merger of Sky and British Satellite Broadcasting (BSB) because the economics of a duopoly in satellite broadcasting were deemed unsustainable by their owners³ (Chippindale et al, 1991). The result was the creation of BSkyB in 1991. The economies of scale possible with BSkyB quickly dwarfed the capabilities of the cable industry (which was still fragmented) and further exacerbated the cable operators' financial difficulties. David Brown, the former Head of Schema, a noted telecoms consultancy, talks about the effect the commercial strength of BSkyB had on the cable industry in the following quote:

³ Sky launched 13 months ahead of BSB and despite BSB's programming output being considered superior, Sky maintained a lead in terms of end-user subscriptions. With both operators making significant losses, a decision to merge them was made in 1991. This led to the creation of British Sky Broadcasting (BSkyB). See Chippindale et. al. (1991) for more details.

The problem was with the content and the cable industry not being able to get content. The content was monopolised by Sky. Sky locked up key content with some foresight i.e. newly released films and sports. This meant Sky appealed very strongly to specific socio-economic groups. Effectively cable companies were starved of content. In an attempt to replicate Sky's efforts, cable industry paid a lot of money for first division football and failed because they did not have premier league [the content that end-users wanted]. Cable got bits and pieces of content and was a mess on the content front. This meant although telephony was a useful addition, due to the regional franchise allocation, cable companies had to rely on BT outside their area of operation. Cable companies also couldn't offer very good data services at that time and struggled for market survival.

Source: David Brown, Unpublished interview conducted by the author.
Hemel Hempstead, 13 December 2011

Combined with the problems of delivering regional content outlined in chapter 5, the cable operators lacked a unique selling proposition. Somewhat ironically, although the broadcast capabilities of cable operators had been conceived as their major activity (to the extent that BT regarded them as a threat. See chapter 5, section 5.3), it was the telephony services which provided better margins to the cable operators during this time. Richard Feasey, who worked with the cable industry during the 1990s, outlines the extent to which this helped the cable operators in the following excerpt:

[...] funnily enough, the economics on the telephony side were quite good. We were talking of getting 7-8% market from BT and were amazed when 20% people signed up. I think we underestimated the pent-up frustration [end-users felt] with BT as the incumbent operator. [...]

Source: Richard Feasey, Unpublished interview conducted by the author.

Milton Keynes, 26 April 2012

Despite the relatively better economics of telephony services in comparison with broadcasting services, the cable operators still needed to rely on BT (or Mercury in some cases) for wholesale access outside their franchise areas. The fragmentation continued to pose problems for the cable industry in the light of the competition from BSkyB and BT. Richard Feasey comments on the role of the original model of franchise allocation, the competition from BT and BSkyB, and the problems it posed to the industry in the following quote. His argument echoes Sir Bryan Carsberg's view in chapter 5 (see section 5.3.2) that the franchise areas were not large enough to build the required scale of operations for the UK cable operators:

[...] The industry structure was completely wrong for ultimately the way the [cable] industry developed. It [cable] is really a scale business where you [the cable operator] need to have scale, national coverage in order to be able to advertise nationally. You [the cable operator] need national coverage to have a decent bargaining position with content providers like Sky. Telecommunications is very much a scales business as well. In my view, it [the original model of franchise allocation] probably meant that cable had a

competitive disadvantage both to BT and to Sky on the content side for the best part of a decade because of its industry structure.

Source: Richard Feasey, Unpublished interview conducted by the author.

Milton Keynes, 26 April 2012

This lack of scale meant that having lost out on the bidding war for film and sports content, in order to solve the content issue, the cable operators were buying content from BSkyB on wholesale basis. Effectively, the cable operators' telephony and television businesses were far from profitable despite the continued investment⁴. As a result of the lack of revenue stemming from lack of economies of scale and margin squeeze on the television and telephony business, the cable industry began to rapidly consolidate⁵. In the following excerpt, Malcolm Taylor, working within the cable industry during this period of financial problems, puts the combination of factors including the role of regulation and poor economics of operation that plagued the cable industry and the consolidation activity in perspective:

I think they [the regulators] have focussed on residential consumer protection and their form of residential consumer protection has been in controlling

⁴ The NTL Annual report 1997 (year ending 31 Dec 1996) states that on the revenue of US\$84,870,000, its net income loss was US\$78,502,000. In the NTL Annual report 2001 (year ending 31 Dec 2000), the revenue was US\$453.1M and the net income loss was US\$416.5M. The Telewest Annual report 1997 (year ending 31 Dec 1996), its revenue was £290,266,000 and net income loss was £262,208,000. See NTL (1997; 2001) and Telewest (1997) for more details.

⁵ Notable examples of acquisitions made by NTL between 1996 and 2000 were CableTel, Cablelink, ComTel, Comcast UK Cable Partners, EGT, and Diamond Cable. For Telewest, the notable acquisitions were Bell Cablemedia and SBC CableComms in 1996. See NTL (1997; 2001) and Telewest (1997) for more details.

certain content and its availability. More specifically, at trying to keep prices at relatively low levels. That has been detrimental to the investment decisions of the major infrastructure players. e.g. the cable industry spent £12B digging the streets of the UK, putting a network in place and effectively had to go through financial restructuring and problems of consolidation. Even now [early 2012], it [cable] has become a viable business but it has taken 15-18 years to get there.

Source: Malcolm Taylor, Unpublished interview conducted by the author.
London, 27 March 2012

Effectively, although the cable operators had the potential capability to deliver integrated telephony and television, their margins were squeezed on both set of services throughout the 1990s. As mentioned in section 6.2.2, the RPI-X price cuts, although intended for BT, also resulted in price cuts for the telephony operations of the cable operators. The resultant lack of revenue had a detrimental effect on the investments in the cable infrastructure which meant that even by early 2000s, despite more than 15 years in operation, the cable infrastructure reached only 50% of the UK premises⁶ (OfTel, 2002a). The margin squeeze on telephony and television business and the continued lack of a unique selling proposition was magnified by the commercial and technical issues as a result of which the expectations around video-on-demand services never came to fruition as expected.

⁶ This limited footprint is relevant for a number of reasons. It essentially limited the number of end-users cable industry could reach and the economies of scale it could achieve. This meant that BT's economies of scale were not only unachievable for the cable industry but also that the cost per end-user was significantly lower for BT. See footnote 9.

6.3.2 The lack of a viable business model for video-on-demand

The example of the UK cable industry shows that, as with any new infrastructure investment, there was a need for high revenue-earning service to justify the investment as soon as possible. Video-on-demand services were thought to be one such service, but the enthusiasm for video-on-demand services was not just confined to the UK cable industry. Although video-on-demand services represented a potential service for the cable operators to distinguish their offering, the economics of video-on-demand were not favourable in the 1990s, a fact which played a key part in its lack of adoption. Graham Sargood worked with the UK cable franchises owned by AT&T and then Telewest in the 1990s and recalls some of these issues in the excerpt below:

It [video-on-demand] was about being able to watch a film whenever you [the end-user] wanted. That was an equivalent on the network of the video rental outlets. The servers and the compression equipment everything was very expensive. [...] Actually what happened was that the business models for video-on-demand were very flaky. It was very difficult to earn money out of video-on-demand [for service providers or operators] given the cost of set top boxes, the cost of content, and the cost of the server infrastructure.

Source: Graham Sargood, Unpublished interview conducted by the author.
London, 09 and 13 February 2012

The problems with business models combined with lack of sizeable revenue-earnings eventually meant that as the end-user demand did not materialise, any

attempts to pursue video-on-demand also ended up being sidelined (see Anonymous, 2000 for a discussion in *The Economist* on the promise and problems of delivering video-on-demand services in the UK). Mike Pemberton, working at the Cambridge Cable franchise for NTL in mid-to-late 1990s, describes the fate of video-on-demand at NTL. The reference to the Internet bubble indicates that he is discussing the events in the late 1990s (covered in section 6.4.2):

As I was getting towards the end of my time in NTL, there was a big project to look at doing video-on-demand. As the Internet bubble burst, the funding for that was scrapped.

Source: Mike Pemberton, Unpublished interview conducted by the author.
London, 10 February 2012

Aside from video-on-demand services though, an important revenue stream had emerged in the form of the Internet/Web by mid-1990s. However, the problems of fragmentation and lack of scale proved particularly problematic when the end-user subscriptions for the Internet had begun to grow in the form of dial-up connections and the demand for better bandwidths had also grown significantly (explored in greater detail in section 6.6.2). The cable operators, by then significantly consolidated (it was mostly Comcast, NTL, and Telewest by late 1990s), attempted to address the demand via cable modems, a technology based on the Data Over Cable Service Interface Specification (DOCSIS) standard which delivered

significantly higher bandwidth than the dial-up modems⁷ (Valdar, 2006; Yassini, 2004). Mike Pemberton offers a view on the potential of the technology and the possible reasons that held it back. He is referring to the financial difficulties at NTL in the following quote:

The underlying technology of cable modems is very good as you can see from the sort of speeds they are offering now. Even the original DOCSIS1.0 modem was a 38 Mbit/s capable service from the late 1990s. This is when 500 kbit/s and 1 Mbit/s were considered premium service. [The problem was] NTL was getting cash strapped [by late 1990s] and went through chapter 11 in the early 2000s. [If NTL had the financial resources] They probably would have been able to do what they [i.e. Virgin Media, the lone consolidated cable company] are doing now - which is to deploy more technology [...]

Source: Mike Pemberton, Unpublished interview conducted by the author.

London, 10 February 2012

Despite the promise of the technology however, as the next section covers, the legacy issues of fragmentation would prove critical to what the cable industry could achieve.

⁷ The dial-up modem works by providing connectivity to the Internet via a telephone call. As a result, when the dial-up modem is in use, the line cannot be used to make or receive telephone calls. The best possible bandwidth via a dial-up modem is 64 kbit/s. See Valdar (2006). In contrast, the cable modem not only used spare capacity on the cable network but could also deliver bandwidth of 1.544 Mbit/s even before the Data Over Cable Service Interface Specification (DOCSIS) standard emerged (Yassini, 2004).

6.3.3 The commercial opportunities presented by the Internet

Cable modem-based Internet connectivity offered an important business opportunity and a unique selling proposition to the UK cable industry⁸. Unlike telephony or television, neither BT nor BSkyB had a significant toehold in the provision of broadband connectivity at this time i.e. mid-to-late 1990s. Despite the opportunity though, a number of issues needed to be sorted out. Mike Pemberton, working at NTL in the mid-1990s, sets the nature of problems faced by the cable operators in perspective:

If we go back to the mid-1990s when there were 3 or maybe 4 operators with several franchises each, around the country. There was Comcast, Telewest, NTL and maybe another one or two here and there. A lot of the networks used different equipment depending on the parent company at the time analogue cable network was built. Both the voice and television networks would have different equipment, different head-ends, and different designs. From a technology perspective, it was very fragmented. I think from a customer's perspective, just as much so. They [the cable operators] didn't have the economies of scale in terms of having very large call centres. Some cable companies had good customer service, some not very good. Certain franchises would be able to support things like cable modems [only] in the year 2000.

⁸ Yassini (2004) discusses how the emergence of the Internet gave the cable operators the opportunity to monetise the additional bandwidth that the cable modems could deliver. An initial problem was the lack of standardisation in cable modem equipment. This problem was resolved with the development of the DOCSIS standard in 1997 (see CableLabs, 1996; 1997a; 1997b; 1997c; 1997d; 1997e; 1997f; 1998 for complete details of the DOCSIS 1.0 standard).

Some franchises did not have an upstream path and you [the cable operator] would not be able to [support a cable modem].

Source: Mike Pemberton, Unpublished interview conducted by the author.

London, 10 February 2012

In the absence of an upstream path some franchise areas lacked the capability to transmit signals bi-directionally. Bi-directional transmission was an important requirement for the Internet/Web, which unlike the television was not a broadcast (i.e. unidirectional) medium and hence required the ability to transmit data in both directions. The lack of upstream path and a number of the issues mentioned above meant that even by 2001, cable modem based connectivity was not available to all the UK premises that were covered by the cable network footprint⁹. Similarly DSL-based broadband connectivity, by late 1990s a contender to deliver broadband connectivity over copper lines, despite the near-universal reach of the PSTN in the UK was also not available to all the premises connected by BT's telephone line¹⁰. An important reason for this was that DSL had remained an unheralded choice for delivering broadband until almost 1997-98¹¹. As the next section will explore, BT's

⁹ Oftel's Broadband and Internet Brief November 2001 states that of the premises covered by the cable networks, Telewest was available to 4.9M homes of which 95% were broadband capable. NTL was available to 8.4M homes of which 50% were broadband capable. This shows that out of the possible 13.3M homes that cable could serve, only around 8.8M homes could receive cable modem based broadband. See Oftel (2001a; 2002a).

¹⁰ As of 2001, DSL-based broadband was only available to 60% of the UK households i.e. 15M homes. See Oftel (2001a; 2002a).

¹¹ Although BT had been conducting trials for DSL from 1991-92 onwards, these trials were for video-on-demand services. The year 1997-98 is important, as the next section will show, because this was

decisions in relation to broadband technologies (particularly DSL) were significantly influenced by its complete transition to the private sector, changed business priorities, and its growing ambitions.

6.4 BT's global ambitions and its impact on the UK infrastructure

Post-duopoly review, an important change to BT¹² was that the government stake in BT operations (i.e. the remaining golden shares) was gradually reduced. By 1994, BT was a completely private company. This was followed by BT's listing on the stock market. BT's annual reports during this time indicate a shift in not only the approach to BT's UK operations but also BT's emphasis on profits and delivering value to its shareholders. In the annual report for 1991-92, while discussing the opening of a hub in Paris for BT's business across Europe, BT states that the centre "[...] will play a vital part in our drive to become the number one telecommunications operator in Europe." (BT, 1992, p. 9). By 1998-99, this ambition had grown "to be the most successful worldwide communications group"¹³ (BT, 1999a, p. 2).

the first time BT conducted DSL trials with the intent to provide Internet access through it. See (BT, 1998c).

¹² British Telecom assumed the trading name 'BT' only as of 1991-92.

¹³ Although perhaps this is too subtle a distinction to be noticed, the change in BT's statement is noteworthy for two reasons. The first point of note is how BT's geographical ambitions had grown from operating in the Europe to being successful worldwide. The second important point is how BT's functional emphasis has moved away from being a telecommunications operator (i.e. focused on voice) to being a communications group (i.e. voice, data, and video). This change is also interesting given the growth in mobile telephony from 1992 to 1999, making it an important part of BT's ambitions as the section 6.4.1 shows.

This meant that BT's commercial decisions followed a two-pronged approach as stated in its annual report for the year 1991-92 (see BT, 1992 for more details) –

1. Protecting BT's share and revenues in the telephony services in the UK. As the section 6.4.1 covers, this revenue effectively powered BT's expansion abroad.
2. Invest in markets that had been opened up to competition. BT's approach in this regard mirrored that of other operators in the US and parts of Europe. A number of these operators had made investments in the UK and were competing with BT for end-users and revenue. BT's response was in part to counter those threats by expanding its footprint abroad.

Of particular relevance to the way DSL deployment took place in the UK is BT's expansion outside the UK, which the next section discusses.

6.4.1 BT's increased commercial focus and aggressive expansion strategy

BT's foreign investments are indicative of a wider trend throughout the 1990s when the US-based operators such as AT&T, Worldcom were attempting to aggressively extend their operations¹⁴. European stalwarts such as France Telecom and Deutsche Telekom were also expanding their operations (Curwen, 1999). With the UK market being liberalised as a result of the duopoly review, BT's position as the dominant operator in the UK was increasingly expected to be under pressure (BT's annual reports during this period of early to late 1990s continually mention the increasing

¹⁴ As a result of this trend for mega corporations in the communications industry, Curwen (1999, p. 239) suggests that the telecommunications industry "was undergoing a massive structural change as a result of take-overs, mergers, and the acquisition of stakes ...".

competitive threat¹⁵. See BT, 1992; 1996; 1998a). With the opportunity to deliver television content not available, BT continued to cite lack of returns on any investments such as optical fibre. BT's position is illustrated by the following quote from the annual report in 1992-93:

While only a very small proportion of the local network's capacity is currently provided by optical fiber cable, where there is sufficient demand and BT judges that it will be economic to do so, optical fiber will be deployed to connect customers' equipment to the local exchange. BT believes that, in general, installing optical fiber to residential customers is only likely to be economic if television and entertainment services can also be carried over it. BT considers that it is unlikely to install optical fiber to residential customers on a widespread basis over the next few years, under the current licensing arrangements regarding these services.

Source: BT (1993a, p. 8)

In addition to the regulatory constraints that BT believed limited its returns on any optical fibre, high-capacity networks; it also reviewed a number of its UK operations. This led BT to curtail investment in what it perceived to be non-core activities throughout the 1990s. Examples of some of these non-core activities were -

¹⁵ Oftel (1998) estimates indicate that over 200 licensed operators including 5 national carriers, 4 mobile operators and over 60 companies licensed to operate in international facilities existed in the UK market as of 1998.

- BT's investments in on-demand services such as the "Open" initiative¹⁶ and
- British Interactive Broadcasting (BIB) services¹⁷.
- Prestel, started with much fanfare in 1986 was officially abandoned by mid-1990s¹⁸.

Each of these actions is indicative of BT's focus being more tuned to commercial returns than to invest in a specific technology or service. When coupled with its ambition to be "*the most successful worldwide communications group*" (BT, 1999a, p. 2), the extent of BT's ambition can be gauged by the amount of money and the sheer scale of geographical investments it made. This ranged from Western Europe, North America to Africa to Asia. By the end of financial year 1998-99, BT had fixed-line services in eight mainland European countries: Belgium, France, Germany, Italy, the Netherlands, Spain, Sweden, and Switzerland (BT, 1999a). In addition, in the Asia-Pacific region, BT had a presence in Australia, China, Hong Kong, India, Indonesia, Japan, the Republic of Korea, Malaysia, New Zealand, the Philippines, Singapore,

¹⁶ Since BT was allowed to provide on-demand services with strict guidelines from the Director-General of Telecommunications from 1993-94 onwards, BT began various trials of such services. "Open" was intended to deliver on-demand content through an ordinary telephone line connected to a digital satellite set top box (BT, 1998c). In order to avoid regulatory complications as a result of such a service, BT (1998c) chose to divest itself of its existing "broadband" cable television interests.

¹⁷ British Interactive Broadcasting (BIB) was an independent company created by BT in partnership with BSKyB, Midland Bank, and Matsushita, to deliver digital interactive services to television viewers in the United Kingdom (BT, 1998c). The "Open" service delivering on-demand content was one of the services planned.

¹⁸ By 1986, BT reported that Prestel system had achieved its first full year of profit (BT, 1986). However, given the lack of end-user adoption, BT sold the Prestel system to a private firm "Financial Express" in 1994. See Mayntz and Schneider (1988) for an analysis of the socio-economic and technical reasons due to which the Prestel system failed.

South Africa, Taiwan, and Thailand, involved variously in fixed, mobile, and Internet markets (BT, 1999a).

Table 6.1 tracks the nature of investments made by BT throughout the 1990s and their outcome. It illustrates the sheer scale of BT's ambition and the financial outlay involved in achieving such an ambition.

Company	Country	Partners	Details
Telepoint	UK		- BT had 45 per cent stake in Telepoint and it ceased operations in October 1991 due to lack of customer demand (BT, 1992).
Cellnet	UK	Securicor (until 1999)	- Formed in 1985 as a 60:40 joint venture between BT and Securicor (BT, 1994a). - In 1999, BT acquired Securicor's 40% stake to take full control of Cellnet (BT, 2000a). - In 1999-2000, BT purchased a UK-wide 3G spectrum licence at the cost of £4.03B (BT, 2000b).
Concert	Worldwide	MCI (US), Telefonica (Spain), and AT&T	- Concert was intended to be a strategic alliance between BT and MCI (originally Microwave Communications, Inc.) to operate

Company	Country	Partners	Details
			<p>in North America, Europe, and Latin America.</p> <ul style="list-style-type: none"> - In 1997, MCI and BT decided to create a merged entity "Concert Plc" (BT, 1997a). - In 1998, WorldCom outbid BT for MCI's stake and BT bowed out with payment of US\$7B from WorldCom (more than £4B at the prevailing exchange rates) (BT, 1998b). - BT bought the MCI shares of existing Concert Communications company and had a net gain of £1,133M on sale of MCI shares (BT, 1999b). - Subsequently BT revived the venture with AT&T in 2000-2001. - The future of the venture was in doubt due to losses of £336M in 2001 financial year (BT, 2001b).
Mitel	Canada		<ul style="list-style-type: none"> - Mitel was a Canada-based telecommunication equipment manufacturer of which BT held

Company	Country	Partners	Details
			<p>51% share (BT, 1993a).</p> <p>- BT sold its shares at a net loss totalling £132M in 1992-93. (BT, 1993b).</p>
McCaw Cellular	USA		<p>- BT sold its shares of McCaw Cellular to AT&T (BT, 1993a).</p> <p>- During BT shareholding, McCaw largely made losses to the tune of £19M in fiscal 1994, £17M (including losses arising through the dilution of the Company's interest) in fiscal 1993 and £23M in fiscal 1992 (BT, 1994a).</p>
StarHub	Singapore	Nippon Telegraph and Telephone Corporation (NTT, Japan), Singapore Telecommunications, and Singapore Power	<p>- The consortium with NTT of Japan, Singapore Telecommunications, and Singapore Power, BT was awarded both fixed and mobile telecommunication licences by the Singapore government in April 1998 (BT, 1999a).</p>
Japan Telecom, J-Phone	Japan	AT&T (USA)	<p>- BT made a joint investment of £1.2B with AT&T (BT, 1999b).</p> <p>- On 2 May 2001, BT agreed to sell</p>

Company	Country	Partners	Details
			its interests in Japan Telecom and J-Phones to Vodafone at a value of £3.7B (BT, 2001b).
VIAG Interkom	Germany	VIAG Aktiongesellschaft (Germany), Telenor (Norway)	<ul style="list-style-type: none"> - Joint venture to challenge Deutsche Telekom in German market. - BT spent £482M on VIAG Interkom development in 1998-99 (BT, 1999b). - In January and February 2001, BT took sole control of Viag Interkom by acquiring the remaining 45% from E.ON (formerly VIAG AG) for £4.6B and bought Telenor's 10% interest for £1B (BT, 2001a). - Through Viag Interkom BT bid for one of the 3G licences in Germany, which was purchased for £5.13B (BT, 2001b).
Airtel, BT Telecomunicaciones	Spain	Banco Santandar	- On 2 May 2001, BT agreed to sell Airtel in Spain to Vodafone for £1.1B (BT, 2001b).

Company	Country	Partners	Details
Albacom	Italy	Energy group ENI (originally Ente Nazionale Idrocarburi), Media organisation Mediaset, and Banca Nazionale del Lavoro	- BT had a share of 23% in Albacom (BT, 1998c).
Telfort	Netherlands	Nederlandse Spoorwegen (the Dutch state railway)	<p>- In April 1996 BT acquired the Rijnhaave group, a Netherlands-based systems integration business and, in March 1997, completed the formation of a joint venture with the Dutch railways organisation to offer telecommunication services in Netherlands (BT, 1997b).</p> <p>- BT spent £103M on Telfort in 1998-99 (BT, 1999b).</p> <p>- In April 2000, BT decided to acquire the 50 per cent that it did not own in Telfort, at a cost of around £1.2B (BT, 2001b).</p>

Company	Country	Partners	Details
			- Through Telfort, BT won a 3G licence in July 2000 in Netherlands for £267M (BT, 2001b).
Cegetel	France	Vivendi (France)	- BT acquired a 26% stake in Cegetel in September 1996 for £1B (BT, 1997b).
Sunrise Communica tions	Switzerland	Tele Danmark	- On 30 November 2000, BT sold its 34% stake in Sunrise communications in Switzerland to Tele Danmark for the equivalent of £464M in cash, realising a profit of over £400M (BT, 2001b).
Bharti Cellular	India		- In March 1997, BT acquired a significant stake in Bharti Cellular, one of the largest mobile operators in India for ₹1.05B (BT, 1997b).
Yellow Book	USA		- BT bought Yellow Book USA, the largest independent yellow pages publisher in the USA for £415M in 1999-2000 (BT, 2000a).
ImpSat	Argentina		- In April 1999, BT acquired a 20

Company	Country	Partners	Details
			per cent stake in ImpSat, for £90M (BT, 1999a; 1999b).
Martin Dawes Telecommunications	UK		In March 1999, BT Cellnet bought an 80 per cent stake in Martin Dawes Telecommunications, a mobile service provider, for around £130M (BT, 1999a).
The Mobile Phone Store	UK		- In April 2000, BT Cellnet purchased the 60% of The Mobile Phone Store that it did not already own, for £45M (BT, 2000b).
LG (originally Leokki Geumseong) Telecom	Republic of Korea		- In the Republic of Korea, BT purchased a 23.5 per cent stake in LG Telecom (LGT) in October for £234M (BT, 1999a; 1999b).
Maxis Communications	Malaysia	Usaha Tegas	- BT bought its 33.3% stake in October 1998 for £279M (BT, 1999a; 1999b). - BT sold its 33.3% stake in May 2001 to partners Usaha Tegas for £350M in cash (BT, 2001a).
SmarTone	Hong Kong		- In May 1999, BT acquired a 20 per cent stake in SmarTone, a

Company	Country	Partners	Details
			leading provider of digital mobile communications services in Hong Kong, for around £240M (BT, 1999a; 1999b).
Rogers Cantel Mobile Communica tions and AT&T Canada	Canada	AT&T (Canada), Rogers Wireless (Canada)	- Jointly with AT&T, BT acquired approximately 33 per cent of Rogers Cantel Mobile Communications and AT&T Canada for £660M (BT, 2000a; 2000b).
Esat Digifone	Ireland	Esat Telecom	- BT first acquired a majority stake in Esat Digifone for approximately £1.5B (BT, 2000a; 2000b). - In April 2001, BT acquired, for £0.85B, the remaining part of Esat Digifone, a mobile operator in the Republic of Ireland, which it did not already own (BT, 2001a).

Table 6.1 – BT ventures and partnerships during 1991-92 to 2000-01 (**Source:** BT Annual reports – 1991-92 to 2000-01)

The result of this increasingly global commercial focus was that BT's financial outlay in the UK was significantly limited, the influence of which is discussed in the next section

6.4.2 Underinvestment in the UK infrastructure

A key outcome of BT's aggressive expansion strategy however was what has been termed systemic underinvestment in the UK infrastructure¹⁹. Malcolm Taylor, who worked in the cable industry during the 1990s, observes that:

BT, during the 1990s, when it had restrictions on what it could do, it invested a lot of money overseas and not enough money in upgrading its local network. Which I think is a fairly critical point. There is a lot of, almost time-expired twisted pair copper and fairly long tails of twisted pair copper in the UK. BT could have taken the opportunity to start to upgrade that during the 1990s. It didn't because it focussed its investments primarily overseas.

Source: Malcolm Taylor, Unpublished interview conducted by the author.

London, 27 March 2012

¹⁹ Although there were a number of other contributing factors to it, the relative lack of optical fibre deployment in the access network can be understood based on the numbers reported in BT's annual reports throughout the 1990s. Even as of 2009, the UK had 128M km of copper wire against 11M km of optical fibre (BT, 2009, p. 22 - these are the latest numbers available). As BT (2013) notes, BT's fibre broadband end-user base within the retail space was 19% of total end-users i.e. remaining 81% are still on some form of DSL connection. This relatively limited penetration of fibre is even more stark considering the fact that core network usually accounts for 10-15% of network capacity against 90-85% of access network capacity. See Valdar (2006) for a more detailed discussion on the different configurations of core and access network capacities.

By 1999, the market sentiment that had favoured such expansion activity on the part of not only BT but also other operators such as AT&T, MCI, and Worldcom had begun to diminish. In the financial year 1998-99, the losses from BT's joint ventures grew to £342M (BT, 1999b). These losses came from BT's investments in Viag Interkom in Germany, Telfort in Netherlands, Cegetel in France, Albacom in Italy, BIB in the UK, and LG Telecom in the Republic of Korea. With increasing losses, by March 2000, BT's net debt grew to £8,700M with an increase of £7,747M in the financial year 1999-2000 (BT, 2000b). By 2001, this situation was about to worsen as the dotcom wave that had fuelled part of this growth had crashed²⁰. The worsening of BT's financial position had an important influence with regard to its choice of technology for delivering broadband connectivity in a context where demand for the Internet/Web was growing rapidly and dial-up connections were increasingly unsatisfactory.

However, before discussing the role of the increased demand for the Internet/Web that put DSL in the forefront as a broadband technology of choice, it would be important to cover the fate of B-ISDN which, like optical fibre had once been considered a frontrunner to deliver high-bandwidth connectivity. Although the deployment of optical fibre in the access network stalled in the absence of what BT saw as revenue-making opportunities, the adoption of B-ISDN did not happen due

²⁰ As Curwen (1999) explains the telecom companies had increasingly begun to dominate the Financial Times 500 (FT500) list to the extent that telecoms was the most dominant industry in the list of top 250 companies worldwide in terms of market equity and capitalisation in the year 1999 at the height of the dotcom wave. In the wake of the dotcom crash and Worldcom bankruptcy, demergers, and increasing debt (Curwen, 2001) this trend had begun to reverse resulting "*in a spiral of debt, credit downgrades and bankruptcy*" in the telecom sector (Curwen, 2002, p. 26).

to a number of technical and non-technical reasons. These reasons played out in a more global context owing to the way B-ISDN/ATM development was driven by CCITT/ITU and were not specific to the UK. However, the outcome, as with ISDN, was that B-ISDN/ATM, despite its technical capabilities, never emerged as a serious contender to deliver broadband connectivity. An important reason, as the next section discusses, was the rise of Ethernet/IP technologies.

6.5 The commercial failure of B-ISDN/ATM

B-ISDN was initiated as a way of overcoming the limitations of ISDN for making higher capacity available for delivering high-bandwidth content including video (Seel, 2006). The main change from ISDN was the way in which optical fibre cable was going to be used more widely in B-ISDN to upgrade the available capacity in the core network (Gallagher, 1994). The other aspect of B-ISDN was its reliance on ATM, a cell-based switching technology which was intended to provide the speed and flexibility of packet switching methods along with the reliability of circuit switching methods (Maxwell, 1998). In the same manner as ISDN, the development of B-ISDN was driven by the telcos and as part of a large CCITT/ITU-sponsored effort. Thus B-ISDN also suffered from the lengthy negotiation of technical standards and long development cycles that had plagued ISDN development (see Ayanoglu and Akar, 2003; Seel, 2006 for more details). Prof. John O'Reilly, former Principal Research Fellow with BT, while commentating on the fate of ISDN, discusses such systemic limitations as follows:

ISDN was the last kick of the old world i.e. the thinking associated with ISDN was in some ways rooted in monopoly days. The long drawn standardisation process. Internet was developing very rapidly in parallel. The progression from ISDN to ATM is interesting in that IP networks accomplished a number of similar features with less time in development.

Source: John O'Reilly, Unpublished interview conducted by the author.
Cranfield, 22 December 2011

Prof. O'Reilly's comment, although it discusses the failure of ISDN, is equally applicable to B-ISDN²¹. Developed in a nearly identical cycle of 4-year cycles, B-ISDN/ATM²² did not see the expected level of adoption due to the emergence of the Internet/Web and the technologies that implemented it – IP/Ethernet²³. As Prof. Jon Crowcroft, who participated in the early trials of ARPANET (which was, in many

²¹ Seel (2006) offers an insider's account of what went wrong with the B-ISDN development. The industry persisted with cell-based switching offered by ATM in order to deliver the requirement of achieving a certain quality of service when the capabilities of packet-based switching had become clear and its success in data transmission was evident in the form of the Internet/Web.

²² B-ISDN was the network intended to deliver multiple services ranging from voice, data, video and multimedia. ATM was the switching and multiplexing technique based on the use of short, fixed length packets (i.e. cells) to deliver such services. See Gallagher (1994).

²³ Although the terms "IP technologies" is used to describe the various technologies associated with packet-based switching networks, each of them serve a different purpose. The Internet protocol (IP) defines the structure of the packets. Transmission Control Protocol (TCP) defines the protocol for communication between the originating and terminating packet switches. Ethernet is a set of computer networking technologies for local area networks defined as part of the IEEE 802.3 standards. See IEEE Computer Society (2012b; 2012c; 2012d; 2012e; 2012f; 2012g) for more details about the 802.3 standard.

ways the conceptual predecessor to the Internet²⁴) discusses, this outcome was in part due to the changing nature of telecommunications and data communications industries. In the excerpt below he is discussing the events in the 1980s:

I was working on what was then considered a stealth project - the Internet, which wasn't intended to compete with what the telcos were doing. The Internet used an open version of packet switching. It was initially intended for defence networking. Public networking was not the primary goal. The objective was intended use by the US DoD [Department of Defense] and its collaborators. It was an open system for an economic reason as that would allow many companies to build equipment against public standards. The fact that the standards were freely available meant that the barrier to entry was very low for equipment manufacturers. Ironically the ITU and ISO standards cost money to get - that created a barrier to entry. Plus the equipment would be connected to licensed telecom operator's equipment. Which meant a licensing overhead because the equipment had to be approved by the telcos. The Internet equipment had no such checks. The Internet in the 1980s did not have any particular application in mind. The telco systems, including ISDN and Videotex, had many intended services and applications which looked almost like the [present day] web.

²⁴ The Internet started life in the late 1960s in the form of switched data network ARPANET developed by Defense Advanced Research Projects Agency (DARPA). See Hughes (1998) for a history of the ARPANET and its development. See Rohlfs (2001) for a more detailed history of how the Internet developed.

Source: Jon Crowcroft, Unpublished interview conducted by the author.
Cambridge, 23 January 2012

The open nature of standards such as Transmission Control Protocol (TCP)/Internet Protocol (IP) that formed the backbone of the Internet meant that the economies of scale achievable by TCP/IP based equipment were considerable and drove down the costs significantly (Seel, 2006). The result is discussed in the following quote by Prof. Laurie Cuthbert of QMUL and co-author of the book "ATM: the broadband telecommunications solution":

When ATM came, it could have been implemented in 1993 but everybody was trying to make it better. In this time, Ethernet came along. B-ISDN was expensive and delivered 150 Mbit/s [...] which the PCs [Personal Computers] couldn't handle. The 10 Mbit/s Ethernet cards using TCP were very cheap and easy to install.

Source: Laurie Cuthbert, Unpublished interview conducted by the author.
London, 13 February 2012

Effectively, as the Internet grew in end-user numbers, the use of TCP/IP became more widespread. This meant that by the end of 1990s, the possibility of B-ISDN/ATM fulfilling its potential had significantly receded. As Prof. Cuthbert explains in the following quote, the cost of implementing B-ISDN/ATM played a key part in the outcome:

TCP/IP was being pushed by the Americans. It was a mature technology because of the ARPANET. It [TCP/IP] works straight out of the box whereas ATM needed setting up and configuration. TCP/IP was cheaper, easy to use, and just caught on.

Source: Laurie Cuthbert, Unpublished interview conducted by the author.
London, 13 February 2012

The result was that with the growth in Internet/Web traffic, the telcos were now on the lookout for technological alternatives that could deliver high-bandwidth capacity. Combined with the need to fulfil the increased end-user demand for Internet/Web traffic, the financial crisis and the recession that plagued the communications industry (in the wake of the dotcom crash) intensified the need for short-term solutions which played a key part in the emergence of DSL as the next section discusses.

6.6 The Internet and DSL to the forefront

With the early prototypes of HDSL having been developed in 1989 (see chapter 5, section 5.5), throughout the 1990s, the trials and testing for DSL variants had continued with a view to providing not only video-on-demand capability but also additional services to PSTN operators over their existing copper twisted pair assets²⁵. With improvements in integrated circuits, processing power, signal

²⁵ The ITU specified the standards related to DSL technologies. The Broadband Forum (initially ADSL Forum) looks after the end-to-end architecture of DSL broadband technologies and the

processing, and modulation techniques, the issues of crosstalk, and noise interference that limited the capabilities of copper to deliver higher bandwidth were also more effectively contained as the 1990s progressed²⁶. The use of single carrier techniques (such as QAM/CAP) and multi-carrier techniques (such as OFDM-based techniques) improved the bandwidth capabilities of copper line networks, the potential of which had been unlocked starting in the 1960s with the use of PCM becoming practical as chapter 4 had outlined. Despite these improvements, DSL still faced a number of key issues during its early trials.

6.6.1 The early DSL trials in the UK

One of BT's very first trials for DSL took place in 1991-92 as part of impulse tests it ran at the NYNEX (now Verizon) Laboratories (see Cioffi, 2011). Gavin Young, then part of BT's team, discusses these trials and the way in which the video-on-demand service actually worked at an early stage. In the first instance, he is talking about the trial that took place at Kevin Foster's (who is now the Head of access platform for BT) house:

There was some competition between BT and NYNEX as to who could do the first trials (in early to mid-1990s). NYNEX would argue that they had the first video over ADSL trial but a lot of their backend systems were not very well automated. They had the downstream [traffic] but the upstream traffic wasn't

certification programme for DSL equipment. For example, see Broadband Forum (1996) and ITU (1998; 1999a; 1999b).

²⁶ For a concise history of how signal processing and modulation based on Orthogonal Frequency Division Modulation (OFDM) developed, see Weinstein (2009). See Cioffi (2011) for details of the race between DMT and QAM/CAP as the modulation technique of choice for DSL.

really there. BT trial had the nCube servers, not just the ADSL but the video infrastructure was there. The very first trial was in Kevin Foster's house. The ADSL modem had been hand-built by John Cioffi's highly qualified PhD students. It was very expensive and cost close to £1000. It worked but had a fan to keep it cool. Later on BT did a trial in the Kesgrave exchange during which [the deadlines were so tight that] the engineers slept in the sleeping bags at the exchange. We were given a deadline to hit a certain date for which a number of people worked round the clock. Then BT did a second, commercial trial in Colchester around 1998 with about a couple of thousand users. Both these trials were primarily video. It mostly worked although the responsiveness to channels wasn't very good. The equipment wasn't optimised for it at that time. It took about 4 seconds to change the channels.

Source: Gavin Young, Unpublished interview conducted by the author.
London, 01 February 2012

Despite the limitations of the equipment and the fact that the bandwidth provided by DSL progressively declined with an increasing length of copper wire from the exchange (Starr et. al., 1999), the DSL technology offered a number of advantages over ISDN and B-ISDN in the short term. One of the main advantages of DSL was that unlike ISDN or B-ISDN, DSL did not require a digital loop to be installed in the last mile and thus offered significant savings in terms of engineering work and installation costs (see Valdar, 2006). Although DSL was originally devised for video-on-demand services, given the failure of such services to gain traction, similar to other high-bandwidth technologies, DSL did not see any significant deployment

until mid-1990s. It was the growth of the Internet/Web that provided the required impetus for deploying such high-bandwidth capability.

6.6.2 The emergence of the Internet/Web into mainstream consciousness

By the mid-1990s, a possible end-user requirement for high-bandwidth connectivity had emerged in the form of the Internet/Web. The Internet had started to become mainstream and gain popularity beyond its origins as a network of networks to connect academic institutions (see Hughes, 1998 for a history of ARPANET and its development. See Rohlfs, 2001 for a discussion on the growth of the Internet). This growth can be seen by the growth in numbers of end-users for dial-up (i.e. narrowband) connectivity in the UK²⁷.

At the same time, as Prof. John O'Reilly, then a Principal Research Fellow at BT, points out, by 1997-98, the effects of the growth in dial-up numbers had begun to be felt in BT's core network (see O'Reilly, 2005 for more details). The effects of the congestion in the network designed for carrying voice traffic had to be managed by not only adding capacity in the core network but also finding more efficient ways of carrying the data traffic. In the following excerpt he is talking about the situation in the mid-to-late 1990s:

²⁷ The UK had 8,000,000 users online in 1998. By 2000 this number had nearly doubled to 15,800,000. See BBC (2008) for a detailed infographic based on the information derived from the International Telecommunications Union (ITU).

The time I got involved, the growth in the Internet traffic on the core [network] switches was very rapid. Port capacity had been squeezed due to a very significant fraction of data. At that time, the prognosis was that if we did nothing, in a year 100% of the core port capacity would be used by Internet traffic. These core switches were designed for voice calls. That caused a very rapid evaluation of how traffic was carried. BT had to upgrade the port capacity in the core switches. Within 12 months, all the existing core switches were taken out and new ports were put in. This was the time when FRIACO [Flat Rate Internet Access Call Origination scheme which provided flat-rate unmetered wholesale Internet access to the Internet Service Providers] was about to be introduced. This was clearly an interim solution. At this point of time, BT wanted Other Line Operators to connect to the local exchanges [i.e. in the access network or closer to the end-user premises] instead of the core [network] switches.[...] What BT wanted was Internet traffic to be routed over this network. BT also wanted to introduce DSL.

Source: John O'Reilly, Unpublished interview conducted by the author.
Cranfield, 22 December 2011

During this time, in the early 1990s, Joseph Lechleider of Bellcore²⁸ had pointed out that given the asymmetric nature of video traffic, the bandwidth available on copper twisted pair could be used better by using more of it for downstream traffic than for upstream traffic (Cioffi, 2011). This paved the way from HDSL, which was symmetric, to the asymmetric DSL – which in theory could provide downstream bandwidth up

²⁸ Joseph Lechleider was also one of the main developers of the original prototype system for HDSL in 1989-90. See chapter 5, section 5.5.

to 7.5 Mbit/s. Peter Adams, who was working with BT as part of its DSL trials for VOD in the early 1990s, discusses how the asymmetric nature of ADSL connectivity became relevant with the Internet/Web:

In the early days of ADSL, the services that could be carried over it were considered. What was mainly looked at was VOD type of services and that is why the asymmetry was chosen. During the course of its development, it became apparent that Internet access was also suitable for asymmetry and hence could be a primary application of ADSL. The service drivers [for ADSL] thus changed.

Source: Peter Adams, Unpublished interview conducted by the author.
Ipswich, 19 January 2012

Peter Adams' comment about the change in service drivers is relevant in the context of how DSL, a technology initially aimed at delivering video-on-demand services, was now considered suitable for Internet access. Combined with the suitability of ADSL for carrying asymmetric traffic, it was the need to add capacity for carrying more traffic that led BT to its first broadband Internet trials with ADSL technology in 1997-98 (BT, 1998b). However, the dial-up modem, despite its limited bandwidth, had important advantages over the then nascent DSL technology (Starr et al, 1999) -

- The dial-up modem was ubiquitous – it cost less than DSL equipment and was easy to install.
- The modem could be connected to any phone line and that enabled a call to millions of other phone lines with a modem attached.

These advantages meant that even until 2001-2002 DSL trailed dial-up/narrowband connectivity significantly²⁹. However, as noted by Prof. John O'Reilly, over a period of time, the growth in Internet traffic outpaced the capabilities of dial-up modems. These in turn highlighted following limitations of dial-up modems (Starr et al, 1999)

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- The dial-up modem, when in use for Internet/Web connectivity, blocked telephony calls, and resulted in traffic congestion at the local exchanges.
- The dial-up modem, since it relied on the circuit-switched PSTN, lacked the capability to connect multiple destinations simultaneously. As a result, it could be used for either telephony or Internet/Web access but not both at the same time.
- The dial-up modem suffered from high-error rates and connection drop-outs.
- The dial-up modem operated over an end-to-end PSTN connection. This was less efficient compared to DSL which operated over a local loop.

As Valdar (2006) notes, a key advantage of the DSL modem was that it did not need to be installed by an engineer and thus offered important cost-savings over both ISDN and B-ISDN. Effectively given its suitability to carry the asymmetric Internet traffic, ADSL technology emerged as an alternative. Compared to deployment of optical fibre and B-ISDN technology, DSL provided not only a good interim technology, it also allowed the incumbent operators (such as BT) to maximise returns on their existing copper assets (Maxwell, 1996).

²⁹ As Oftel (2001a) explains, the number of premises (home + SME) connected to the Internet were 12M in the UK. Of these, only 100,000 were on DSL and 96,000 were on cable modems. The remaining premises were connected via dial-up modems.

6.6.3 DSL and the uncertainty around return on investment

For the financially constrained BT (see section 6.4.2), when compared to B-ISDN or optical fibre, even a relatively lower cost rollout of DSL could not be done without a commercial justification. Given the low price dial-up modem connectivity available to end-users, whether they would be willing to move to higher-priced broadband connectivity was an unknown. Prof. Andy Valdar, who was a key member of BT's network strategy and planning team in the late 1990s, throws some light on the situation facing BT – that of return on investment (ROI) in the following excerpt:

The problem with broadband is/was the business case. [...] BT technically had the solutions [whether optical fibre, B-ISDN, or DSL] for many years. [...] The problem was the question of business case. The business case for broadband would need to provide the costs of network rollout along with the expected revenue streams and services. The services to be provided and the expected average revenue were difficult to predict at that stage.

Source: Andy Valdar, Unpublished interview conducted by the author.
London, 18 April 2012

This perceived lack of business case combined with uncertainty over whether end-users would be willing to switch from the cheaper dial-up services to the higher priced DSL, and BT's financial problems, meant that BT's position with regard to deploying DSL was cautious. By September 1999, based on the European

Commission Licensing Directive (as part of the 1999 Communications Review i.e. COM(1999)539. See EC, 1999), BT's licence provisions were modified and the restrictions on BT around conveyance and provision of broadcast visual services to homes were removed (BT, 2000a; 2000b). BT was henceforth permitted to 'broadcast' video over its network. In spite of this new-found freedom and an additional incentive to deliver broadband connectivity, BT faced the same challenges for content that the cable industry did – the commercial strength of BSkyB and the emergence of a new digital television platform (which later became FreeView). BT's position was made more difficult over the bidding war over 3G spectrum³⁰ at the end of which, BT had acquired a costly licence at £4.03B (BT, 2000b). Peter Shearman, the Head of Infrastructure Policy with the Broadband Stakeholder Group (BSG) at the time of the interview, comments on BT's approach to DSL at this stage and the role these factors played in relation to its decision on deploying DSL. By Cellnet, he is referring to BT's mobile telephony services division, which as the events in chapter 7 show, had to be sold off in order to reduce BT's high-levels of debt:

³⁰ This auction raised £22.5B for the UK Treasury (NAO, 2001). See Binmore and Klemperer (2002) for an inside account of the auction process.

BT was slow to come to the DSL party relatively speaking but that was not an uncommon position for BT to take at the point. At that time they had massive cash flow issues. They had to get rid of Cellnet which was a massive strategic black mark for them. But they didn't have much choice [with regard to the sale of Cellnet]. They went from being a huge multinational telecom operator to one that had 80% of its business in the UK. So there were a number of issues at that time that impacted their ability and desire to invest.

Source: Peter Shearman, Unpublished interview conducted by the author.

London, 09 February 2012

As a result of BT's cautious approach, Oftel (learning from the experience of unbundling in Denmark, Germany, and Austria. See Oftel, 1999b) decided it needed to intervene. This intervention took place in the form of a consultation on local loop unbundling³¹ "Access to Bandwidth: Delivering Competition for the Information Age" (Oftel, 1999b). David Clarkson, a policy director at Ofcom, indicates the extent to which this consultation was motivated to spur investment in broadband infrastructure:

³¹ With local loop unbundling, the non-BT operators were offered space in the BT exchanges and thus allowed to build their own last mile access if they chose to do so. See Oftel (1999b).

In 1999, Oftel published a consultation to consider the options that could be used for unbundling. At the end of 1999, they published a statement indicating that they were going ahead and open up BT's local loop. The idea being that if BT didn't believe it was worth investing [in broadband], perhaps somebody else might think it was.

Source: David Clarkson, Unpublished interview conducted by the author.

London, 27 January 2012

Combined with the UK government's stated ambition for the *"UK to have the most extensive and competitive broadband market in the G7 by 2005"*³² (Oftel, 2001b, p. 3) and the possibility of opening up its last mile access to competitors, there was now pressure on BT to deploy broadband infrastructure in some form. In consequence, DSL was the most expedient option for BT in technological, commercial, and political terms by the end of 1990s. Effectively DSL, an option devised for video-on-demand and previously unheralded due to its use of copper twisted pair was now the front-runner to provide the required broadband connectivity to the Internet/Web.

6.7 Discussion and Conclusions

This chapter has covered the events in the 1990s at the end of which DSL emerged as a front-runner for delivering broadband connectivity. The UK communications

³² G7 refers to the group of seven developed nations – US, UK, France, Germany, Italy, Canada, and Japan.

industry was opened up to further competition after the duopoly review of 1991-92. As BT's transition to the private sector was completed with the remaining government shares being sold, it was listed on the stock market in 1994. With regulatory restrictions still in place, BT increasingly focussed on expanding its operations outside the UK. As a result of BT's aggressive expansion strategy, it accumulated significant financial debt by the end of the 1990s. During this time, BT's UK infrastructure saw limited deployment of optical fibre in the access network. The UK cable industry, still struggling with issues of fragmentation and lack of content, saw additional competition emerge in the form of BSkyB. With BSkyB capturing premium sports and film content, the UK cable industry's financial situation worsened further, and the deployment of cable network slowed down significantly.

Underpinning these events was the pursuit of video-on-demand services which mostly failed to materialise in the absence of financially viable models. It was only when the Internet/Web emerged in mid-1990s that the end-user demand grew to suggest a need for high-bandwidth capacity. Although the telcos had continued to develop a high-bandwidth technology such as B-ISDN/ATM, its costs of deployment remained too high. ADSL, although initially developed for delivering video-on-demand services over the copper line, was found to be equally suitable for delivering Internet/Web traffic. Combined with BT's financial problems and regulatory pressure, the previously unheralded alternative of DSL emerged as a front-runner for delivering broadband connectivity.

The following sections analyse the reasons due to which the investments in optical fibre and coaxial cable were affected and how DSL emerged as an alternative. The discussion of B-ISDN/ATM and IP technologies is done in terms of Hughes' 'technology as a system' approach and reverse salients continuing the previous thread of discussion in chapters 4 and 5 around technologies that struggled to achieve greater adoption. The unexpected manner in which the Internet/Web grew into mainstream consciousness is considered from the perspective of path dependence to understand the role the success of the Internet/Web played in relation to the selection of DSL. The discussion starts off with an analysis of how the function and meaning of broadband came to be centred on Internet/Web access and DSL.

6.7.1 Converging views about the function and meaning of broadband

As established in chapter 5, at the end of 1980s, the various relevant social groups i.e. regulators, BT, non-BT operators, and end-users had different ideas about what broadband connectivity would do and how it could be implemented. In consequence, the various relevant social groups had different technological frames i.e. cognitive, social, and technical elements that guide the meaning and behaviour in relation to broadband technology.

By the early 1990s, the telcos and cable operators were mostly focused on video-on-demand services as the main function of the broadband connectivity. The technologies in consideration were B-ISDN, optical fibre, coaxial cable/HFC, and ADSL. The resulting situation shows the technological frames of various relevant

social groups converging when the business models for video-on-demand services failed to materialise and the Internet/Web grew in popularity. By the mid-to-late 1990s, when dial-up connectivity was increasingly proving unsatisfactory, the function of broadband connectivity to deliver high-bandwidth Internet access had taken hold with the various stakeholders. When these events are combined with the emergence of DSL as the broadband technology of choice, the outcome further underlines the importance of the systemic context for analysis from a social constructivist perspective. The two key concepts for this analysis are interpretative flexibility and technological frames.

As the discussion in chapter 5 covered, interpretative flexibility is evident in the way broadband not only signified different services such as Videotex, video-on-demand, or video conferencing but also the different transmission media in consideration such as coaxial cable, optical fibre or DSL. Specific to the events discussed in this chapter, the notion of interpretative flexibility has further relevance if the way ADSL was repurposed is considered. As mentioned by Peter Adams in section 6.6.2 the service drivers for ADSL changed from video-on-demand services to Internet/Web access. Since the capability to deliver asymmetric traffic was equally useful for Internet/Web, the function of ADSL was revised in line with the telco requirements. Such a reinvention of ADSL's capabilities fits with the way interpretative flexibility applies to a technology resulting in updated understanding of its function and meaning to the various stakeholders. In the context of this chapter, the emergence of DSL as the front-runner for delivering broadband connectivity shows that not only telcos but also other relevant social groups including regulators and end-users had accepted this interpretation.

With regard to the technological frames, throughout the early-to-mid 1990s, BT and cable operators were mostly focussed on video-on-demand services as the core business proposition for broadband connectivity. By late 1990s however, the technological frames of the relevant social groups including BT, cable operators, and end-users, had converged on providing high-bandwidth Internet/Web access. With the failure of the business models pursued by BT or the cable operators in relation to end-to-end ownership of video-on-demand services, it was the end-user demand for high-bandwidth Internet access that emerged as the most influential technological frame. The outcome reflects an important change in the way the UK communications industry had come to function.

Consider for example how the dominant technological frame during the Post Office monopoly days was that of end-to-end ownership of products, services, and technologies by the Post Office. As the discussion in chapter 4 showed, other relevant social groups had very little say or influence on this technological frame due to the lack of alternatives in the market. With the denationalisation of BT, not only did additional relevant social groups emerge but as a result of the competitive market, the Post Office's technological frame had reduced influence. The regulator and non-BT operators particularly the cable operators had a different vision of what high-bandwidth connectivity would do as shown in chapter 5. In the context of the events covered in this chapter, it becomes clearer that the competitive nature of the market had placed the end-user at the centre of any market-related activity whether introduction of services or deployment of new technologies. In consequence, it was

the end-users' demand that had made broadband Internet access the dominant technological frame.

The influence of the end-users' demand for the Internet/Web access and resulting convergence of the technological frames was an outcome of the changes in the way the market functioned. Bijker's and Pinch's studies show technology being 'interpreted' in a context where there is not yet a clear market or demand. The situation in case of broadband technologies is different as the demand for Internet/Web access in the late 1990s shows. In the case studies of the bicycle, fluorescent lamps, or the Dutch housing schemes, the relevant social groups are seen to employ specific micro-political power strategies to shape the interpretation of the technological artefact. In case of broadband technologies, similar use of micro-political power strategies by the various stakeholders is not discernible because of the uncertainty over what services broadband connectivity would deliver and how it could be delivered. The outcome is instead significantly influenced by the changes to the UK communications market in terms of the focus on ROI and price competitiveness.

Unlike Bijker and Pinch's studies, it is the influence of the changes in the UK communications industry that provides an atypical context in which the function and meaning of broadband has stabilised. However, both Internet/Web and DSL have continued to evolve. Despite the extent to which broadband connectivity has a stabilised association with Internet/Web and DSL, whether closure (i.e. agreement between the relevant social groups about the interpretation and consensus on the function of the technology) has taken place in relation to broadband remains

difficult to determine. The Internet/Web may evolve into an Internet of Things (Ashton, 2009; Gubbi et al, 2013), and thus its function is likely to undergo significant changes. The DSL technology itself has evolved from ADSL (i.e. 8 Mbit/s bandwidth) to Gigabit DSL (nearly 1 Gbit/s bandwidth) as the discussion in chapter 7 will show. With increased efforts to deploy fibre-based networks closer to the end-user premises i.e. in the last mile, the association of broadband with DSL is also likely to change over time. Such a situation in which the Internet and the DSL technologies may change significantly suggests that closure as defined by Bijker and Pinch has not yet taken place in relation to broadband technologies.

6.7.2 The changes in the market and historical contingency

Two key examples of historical decisions that brought DSL to the forefront are the regulatory policies of infrastructure competition and price control. The influence of regulatory policies on the infrastructure deployment throughout the 1990s aligns with how Hughes defines legislative artefacts i.e. rules of governance in a large technological system. As the analysis in chapter 5 established, the interaction between the legislative artefacts (regulatory and government policies) and the organisations (i.e. the operators and regulatory bodies) is seen to influence how the physical artefacts (i.e. the transmission technologies in the last mile, the networks, and exchanges) were developed and deployed. The policies of infrastructure competition and price control had significant influence when the slowdown in the deployment of cable networks and underinvestment in BT's existing copper network is considered. As the narrative in this chapter shows, the regulatory policies in fact hindered the emergence of a major infrastructure competitor to BT. Despite the

expectations associated with the cable industry, it could not compete with BT due to the way it was set up and because the cable operators struggled to develop unique, lucrative content.

As outlined in section 6.2, the policies of infrastructure competition and price control contributed significantly to the financial problems faced by the UK cable industry. The aim of encouraging infrastructure competition was central to the allocation of cable franchises as regional monopolies, which as section 6.3.3 showed, led to fragmentation issues when deploying cable modem based broadband connectivity. On the other hand, the policy of price control meant that telephony services, which somewhat surprisingly contributed better margins than television content, had to be priced lower than BT in order to ensure competitiveness. Another decision which influenced the financial difficulties of the cable industry in an unintended manner was the merger of Sky and British Satellite Broadcasting. The economies of scale possible with a single UK-wide satellite broadcaster were unmatched by the fragmented cable industry. The result was a further squeeze on the margins of the cable operators due to the need to buy the sports and film content from BSkyB on a wholesale basis. Each of the regulatory decisions thus had unintended consequences which undermined the extent to which the cable industry could develop as an alternative to not only BT's infrastructure but also BT's telephony services.

The outcome of each of these events however was that as the need to consolidate and build economies of scale took priority, the efforts to build the cable network footprint had significantly slowed by mid-1990s. This can be witnessed by the fact

that even after 15 years of operation, the footprint of the cable network was only 50% of the UK premises (OfTel, 2002a). Although the additional capacity available in the cable networks (see the discussion in chapter 5) provided an important advantage for the early cable modems over the prevailing dial-up connections, as the discussion in chapter 7 will reveal, the lead taken by cable modems in broadband connectivity could not overcome the limitations of the cable network footprint, a result which had its roots in the historical decisions that affected the evolution of the cable infrastructure.

Similarly, BT's commercial focus and efforts to maximise revenue by investing outside the UK can be significantly attributed to its complete transition to the private sector once the UK government sold off its remaining golden shares. Once it was listed on the stock markets, as section 6.4.1 outlines, BT ambition continued to grow and so did the footprint of its operations outside the UK. The sheer scale and audacity of BT's ambition is reflected in table 6.1 which describes nearly all of BT's major investments throughout the 1990s. Although the regulatory policy was not intended to drive BT's investment out of the UK, a number of restrictions related to broadcasting were an important factor in BT's lack of interest in the UK infrastructure. As Malcolm Taylor argues in section 6.4.2, a critical outcome of such an underinvestment was the reliance on copper as a transmission technology, a situation which proved important in the emergence of DSL as a broadband technology. BT's changed business priorities and the prevailing regulatory regime were thus two important factors that contributed to a sequence of events that led to the selection of DSL by the end of 1990s.

6.7.3 B-ISDN/ATM and the constraints imposed by the telecommunications system

The commercial failure of B-ISDN/ATM shares a number of similarities with the way ISDN fared commercially. Although B-ISDN was intended to overcome the bandwidth limitations of ISDN, it remained locked into similar 4 year development cycles and the result was a technology that although quite capable, did not address real-world requirements. This is reflected in Prof. Laurie Cuthbert's comment in section 6.5 in which he argues that although B-ISDN could deliver bandwidth of 150 Mbit/s as early as 1993, the personal computers were simply not capable of using such bandwidth capacity. Although the emergence of the Internet/Web meant that a service that could have used the high-bandwidth capacity of B-ISDN existed, as Prof. Crowcroft points out (section 6.5), the cost of implementing a CCITT/ITU standard such as B-ISDN was an important hindrance. Since personal computers could only deal with 10 Mbit/s LAN connections even in late 1990s, B-ISDN did not address real-world requirements as well as Ethernet/IP technologies. In the absence of effective solutions to these issues, like ISDN, B-ISDN failed commercially.

Unlike ISDN, the limitations of 128 kbit/s bandwidth had been resolved with B-ISDN. Thus the reverse salient (i.e. an unsolvable problem as defined by Hughes) that had proved a hindrance for ISDN adoption had been parsed into a critical problem (i.e. a problem that could be resolved). Despite the bandwidth capabilities of B-ISDN however, its failure highlights Rosenberg's (1994) argument about how the systemic nature of the telecommunications industry influences the choices in relation to selection and deployment of technology. As Rosenberg (1994) points out

the capital intensive nature of the industry necessitates a long-term view of infrastructure investments dictated by returns on investment.

In the early days of the World Wide Web, when most users were relying on dial-up modems, not only was the need for 100s of Mbits of bandwidth an unknown, whether the end-users would be willing to pay the high costs of such bandwidth was also an unknown. Even in the wake of the increasing end-user demand for Internet/Web, the telcos lacked a long-term business case for the capabilities offered by B-ISDN/ATM. A number of these capabilities could be delivered with a much cheaper technology such as IP that worked with the existing copper infrastructure. As the IP technologies continued to deliver quick improvements in rapid development cycles, and narrowed the feature gap with B-ISDN/ATM, the returns on investing in IP-based equipment were better than B-ISDN/ATM-based equipment.

As the video-on-demand services remained mired in issues of licensing and pricing, B-ISDN had the same problem that ISDN had – lack of commercial justification for what was a large financial investment in a complex technology. The cost of deploying B-ISDN/ATM equipment, the absence of viable video-on-demand business models, and the fact that the capabilities of B-ISDN/ATM did not address immediate real-world requirements, none of these problems were unsolvable i.e. reverse salients as defined by Hughes. These problems were constraints imposed by the telecommunications system which emphasised maximising returns on the existing infrastructure. As a result, DSL fit the requirements of the telcos better than B-ISDN/ATM.

Such a scenario in which B-ISDN/ATM failed commercially, despite the bandwidth capabilities and functionality it offered for various types of traffic (i.e. data, voice, and video) underlines the influence of non-technological factors in its deployment and adoption. In the same way, as coaxial cable, DSL or optical fibre, the deployment of B-ISDN/ATM was not entirely bound by its technical capability but decided by socio-economic factors such as cost of deployment, availability of cheaper technology such as IP, and the bandwidth limitations of the computing technology available in the 1990s. The lack of wider deployment and adoption of ISDN and B-ISDN/ATM are also examples of how in order to be successful, a technology needs to address real-world requirements first and foremost. As the next section explores, it was this capability to address real-world needs that proved pivotal to the emergence of DSL.

6.7.4 The growth in the Internet/Web and the emergence of DSL

In analysing how technology adoption is influenced by a specific sequence of events, Arthur (1990) discusses how "small events" can lead to unexpected results and change the way a technology is deployed and adopted. If the rise of the Internet/Web by mid-1990s and the manner in which the communications industry, particularly the telcos responded to the increased end-user demand for data connectivity is considered, its influence on the selection of DSL becomes clearer. Although in retrospect the Internet/Web can be clearly seen as an important event in terms of the role it has played in relation to the deployment of broadband technologies, in the mid-1990s the telcos were clearly caught off-guard by the surge

in end-user demand for Internet/Web access. Seen in the historical context and the modest ambitions with which the Internet had been created, the emergence of the Internet started off as a "small event" and resulted in a scenario for which the operators were unprepared. The telcos, in particular, needed a low-cost, short-term solution - a situation that played a key part in the selection of DSL and its subsequent widespread deployment.

Although the communications industry had been preparing for delivering high-bandwidth services and connectivity for more than a decade, the efforts were focussed on centralised, end-to-end systems such as interactive Videotex or video-on-demand services over which the operators retained significant control and for which the telcos owned content, or had it licensed to them. As Prof. Crowcroft mentions in section 6.5, a number of features in the Videotex implementations even resembled the latter day Internet/Web. The reason the telcos were unprepared for the demand for the Internet/Web was that due to its decentralised nature the Internet/Web was the antithesis of the kind of service that the telcos had attempted to introduce and manage on an end-to-end basis. Although dial-up modems were used initially, it quickly resulted in the core network running out of capacity as Prof. O'Reilly clarifies in section 6.6.2. The result was not only pent-up demand for higher bandwidth but also a need for short-term solutions that could be delivered at a lower cost than alternatives such as optical fibre or B-ISDN that required heavy expenditure. The unforeseen success of the Internet/Web meant that the telcos were potentially reduced to providing network capacity for carrying data rather than owning and distributing the content themselves. With the Internet/Web a potential 'killer application' that could utilise the high-bandwidth capability had emerged,

leading to a further sequence of events in which DSL, an unheralded alternative emerged as a technology of choice – underlining Arthur's argument about how "small events" lead to unexpected results in terms of deployment and adoption of technologies.

Important as the unexpected success of the Internet/Web was, a number of other factors such as BT's financial difficulties at the end of 1990s, the fragmentation in the cable industry, the dominance of BSkyB in relation to the premium content, and the way in which the regulatory policies had unintentionally undermined the competition in the UK market, were also important. The outcome in terms of emergence of DSL, when considered with the prevailing market conditions, also echoes a number of different themes in the field of technologies studies. A useful insight is available in the form of Coombs et al's (1987) idea of 'imperfect competition' in which they discuss how competitive markets rarely result in the kind of efficient, perfect competition that they are intended to achieve. As discussed in chapter 3 (section 3.7.2) in detail, Coombs et al suggest that a competitive market is more likely to move from one state of disequilibrium to another. Such a disequilibrium in turn influences the way in which deployment and adoption of technology takes place. If the situation in the UK throughout the 1990s is considered, the argument presented by the idea of 'imperfect competition' and the way in which it shapes technological change is particularly relevant. Consider for example how although BT remained the dominant operator within telephony, its global ambitions had resulted in underinvestment in the UK infrastructure. The cable industry had never achieved financial solvency despite more than a decade and billions of dollars' worth of investment. The dominance of BSkyB meant that

cable operators were in fact struggling to be relevant in their core business of broadcasting television content. In such a context, the operators, whether BT or cable, were in a state of flux and unprepared to handle the pressure the demand for Internet/Web created on the existing infrastructure. The allocation of cable franchises as regional monopolies not only created fragmentation issues and also held back cable network deployment, as a result of which BT's market dominance was not challenged effectively – a situation that played an important part in the emergence of DSL as a broadband technology.

The extent to which DSL allowed the telcos to extend the life of the existing copper-line network also reflects David Edgerton's (2006) position about the importance of maintenance phase of a technology. As Edgerton points out, it is the maintenance of the technology, once it is introduced, that forms the most significant part of its life cycle. Intended to enhance the capabilities of the existing copper-line network, DSL was essentially a maintenance-based innovation that prolonged the life of the copper PSTN. As the narrative in chapter 7 will show, once deployed, the capabilities of DSL saw further improvement and strengthened the business case for its continued use – an outcome that underlines Edgerton's position about the role and importance of maintenance-based innovation.

However, despite the emergence of DSL as a technology of choice for the telcos and an incumbent such as BT, even at the end of 1990s, the success of DSL was far from guaranteed. As the discussion in chapter 7 will show, on the one hand, cable modems had a sizeable lead for delivering broadband connectivity during the early 2000s. On the other hand, BT remained uncertain about the potential end-user

demand for broadband and whether the demand justified investment even in a lower cost alternative such as DSL.

7 Uncertain market conditions, bankruptcy in the cable industry, and the bandwagon effect

7.1 Introduction

Although DSL had emerged as a broadband technology of choice by the end of the 1990s, its adoption and growth as the most widely used broadband technology in the UK was far from certain at the start of the 2000s. Given BT's large financial debt and the lack of investor confidence in the wake of the dotcom crash, BT's position regarding even a low-cost alternative such as copper DSL was not completely decided. Combined with uncertain projections of end-user demand and unwillingness to cannibalise its existing wholesale dial-up revenue, BT's approach vis-à-vis DSL remained cautious. In order to stave off the regulatory pressure in the form of local loop unbundling and the competitive threat of cable broadband, BT relied on a DSL registration scheme to assess end-user demand and also prioritise the areas that would be covered by DSL broadband connectivity. The success of the DSL registration scheme meant that the adoption of DSL broadband grew quickly. As a result, by 2006-07, around 99% of BT exchanges had been enabled for DSL broadband connectivity.

However, even as early as 2004-05, the market was deemed to be over-dependent on BT's wholesale DSL product by the Office of Communications (Ofcom), a regulatory body created in 2003 by merging the regulators for postal, telecommunications, broadcasting (terrestrial and cable), and wireless industries respectively. The aim of Ofcom was to supervise the converged functions of voice, data, and video across multiple market segments of telecommunications, cable, mobile telephony, radio,

and television (except the BBC). To encourage competition within the broadband market, Ofcom renewed its focus on unbundling. In 2006, Ofcom reached an agreement with BT to functionally separate BT's retail and network operations paving the way for equal access to BT's exchanges for Other Line Operators (OLOs). The result was an accelerated investment in the next-generation DSL technologies such as ADSL₂ and ADSL₂₊ which not only led BT to expedite its investment in ADSL₂₊ but also brought down prices within the retail broadband market.

During this time, although the cable operators had enjoyed an early lead in terms of cable broadband deployments in 2001-02, it was short-lived due to the departure of US-based investors from the UK cable industry. As a result, not only did the remaining two cable operators NTL and Telewest end up filing for bankruptcy and debt restructuring respectively, their operations were merged to create a single cable operator across the UK in the name of Virgin Media. After the final round of consolidation Virgin Media focussed on minimising the problems of fragmentation and incompatible equipment implementations. It also decided against further expansion of the cable network which meant that the cable network footprint remained unchanged at 50% even by the end of the 2000s. The result was that although cable broadband had taken an early lead in broadband adoption, by 2013 DSL broadband was the technology with the most market share in the UK.

The narrative in this chapter covers the initial uncertainty surrounding the end-user adoption of broadband connectivity coupled with how return on investment in DSL dictated its deployment as a broadband technology. The growth in DSL deployment triggered by the functional separation of BT and the renewed push for unbundling is

analysed in terms of the extent to which the outcome was path dependent. W. Brian Arthur's ideas of increasing returns and lock-in are also discussed along with the role of the bandwagon effect in the deployment of DSL broadband. This discussion is rounded out by coverage of the role of regulation and government policy and the systemic nature of the telecommunications industry that rewards the re-use of existing assets.

7.2 Unfavourable market sentiments and the meltdown of telco stocks

In the wake of the dotcom crash, having pursued an aggressive expansion strategy outside the UK throughout the 1990s, BT found itself with a very large debt of £27.9B (BT, 2001b). At a time when demand for the Internet/Web was growing, BT lacked the financial wherewithal to make any significant infrastructure investments in the UK¹. As a result, not only was BT's deployment of DSL broadband equipment to its exchanges slow, DSL broadband lagged behind availability of cable modem based broadband connections as of 2000-01².

BT's reluctance to move beyond a dial-up offering was however consistent with its culture of caution where new technology was concerned, as Prof. John Cioffi, whose

¹ Oftel (2001a) estimates that there were over 400 ISPs operating in the UK. 80% of the online households and 63% of the SMEs with Internet access relied on dial-up connections. Effectively 10M homes and 2M SMEs were using dial-up connectivity as of November 2001.

² As of July 2002, the number of end-users of cable broadband had risen to 419,000 compared to DSL which had 290,000 end-users (Oftel, 2002b).

research on DMT (part of the multi-carrier techniques based on OFDM) was important in making DSL a practical technology, observes:

Although they [BT] did some of the early trials, UK was late in introducing DSL. Such delays are in some ways a reflection of the cautious approach to technology prevalent in BT and overall in the UK.

Source: John Cioffi, Unpublished interview conducted by the author. Milton Keynes, 15 December 2011

BT's approach was also consistent with the expectations of the stock market and the financial sector, which due to the dotcom crash and given the "meltdown" of the telecommunications industry stocks (see Curwen, 2002; 2003), did not favour new investments. Peter Shearman, part of the BSG team that wrote "Pipe dreams" (a vision document for UK broadband deployment), commentates that:

The city doesn't like it when telecom companies invest. They [the financial markets] like it when they [the telcos] sweat the assets and produce cash. There were lots of pressures on BT to not invest and a number of issues that needed resolving.

Source: Peter Shearman, Unpublished interview conducted by the author. London, 09 February 2012

At the start of the 2000s, the commercial incentive to offer DSL broadband to end-users was far from straightforward. Given the regulatory rules on wholesale unmetered access products, the dial-up market was extremely price competitive³. There were more than 10M end-users on dial-up connectivity which meant that shifting such a large number of end-users to a higher-priced DSL broadband product was a significant task⁴. Most dial-up connections relied on wholesale access to BT's network, with the result that although BT was not the most popular retail Internet Service Provider (ISP) in the dial-up market (that was Freeserve at 19% and America OnLine i.e. AOL at 16% market share before BT at 15%, see Oftel, 2001a), BT still gained part of the total revenue attracted by dial-up connectivity.

7.3 Continued financial problems in the cable industry

The growing demand for Internet/Web connectivity at the time of the dotcom crash, and BT's cautious and financially constrained position, meant that the cable industry had a head-start with its cable modem based broadband connections (see footnote 2), especially given the superiority of cable over dial-up (and other alternatives such as ISDN and DSL). However, as this section shows, the cable industry had its own problems which prevented it from fully exploiting the potential of the cable networks.

³ The flat-rate wholesale unmetered access product that Oftel made mandatory for BT to provide to other ISPs was Flat Rate Internet Access Call Origination (FRIACO). Because of the availability of FRIACO products, the charging for dial-up connectivity was no longer volume based. It was instead a flat-rate monthly cost regardless of the extent of use. Given the extent of competition (400 ISPs in the dial-up market), and that the average cost of a FRIACO-based, fully unmetered dial-up connection was £12.99 – £14.99 per month (see Oftel, 2001a).

⁴ The average monthly cost of DSL for residential and small business end-users in November 2001 was £40 in contrast to the price of £14.99 per month for dial-up (Oftel, 2001a).

7.3.1 The departure of the US-based investors

Coaxial cable/HFC's superiority for data, relative to DSL, was due to the fact that it suffered far less from signal attenuation⁵. Graham Sargood, who worked in the cable industry in the nascent stages of the broadband market, suggests that with cable, a large amount of spectrum was available for delivering high-bandwidth data connectivity in addition to its broadcast capacity. This meant that unlike DSL, cable broadband would have far more excess capacity:

I think, if you look at the coax networks the cable operators have, if you look at 750 MHz worth of spectrum that has the capability to carry Gigabits worth of data to each individual customer. The difference between DSL and cable is the fact that cable inherently has the capacity to deliver 100s of digital channels on it. Cable can also have a portion set aside for broadband. DSL, by its nature, doesn't have the capacity to carry what cable carries. So they [DSL] have to come up with a different architecture to put content down a broadband line. So cable is, by far, the broadest infrastructure in the UK and to each home effectively [in terms of bandwidth]. [...] Without favouring either DSL or cable,

⁵ The attenuation of all metallic cable increases with increasing frequency, so the usable transmission distance decreases with increasing data rates. Furthermore, factors other than attenuation, such as crosstalk (which is worse at higher frequencies), also affect the usability of cables in specific applications. Coaxial cables are specifically designed for high-frequency transmission and consequently can be used more easily for carrying high data rates over long distances, compared to copper twisted pairs. This meant that in the early stages of a nascent broadband market, coaxial cable not only offered better bandwidth but also better end-user experience. See Maxwell (1998) for a further discussion on the problems with crosstalk, signal attenuation, and rate adaptation faced by DSL broadband connections.

the cable network and its bandwidth carrying capacity is better, even when BT starts pushing fibre closer to the exchanges [i.e. beyond the core network, further in the access network]. When BT talks about VDSL2 [Very-high-bit-rate DSL version 2] or VDSL2+, it is talking about 100 Mbit/s. That is competing with a bit of spectrum that cable set aside purely for the Internet and then they [the cable operators] have all the other spectrum they are providing TV services over.

Source: Graham Sargood, Unpublished interview conducted by the author.

London, 09 and 13 February 2012

Despite the bandwidth capabilities of the cable network, the cable industry was beset with problems as a result of which it did not capitalise on the early lead in broadband connections. Aside from the lack of sufficient revenue from television and telephony services, the cable industry was plagued by financial difficulties. One of the reasons contributing to these continued financial problems was that additional investment from the US-based owners was no longer available. This was owing to the changed regulatory scenario in the US. With the US Telecommunications Act 1996 (FCC, 1996), the restrictions placed on the US-based telcos regarding mergers, acquisitions, and expanding their operations outside franchise areas were mostly removed (see Atkin et al, 2006 for a discussion on the impact of the act on the US communications market). Richard Feasey, then working in the cable industry, discusses how this added to the problems faced by the UK operations:

By the early to mid-2000s, telephone companies in the US could grow again. You had the BellSouth mergers, USWest got bought, Bell Atlantic and all that. There was beginning to be consolidation in the US. If you were a US telecoms executive your view was – "Why should I put any more money in the UK? The real opportunities now are beginning to emerge in US (the home market) which is much bigger anyway". So basically the US telcos lost interest in putting any more money in the UK cable [industry]. As a consequence, these companies [the UK cable operators], once they were not going to be underwritten by the [US] telcos anymore, the economics didn't work.

Source: Richard Feasey, Unpublished interview conducted by the author.

Milton Keynes, 26 April 2012

With the exit of not only the US-based telcos but also the US-based cable operators, the result was additional consolidation in the cable industry. Malcolm Taylor, then working with Telewest, corroborates Richard Feasey's view in this regard:

Another one of the reasons why the consolidation occurred was because the US-operators exited the UK market. [...] I think it was the 1996 [US Telecoms] Act that allowed [US-based] cable operators to go into other areas [in the USA]. The US operators thus wanted to withdraw from the UK, having invested the money on a learning curve [in the UK]. Once their own markets opened up, they [the US-based owners] wanted to withdraw from here [the UK]. We in Telewest, for example, bought Comcast's interest in Birmingham Cable and

Cable London in the late 1990s for that very reason. Because they [Comcast] wanted to go [and leave the UK market].

Source: Malcolm Taylor, Unpublished interview conducted by the author.

London, 27 March 2012

This meant that by 2001-02 there were only two major cable operators left – NTL and Telewest. Of these, NTL filed for bankruptcy protection in 2003 (NTL, 2004). In 2004, Telewest underwent debt restructuring. In March 2006, the operations of NTL and Telewest were consolidated to create "NTL:Telewest" (NTL, 2006). A further merger with Virgin Mobile in July 2006 led to the creation of a rebranded, single entity - "Virgin Media". In effect, Virgin Media became the first UK company to offer a quadruple play of services i.e. television, broadband, fixed and mobile telephony (Virgin Media, 2007).

7.3.2 Uncertainty about the broadband market

Throughout this time of financial turmoil and the final round of consolidation, the cable industry was uncertain about the way in which broadband connectivity could be put to use and the nature of services that could be offered. John Cluny, a regulatory economist with a focus on the cable industry, outlines this uncertainty:

At that time, in the mid-1990s, broadband was a relatively little understood concept. Its potential was certainly little understood. [...] We [cable operators] did start to look at what markets might look like in a broadband world but it

was very tentative. [...] We were trying to think how a broadband market might develop and how this might impact the existing revenue streams of cable operators. We didn't understand it [i.e. what the broadband market would look like] and it wasn't until several years later with trials and whatever that broadband started to take precedence the way it did in the cable industry

Source: John Cluny, Unpublished interview conducted by the author. Milton Keynes, 19 April 2012

Other problems facing the cable industry were a legacy of its highly fragmented implementation going back to the regional franchise allocation in 1984. Although the cable industry had been consolidated into two main companies by the early 2000s, its former regional structuring made infrastructure consolidation difficult. Expansion into the broadband market was thus severely hampered, as John Cluny, explains:

... we [cable operators] were, still at that point, having problems with the consolidation process. In order to develop new and interesting products, there was a need for the cable operators to improve things like billing systems, marketing. There was a much greater emphasis on finessing the product side and not do what the cable operators had been doing in the recent past - which was that its underlying technology was vastly superior to that of BT...There were problems in doing that [exploiting cable's technical superiority] because of this legacy in terms of data, billing systems etc.

Source: John Cluny, Unpublished interview conducted by the author. Milton Keynes, 19 April 2012

The cable industry's legacy problems were not only organisational. As Trevor Smale, a regulatory advisor with NTL and then at Virgin Media discusses in the quote below, the fragmentation in the industry had left it with a number of technical problems as well:

You had 100 or more operators who have built out their systems in a particular way. There is no commonality. Some systems were in tree-and-branch configuration. Some were in switch-star configuration. They were all constructed in different ways. When the industry went for consolidation, they had to figure out how to join up these networks and get them to work in a common way. That was a massive problem. When NTL and Telewest merged, they had different customer premises equipment, different manufacturers which had different capabilities. You had customers who were ex-NTL

customers and were not able to receive the services ex-Telewest customers were able to and vice-a-versa. For the first couple of years, post-consolidation, most of the work was inward-looking and trying to get the internal plumbing of the [new] company [i.e. Virgin Media] fixed.

Source: Trevor Smale, Unpublished interview conducted by the author.
Milton Keynes, 11 April 2012

Thus, following consolidation, a priority for the cable industry was not competing with BT or Sky, but integrating their operations across different franchise areas, consolidating and rationalising internal operations, and basically attempting to build the required economies of scale as much as possible.

7.3.3 Lack of further expansion

Throughout the late 1990s, early 2000s, and even after the creation of the single cable entity Virgin media, a significant amount of the cable industry's effort was focused on its own operations instead of aggressively courting new end-users. Having minimised a number of these legacy issues however, the possibility of the cable network being expanded remained unlikely. The result, as John Cluny suggests, is that aside from winning new end-users in their existing areas of operation and end-users switching their broadband connection from existing service provider, the extent to which cable broadband adoption could grow its market share was limited in the immediate future:

Sadly, I don't see them [Virgin Media] expanding too much on their 50% footprint. They have always been against the idea of a new dig. Their policy has been to exploit aggressively the coverage they do have. I was looking at the written evidence for the House of Lords select committee investigation into super-fast broadband. Even there I was slightly disappointed to see that Virgin Media's attitude was - We are where we are and we are doing great things rather than saying we hope to develop that further. Even though there is public money said to be available for some of that work, I've seen no indication that Virgin Media plan to exploit it.

Source: John Cluny, Unpublished interview conducted by the author. Milton Keynes, 19 April 2012

The House of Lords Select Committee investigation that John Cluny refers to is considered in more detail in section 7.6 as part of the discussion of UK government efforts to deliver broadband to the UK areas which are currently without a broadband connection delivering minimum bandwidth of 2 Mbit/s. Although cable broadband is a strong contender in the areas where it is available by the end of 2012-13, given the cable industry's lack of participation in the Broadband Delivery UK (BDUK) bidding process (see section 7.6), the market share of cable broadband has remained relatively constant⁶. Its footprint of 50% coverage across the UK has also

⁶ The number of end-users on cable broadband has grown from 3.4M in 2007 to 4.3M in 2012. During this time, the number of LLU ADSL end-users grew from 3.7M to 8.8M. The total number of end-users on some form of DSL connectivity grew from 12.4M to 16.3M. See Ofcom (2013b) for more details. The limited growth in cable broadband adoption is striking given that as discussed in chapter 6 (see footnote 9), even as of 2001-02, 8.8M homes could potentially receive cable broadband connectivity.

remained relatively unchanged since the early 2000s. The absence of a real push from the cable industry at an early stage of the nascent broadband market in the early 2000s and the lack of expansion in the late 2000s proved crucial in the comparatively rapid deployment and adoption of DSL throughout the 2000s. Despite the limited market share of cable broadband and the extent of problems faced by the cable operators however, the competitive pressure from cable and its early lead in broadband connections played a key part in influencing the choices made by BT in relation to DSL broadband. As Mike Pemberton, who worked with Cambridge Cable in the late 1990s, points out:

[...] I am sure they [BT] would have had ADSL worked out in terms of what to do with it as a technology for many years, probably [by] early to mid-1990s [BT would have had a better idea of ADSL's capabilities]. Because of the good revenue from dial-up, they would have had no impetus to start deploying it until cable started to push them along.

Source: Mike Pemberton, Unpublished interview conducted by the author.

London, 10 February 2012

However, as the next section discusses, BT's shift from dial-up to DSL was not entirely due to the competitive pressure from the cable industry. Additional factors related to change in corporate strategy and regulatory policy about local loop unbundling were also at work.

7.4 BT's tentative investment in DSL and an overall shift in approach

BT had accumulated £27.9B worth of debt by the financial year 2000-2001 as a result of which its financial position had become difficult (BT, 2001b). In response to this debt, a significant restructuring took place in BT in the early 2000s. A number of BT's forays into the markets outside the UK were curtailed to refocus its operations on the UK market⁷. Although BT was not the leading retail ISP in the dial-up market, the wholesale unmetered Internet access business was dependent on BT's ubiquitous copper PSTN infrastructure⁸. As a result, BT's position regarding expanding its DSL trials into wider deployments across the UK was undecided. Part of this indecision was attributable to the way DSL connectivity was to be implemented.

7.4.1 The role of cost in DSL deployment

Gavin Young, who worked at BT during the DSL trials and then at Bulldog, one of the first OLOs to actively pursue unbundling, highlights the extent to which BT's

⁷ BT demerged its wireless business and a new company named mmO2 was formed in November 2001 (BT, 2002b). BT also unwound Concert, its venture with AT&T (BT, 2002a). BT disposed of Yell, its directories and e-commerce business, and its interests in Japan Telecom and J-Phone, and Airtel in Spain for close to £7B (BT, 2002a). In 2003 BT sold off its stake in Cegetel, France for £2.6B (BT, 2003a). Around the same time BT also sold its stakes in BSKyB, Mediaset, Blu, and SmarTone (BT, 2003b). This led to a significant reduction in BT's debt from £27.9B as at 31 March 2001 to £9.6B as at 31 March 2003 (BT, 2003a).

⁸ BT was required to provide Wholesale unmetered access in the form of FRIACO to other network operators as part of an Oftel Directive in May 2000. This directive was part of Oftel's efforts to regulate the prices and competition in the dial-up access market. See Oftel (2001a).

focus on end-to-end control and insistence on quality of service played a part in the uncertainty over DSL implementation in the following two quotes. The first of these relates to the way in which equipment would be installed at end-user premises:

In the early days of ADSL, BT believed that a master splitter needed to be installed at the customer's premises to get a quality connection in the home network. But that was expensive due to the need for an engineering visit. BT was sceptical of microfilters [which provided two separate sockets for the phone signal and broadband signal to ensure that the signals did not interfere with each other] since they did not provide similar quality of service. However microfilters did not need an engineering visit, end users could do it themselves. The cost of provisioning was significantly reduced and then the volumes went up. The compromises in quality were offset by lower deployment costs. That was pretty significant in that it underlines that it is not about the most perfect technical job but it is about the best overall proposition for the customer in terms of technology and cost.

Source: Gavin Young, Unpublished interview conducted by the author.

London, 01 February 2012

The above quote shows the extent to which the role of cost continued to play an important part in the deployment of DSL-related technologies and equipment. In the following quote, Gavin Young talks about the extent of debate over ATM vs. Ethernet in BT (see chapter 6 for a discussion on ATM vs. Ethernet) and how cost was again an influencing factor in the final decision:

Another view within BT was that ATM25 interfaces were needed and Ethernet was considered a broadcast domain. Ethernet was considered too uncontrolled and there were concerns about quality. A lot of the early BT trials used the ATM25 interface. [...] there was a big debate about ATM vs. Ethernet not as a main layer in the network but in presentation to the customers. Eventually it came down to cost. Ethernet was much cheaper and ubiquitous. Thus ADSL modems with Ethernet were significantly cheaper than those with ATM25. As Ethernet moved from 10 Mbit to 100 Mbits, throwing bandwidth at it wasn't so much of an issue.

Source: Gavin Young, Unpublished interview conducted by the author.
London, 01 February 2012

Since the lower cost ADSL solutions relied on IP technologies and packet switching (instead of ATM which the telcos preferred), it was considered to lack the kind of quality of service capabilities that the telcos emphasised. In addition, the prevailing telco model of charging end-users per minute (i.e. based on volume and subscription of services) did not apply effectively to charging for data (Maxwell, 1996; 1998). In consequence, the telcos needed to rethink their existing approach for billing of services in relation to Internet/Web access. The result was that while BT remained uncertain and cautious about the choices in relation to the equipment it needed to deploy for its DSL kit, by the early 2000s some of the early broadband access market was cornered by the cable operators (see footnote 2), and the increase in dial-up connections and demand for bandwidth was doubling every 10 months

(O'Reilly, 2005). As discussed in chapter 6 (section 6.6.3), by 1999-2000, broadband connectivity and its economic implications had become an important part of government and hence regulatory policy⁹. The Oftel (1999b) consultation for Local Loop Unbundling (LLU) 'Access to Bandwidth: Delivering Competition for the Information Age' considered various technologies in the fray such as DSL, cable modems, broadband wireless, third generation mobile, and even digital TV networks for delivering broadband connectivity. Given Oftel's stated policy of enabling competition to deliver best results across different market segments, this meant Oftel looked to enable competition within the local loop. To lessen the influence of BT's dominant position in the last mile, Oftel's solution was to drive growth in the broadband market through LLU.

7.4.2 The regulatory pressure of unbundling

With LLU, part of Oftel's aim was to reduce BT's influence in the last mile by allowing other line operators access to BT's exchanges and thus part of the access network from the exchange to the end-user's premises. Oftel (1999b, 2001b) hoped that this would lead to increased investment in copper DSL or potentially higher bandwidth technologies such as optical fibre. While the regulatory debate for LLU continued in the form of various consultations, BT's previously foundering approach to DSL deployment started to change. David Clarkson, a policy director at Ofcom, offers a more competition-orientated perspective to BT's motivations in the quote below:

⁹ The stated goal was for the "UK to have the most extensive and competitive broadband market in the G7 by 2005" (Oftel, 2001b, p. 3). G7 refers to the group of seven developed nations – US, UK, France, Germany, Italy, Canada, and Japan.

BT's real drive to start offering broadband was maybe in part due to the fear of LLU beating them to the market and the fact that cable were starting to offer their broadband services.

Source: David Clarkson, Unpublished interview conducted by the author.
London, 27 January 2012

The problem, as Sandbach and Durnell (2002) state, was not only with the pricing of the unbundling product offered by BT but also the way access was being provided to the BT exchanges. The term 'central office' means 'local exchange' in the UK context:

... in the UK, BT was able to provide itself preferential access to central office collection space for its own DSL equipment, while competitors were forced to apply to a tortuously long process that allocated space on a piece-meal basis, and initially excluding the most popular sites. This made it impossible for competitors to plan a nationwide network giving the incumbent a significant first-mover advantage.

Source: Sandbach and Durnell (2002, p. 26)

Effectively, the OLOs had to buy a certain capacity regardless of their needs and actual number of end-users signed up which meant that getting connection to BT exchanges was not delivering any returns to the OLOs compared with buying

capacity from BT wholesale. This meant that despite the best of regulatory intentions, the OLOs chose to rely on BT's wholesale broadband access products instead. As David Clarkson explains, the barrier to entry was very high for the OLOs:

Moving into 2000, the cable companies started to offer broadband products - quite expensive for that time. BT also started to offer DSL broadband - [which was also] quite expensive for the time. Take up was very low. The LLU process got bogged down in quite a lot of detail. Actually getting that process working on a mass scale was a very drawn out and painful process for everyone involved. Given the relatively high fixed costs of entry, even if you were going to use BT's [local] loops, you needed to purchase and deploy at a lot of sites, you needed to build the backhaul network.

Source: David Clarkson, Unpublished interview conducted by the author.

London, 27 January 2012

Part of the slow demand for broadband in early 2000s was due to the large number of end-users on dial-up modems and low-cost, unmetered access in a highly competitive dial-up market¹⁰. As a result of the early high pricing of DSL¹¹ and given the risk of cannibalising its wholesale dial-up revenue, despite the regulatory attempts to build market pressure, BT's DSL deployment did not pick up pace until

¹⁰ With 400 ISPs, 10M homes and 2M SMEs using dial-up, the market was arguably saturated even as of November 2001. See Oftel (2001a).

¹¹ The average monthly cost of DSL for residential and small business end-users in November 2001 was £40 (Oftel, 2001a). In contrast, the average cost of a FRIACO-based, fully unmetered narrowband connection was £12.99 – £14.99 per month (see Oftel, 2001a).

a change in management at BT. BT's approach to DSL changed in 2002-03 for two main reasons. The first one was the decision by the management team headed by Ben Verwaayen to focus on broadband as a product and the second was the decision to initiate the DSL registration scheme. Both these decisions played a key part in strengthening the prevailing market conditions that consolidated the choice of DSL as a broadband technology.

7.4.3 Focus on DSL broadband and the DSL registration scheme

As of 2000-01, despite the European Commission (EC) Directive 1999 (as part of the 1999 Communications Review i.e. COM(1999)539. See EC, 1999), price caps had remained in place on BT's retail and wholesale telephony services products. This meant that when Ben Verwaayen became the chief executive of BT in 2003, the possibilities of further revenue growth in fixed-line telephony services were very limited¹². As noted in chapter 5, the price caps despite being mostly targetted at BT's retail and telephony business, had also influenced the telephony revenues of non-BT operators. In the following quote, Richard Feasey, who was then working in the cable industry, talks about how the revenue squeeze on BT's voice business (due to the continued price caps) influenced not only BT's but also the cable operators' position regarding non-voice revenue streams such as broadband:

¹² Not only were BT's prices for the retail and wholesale telephony services capped by Oftel (see chapter 5 and 6 for a discussion on the RPI-X price regulation), combined with the growth in competition (more than 200 licensed operators. See Oftel, 1998), the potential for growing revenue on telephony services was also diminishing since mid-1990s. Given such a context, the revenue from dial-up access in the form of the wholesale FRIACO product was important for BT.

The biggest driver for BT and to some extent the cable companies was that the regulator drove down the profitability of their traditional [voice] business. That, in a sense, forced BT to find new revenue streams. The whole issue of broadband and mobile data to some extent is [about] companies that find their legacy businesses under threat. And therefore need to go and find [and] innovate new technologies to build new businesses. BT would have never gone into broadband at least not as early, if its existing narrowband voice businesses had not been under pressure.

Source: Richard Feasey, Unpublished interview conducted by the author.

Milton Keynes, 26 April 2012

In addition to the continued pressure on BT's voice revenue, BT's finances were further affected by the 3G spectrum bidding war that had earned the UK treasury £22.5B (see chapter 6, section 6.6.3). Despite having acquired a costly 3G spectrum licence for £4.03B in 1999-2000, BT had to demerge its mobile services division Cellnet as part of its debt restructuring plan¹³. The demerger of BT's mobile services division meant that BT lost out on the revenue in the mobility segment of the market which grew rapidly in the latter half of the 2000s with the availability of smartphone devices¹⁴. Ben Verwaayen, who was the BT Chief Executive Officer (CEO) from 2003-2008, puts the impact in perspective:

¹³ The demerger was completed in November 2001 when mmO2 plc was created and operated under the "O2" brand (Curwen, 2009). In 2005, Telefónica, the Spanish Telecommunications operator agreed to buy mmO2 and BT Group's mobile business in the Europe for £17.7B (Curwen, 2006).

¹⁴ The extent to which BT lost out on revenue can be understood by the fact that mobile operators accounted for 41% of UK voice minutes by 2007 and as a result precipitated a major portion of the decline in fixed-line voice calls (BT, 2007). The number of active mobile end-users (pre-paid + post-

It was not out of luxury that BT had to sell its mobile business. It came out of the Internet crisis like many other players in 2000. It [BT] had to restore the balance sheet. It [BT] had to sell what it had. I came there to restore order afterwards. It was a drama. Not having the mobile assets has been, since then, a big, big issue [for BT].

Source: Ben Verwaayen, Unpublished interview conducted by the author.

Milton Keynes, 14 February 2012

As the Head of wireless strategy in a European communications multinational (name anonymised at the participant's request) discusses, coupled with the loss of BT's mobile services division, its difficult financial situation dictated its choices regarding a broadband technology such as optical fibre significantly:

... they [BT] sold their mobile arm so they didn't have the profit from wireless to invest in fibre. BT was not far from bankruptcy only a few years ago. It was only 3 or 4 years ago that the deficit on their pension fund was larger than their market cap [i.e. market capitalisation]. They were almost junk bond status in investment worthiness. BT was in serious trouble. They had a new CEO [Ben Verwaayen] who was under a lot of pressure to cut costs and they simply could not make the investment case for fibre. Both their equity investors and the debt

paid) were above 40M as early as 2001 and had grown to 54.7M by 2004 (Ofcom, 2004a). The total mobile revenue grew from £1.9B in 2001 to £2.8B by 2004 (Ofcom, 2004a). During this period, the Average Revenue Per User (ARPU) was £20+ per month for Vodafone, £15+ for O2, T-Mobile, and Orange (Ofcom, 2004a). As a result of the Cellnet demerger, BT effectively lost out on this growing segment of the market and the revenues.

market were quite likely against it. Even if you were talking about fibre-to-the-curb investments, with tens of billions, they couldn't get the money.

Source: The Head of wireless strategy in a European communications multinational, Unpublished interview conducted by the author. Milton Keynes, 12 March 2012

The result of such a difficult financial situation was that although the technology for DSL broadband had been tested, trialled, and piloted successfully throughout the 1990s¹⁵, for cash-strapped BT, even the investment in DSL, which cost far less than optical fibre to deploy, needed to be justified¹⁶. In the following quote, Ben Verwaayen himself comments on the market conditions and BT's position vis-à-vis broadband:

¹⁵ As discussed in chapter 6, BT conducted trials for DSL throughout the 1990s. Its earliest trials were in 1992-93 for DSL as a means to deliver video-on-demand service. The trials for DSL to deliver broadband Internet access first took place in 1997-98.

¹⁶ Although the demand for DSL broadband had started to pick up in the US and Western Europe, in 2001-02 a strong precedent for financially viable DSL broadband offerings had not been established. Nor were the business models in terms of pricing of the products clear. See Maxwell (1998) for an engaging discussion on the nature of market that was expected to emerge with the deployment of residential broadband solutions based on DSL.

First of all, when I arrived, there was no broadband, only a handful [of end-users]. [...] At that point of time, there was no other choice to be made. [...] Copper was the only game in town. DSL was an innovation at that point in time.

Source: Ben Verwaayen, Unpublished interview conducted by the author.

Milton Keynes, 14 February 2012

The result of this focus on broadband was a public declaration as part of which BT proclaimed that it would achieve 5M end-users (retail and wholesale) by the year 2006 (BT, 2002a). Prof. Andy Valdar, who was then part of BT's network strategy and planning team, discusses BT's position, the ongoing impasse over the business case for DSL deployment, and the impact of Ben Verwaayen's arrival in the quote below:

... It wasn't until Ben Verwaayen came in as a new CEO from Lucent [that things changed]. [...] BT was behind the rest of the world now in rolling out broadband. BT may have led technically but commercially it was well behind. BT had a terrible reputation as a result of that. There were political rumblings and so on. He [Ben Verwaayen] said we [BT] are just going to roll it out. [...]. Credit to him for doing that. What's more, [he said] we are going to roll out 4 million lines in the first year, 20 million lines by such and such time. People were incredulous at the audacity of it. But it happened.

Source: Andy Valdar, Unpublished interview conducted by the author.

London, 18 April 2012

Although the success of DSL broadband in hindsight seems a foregone conclusion, at that time whether a DSL broadband product would find end-user acceptance at a sustainable margin for the operators was the key question. The significantly higher price for DSL over dial-up (see footnote 4) meant BT was unsure whether end-users would be willing to pay a premium for the advantages of high-bandwidth broadband connectivity. The need to justify such an investment in DSL rollout was partially solved by BT's DSL registration scheme. The DSL registration scheme required end-users within the exchange areas identified by BT to register their intent to subscribe to the broadband product if the exchange was DSL enabled. The trigger levels for enabling an exchange were set from 200 to 750 end-users depending upon the exchange area (Of tel, 2002c). BT had committed to enabling exchanges for broadband connectivity subject to 75% of registrations being converted to orders (Of tel, 2003a). As it turned out, the demand for broadband connectivity surpassed BT's expectations¹⁷ and in some cases posed unforeseen challenges.

7.4.4 Bypassing optical fibre and a business case for broadband

One of the most interesting developments when BT began the rollout of DSL to its exchanges for wholesale and retail provision of broadband was in relation to

¹⁷ More than 560,000 potential end-users registered for the BT ADSL registration scheme by September 2003 (Of tel, 2003c). This indicated a potential 50% increase in the number of end-users which in September 2003 were at 1,380,000 for DSL broadband.

housing developments built during 1980s. These housing developments were connected to their exchange by optical fibre (although the exact details are unclear from the available documents, these optical fibre deployments were most likely a form of Telephony over Passive Optical Network i.e. TPON solution. See Stern et al, 1998 for BT's approach to TPON solutions in the late 1980s). BT's initial trials revealed that end-users in such households could not get broadband because optical fibre did not support ADSL technology. BT's solution to deliver broadband connectivity to such end-users was to bypass the optical fibre through the use of copper (see Oftel, 2003b).

David Brown, the former Head of Schema, a noted telecoms consultancy, also mentions the unusual nature of this scenario in the following quote:

... This brings to attention peculiar environment requirement for end-users that had DLL [Digital Local Loop]. In this case, if you [the end-user] had a digital service - Fibre-to-the-home, you couldn't get DSL because there was no copper in the local loop. As a result, despite the presence of fibre to the home, copper had to be retrofitted in such areas so that customers could get broadband connectivity.

Source: David Brown, Unpublished interview conducted by the author.

Hemel Hempstead, 13 December 2011

Despite some of the challenges however, the DSL registration scheme started in 2002 clearly established an end-user demand and also provided a business case for

BT and non-BT operators. The success of the registration scheme in terms of signing up end-users meant that by 2004, BT discontinued the scheme and unveiled a plan to install DSL equipment in all the exchanges that could be technically enabled (BT, 2004). The importance of the registration scheme to BT's plans is underlined by the Head of wireless strategy in a European communications multinational (name anonymised at the participant's request) who commentates on BT's approach in the following quote. He also provides a more commercial context to the way cable industry was working, the financial viability of DSL, and unbundling:

[...] They [BT] innovated very cleverly with that registration scheme. That [scheme] kind of guaranteed demand before investment, which was a smart move [on the part of BT]. [...] Cable stopped investing in capacity just at the time BT was rolling out DSL probably. And then soon after that unbundling came, which stimulated even more investment.

Source: The Head of wireless strategy in a European communications multinational, Unpublished interview conducted by the author. Milton Keynes, 12 March 2012

Thus BT's DSL registration scheme allowed it to hedge its position with regard to its shareholders and the regulator. To the shareholders it was a way of demonstrating demand (or lack of it) and hence justifying deployment of DSL kit to the exchanges. To the regulator it was a way of demonstrating BT's commitment to delivering broadband subject to end-user demand reaching a specific threshold. On the one hand, the DSL registration scheme facilitated a rapid deployment of DSL kit to the

existing exchanges¹⁸ thereby accelerating the availability of broadband Internet to 99.6% households by 2007 (BT, 2006b; 2008). On the other hand however, BT held significant market power in both retail and wholesale broadband markets by 2005-2006. This meant that although the consolidated cable industry in the form of Virgin Media offered vertical integration and quadruple play capabilities of delivering voice, data, video, and mobility services that BT lacked¹⁹, the market was deemed to be over-dependent on BT's wholesale DSL product by Ofcom, the regulator newly appointed in 2003 (see next section). The result, as the next section covers, was the re-introduction of LLU coupled with BT's functional separation that further fuelled the investment in DSL broadband.

7.5 Creation of Ofcom, second round of unbundling consultations, and functional separation

As detailed in chapter 6, by the end of 1999-2000, the European Commission Directive (as part of the 1999 Communications Review i.e. COM(1999)539. See EC, 1999) had come into effect, as a result of which the restrictions on BT regarding provision of television/broadcasting were removed. In the light of the increased

¹⁸ At the start of the registration scheme, the number of UK households covered by DSL was 66% with 1115 exchanges being DSL-enabled (OfTel, 2002b). By September 2003, the availability of DSL had increased to 80% with 1708 exchanges being DSL-enabled (OfTel, 2003c). The scheme ran until 2004 and based on 860,000 registrations, BT enabled 2,652 exchanges for broadband by 19 May 2004 (BT, 2004). By March 2006, BT had upgraded 5501 exchanges and 99.6% of UK homes and businesses had access to broadband (BT, 2006b; 2008).

¹⁹ Virgin Media continues to leverage its quadruple-play capabilities and the strength of its cable network to drive competitive pressure on BT's broadband offerings. See Fry, Kelly, Romero, and Johnstone (2012) for a more commercial perspective on Virgin Media's strategy in relation to broadband.

convergence of voice, data, and video services²⁰ and the extent to which the boundaries between these market segments had been blurred due to the growth in the Internet, the possibility of merging various regulatory functions associated with telecommunications, cable, broadcasting, and wireless communications began to be considered (see Oftel, 1999a). At the conclusion of a consultation on the convergence of various regulatory functions, in 2003, a single regulatory body for overseeing the communications industry, the Office of Communications (Ofcom) was created (Oftel, 2003d).

Between 1999 and 2006, BT's DSL product offering had grown substantially to cover over 99% of the UK market. Starting with 100,000 end-users in November 2001 (Oftel, 2001a), the total number of DSL end-users had grown to 2.8M as of second quarter (Q2) of 2004 (Ofcom, 2004a). As of June 2004, there were only 13,500 unbundled lines in the UK (Ofcom, 2004a). BT had the largest share of the wholesale broadband market with 60% of the broadband infrastructure provision (Ofcom, 2004a). The growth in DSL numbers and the lack of uptake in unbundling had meant that Ofcom perceived the broadband market as being over-reliant on BT. Given BT's position; the need to accelerate unbundling was strongly felt in Ofcom. The result was a consultation named 'Strategic Review of Telecommunications' which the next section discusses in detail.

²⁰ The convergence between voice, data, and video services continues to be important for operators given the possibilities it offers for revenue generation combined with broadband connectivity. See Murdock-Smith et al (2010) for the perceived potential of convergence from the perspective of financial markets.

7.5.1 The Strategic Review of Telecommunications - Phase 1 and 2

The Strategic Review of Telecommunications (often shortened to Telecoms Strategic Review i.e. TSR) was conducted in two phases of consultations as a result of which Ofcom could have recommended a structural separation of BT's retail and network operations to the Competition Commission²¹ (previously Monopolies and Mergers Commission) (Ofcom, 2004b; 2004c). Thus if the structural separation had taken place, BT Group would have no longer owned the UK-wide core and access network it had inherited as a former monopoly – a critical part of its significant market power in the UK market. This possibility of structural separation was averted when an agreement was reached between Ofcom and BT to functionally separate the retail and network operations so that other line operators were provided with an equal access to BT's network without any priority, privilege, or preference to BT's own retail division (BT, 2006a; 2006b; Ofcom, 2006. See Whalley and Curwen, 2008b for a discussion on Ofcom's approach). BT's network operations were thus separated under a new division named Openreach.

In addition to the creation of Openreach, Ofcom unveiled a number of initiatives including a bulk migration process from BT's wholesale broadband products to LLU and price reductions for unbundled local loops. As a result, not only did the investment in broadband access infrastructure accelerate, the competition within the retail broadband segment of the market also grew significantly. Although there were only 70,000 unbundled lines in the UK as of June 2005, by March 2006 the

²¹ See Cadman and Carrier (2002), Cave (2002), and Xavier and Ypsilanti (2004) for a more detailed discussion on the merits and demerits of structural separation. See Whalley and Curwen (2008a) for a discussion specific to BT's functional separation.

number of unbundled lines had grown to 360,000 (Ofcom, 2006). Unencumbered by BT's first-wave ADSL-based services, LLU operators such as Bulldog, Easynet, and Be had begun to offer ADSL2+ based connections with bandwidths up to 24 Mbit/s (Ofcom, 2006). Mike Pemberton, now working with Sky Network Services, one of the biggest LLU operators in the UK, suggests that this was due to the way in which the approach of the LLU operators differed from BT's:

At the time Openreach was created, while there was some LLU, it wasn't having much impact on the market. [...] There were services available before that but BT had got a frustratingly cautious approach to introducing new technology. They would have probably just been launching ADSL2+ now [in 2012] if the LLU operators hadn't turned up in 2006 and started to put ADSL2+ kit in the exchanges. Whereas BT's approach is to wait for every standard imaginable to be complete, wait for years and years of test events that reach 99% test success before they consider deploying technology. They were probably three years behind the LLU companies in deploying ADSL2+.

Source: Mike Pemberton, Unpublished interview conducted by the author.

London, 10 February 2012

Mike Pemberton's comment about the role of unbundlers in relation to quicker introduction of ADSL2+ is also echoed by Gavin Young, who previously worked with BT and then with Bulldog, one of the first LLU operators who beat BT to the introduction of ADSL2+ (Ofcom, 2006). In the following quote, he underlines Mike

Pemberton's comment about BT's cautious approach to technology, particularly in relation to DSL:

I remember in the early days of ADSL, one of the BT directors in a volume control schedule, which is a projection of forecast, said that we [BT] will only ever sell 140,000 DSL lines in the next 10 years. [...] And yet, LLU operators worked with a different view and looked to provide Internet connectivity with DSL.

Source: Gavin Young, Unpublished interview conducted by the author.
London, 01 February 2012

However, an additional, and more important outcome from the regulatory perspective, was the increased competition for broadband in the retail space as the next section covers.

7.5.2 Competition in retail broadband market and the problem of the Final Third

Prof. Martin Cave, a noted regulatory economist, sums up the effect of the second round of unbundling and the functional separation of BT's network and retail operations in the following quote:

Because of those two changes [second round of unbundling and functional separation] at the same time, it is difficult to say which one was decisive or

whether both were required in order to get the unbundled local loop market taking off the way it did. But it certainly did take off and there is no doubt that the unbundling of local loop gave competitors the opportunities to differentiate their products and to offer higher speeds. The rest is history with BT now having about 25% market share with cable [also] having quite a big stake. Unbundlers collectively having the largest share, I think about 50% between them. Unbundled local loops became the principal medium for the introduction of competition into the fixed market.

Source: Martin Cave, Unpublished interview conducted by the author.
Milton Keynes, 02 April 2012

The competition in retail broadband market had been possible because as a result of the Strategic Review of Telecommunications the terms for unbundling were finally favourable to the LLU operators. Mike Pemberton, working with Sky Network Services, describes the extent to which the creation of Openreach proved helpful to the unbundlers and the way the revenue margins improved for the unbundlers in the following quote:

It was that point in 2006 onwards [after the creation of Openreach] when Sky and TalkTalk, Tiscali and various other companies began looking at the LLU business case. [...] By doing the voice service with your own infrastructure instead of taking the WLR [Wholesale Line Rental] voice services from BT then you [the OLO] got to charge line rental and could make a small margin on

that. This way you had the voice revenue and the broadband revenue. It was a brilliant business case which is still working today.

Source: Mike Pemberton, Unpublished interview conducted by the author.

London, 10 February 2012

The increased viability of building their own local loop meant that there was increased competition and the investment by OLOs. By 2009, TalkTalk, Virgin Media, and BT Retail had similar market share within the retail broadband space with Sky also registering double digit market share²². The outcome was that the broadband tariffs continued to reduce in favour of the end-user²³ and provided further incentives to DSL broadband adopters. By this time, the near universal adoption of the IEEE 802.11 WiFi standards (see IEEE Computer Society, 2012a) in devices such as laptops, mobile phones, and customer premise equipments (CPEs) had made broadband adoption an easier and more attractive prospect for end-users. The improvements in the 802.11 standards and the increased availability of wireless connectivity via WiFi hotspots provided an important benefit for the growing number of end-users. The reliance of these WiFi hotspots on DSL broadband combined with the increased demand and competition was one of the factors that led to the introduction of ADSL2 and ADSL2+ products. Effectively, the average

²² In 2009, the market share in the retail broadband segment for BT, Virgin media, TalkTalk, and Sky was 25.9%, 22.5%, 24.7%, and 12.4% respectively (Ofcom, 2009).

²³ The average monthly cost of DSL for residential and small business end-users in November 2001 was £40 (Ofel, 2001a). The average monthly cost of DSL for residential and small business end-users in September 2003 was £22-£24 (Ofel, 2003c). By 2013, when bundled with landline (excluding line rental) the monthly costs were as low as £5.99 depending on the contract length, bandwidth, and data usage (Ofcom, 2013b).

actual residential broadband bandwidth in the UK increased up to 7.6 Mbit/s by November 2011 (Ofcom, 2009; 2011b; 2012a).

Given the growth in bandwidth, lowered tariffs, and increased competition, Ofcom's policy of introducing competition via LLU had achieved its intended purpose. However, despite the growth in broadband deployment, a significant portion of the investment had been in urban and semi-urban areas, covering only two thirds of the UK. This problem was highlighted in 2009, as part of the UK government report titled 'Digital Britain' which stated the ambition of having 100% broadband coverage in the UK by 2012, with a minimum bandwidth of 2 Mbit/s (BIS, 2009). The report also introduced the term the 'Final Third' i.e. the remaining one third, mostly rural areas of the UK that were not only commercially unviable to rollout broadband connectivity but also did not have 2Mbit/s minimum bandwidth. The result was Ofcom consultations to unlock the potential of wholesale broadband access in the rural market along with the UK government-led initiative to fund deployment of next generation access (NGA) to the Final Third. The next section considers these initiatives and the extent to which these are likely to influence DSL's position as the most widely used technology to deliver broadband connectivity.

7.6 The push for next generation access (NGA)

Despite the generally high levels of competitiveness of the UK retail broadband market, regulatory concerns remained about the low level of competition in

wholesale broadband access²⁴ and about the poor provision of broadband to the Final Third (Ofcom, 2010a). In order to boost investment and encourage competition, Ofcom conducted a consultation in 2010, and another consultation was scheduled for completion in September 2013. In 2011, Ofcom revised price caps for BT wholesale broadband products in rural areas where BT was the only broadband provider with exchanges in order to encourage competition (Ofcom, 2011a). The intent in reviewing the wholesale broadband access market was three-fold (Ofcom, 2013a) -

1. to assess significant market power based on ownership of exchanges in particular areas,
2. to assess the availability of a broadband product from more than one operator, and
3. to pursue remedies that will deliver best prices for end-users along with a choice of service providers.

Ofcom's focus on the wholesale broadband access market reflected a wider emphasis on broadband provision and improving bandwidths which also led the UK government to launch an initiative called "Broadband Delivery UK" (BDUK) independently of Ofcom.

The BDUK initiative was put together *"to provide superfast broadband to at least 90% of premises in the UK and to provide universal access to standard broadband with a speed of at least 2Mbps"* (DCMS, 2013). On a different front, an ambition to

²⁴ As defined in the "Review of wholesale broadband access markets", *"WBA [Wholesale Broadband Access] products offer the opportunity to enter the broadband market without the need to deploy an access network ..."* (Ofcom, 2013a, p. 7).

extend the length of optical fibre network and deliver superfast/ultrafast connectivity²⁵ was visible in the investigation carried out by the UK's House of Lords Select Committee on Superfast broadband in 2012 (see House of Lords Select Committee, 2012 for more details). The aim of the Select Committee investigation was to consult the various stakeholders in the UK communications industry to decide the best way of achieving deployment of superfast broadband connectivity (i.e. bandwidths of 100 Mbit/s to the end-user premises) to 90% of premises in the UK by year 2015²⁶.

The push for higher bandwidths as targeted by parliamentary committees and Ofcom's intentions of pursuing competition in wholesale broadband access provision suggest that in the future the deployment of fibre will not be driven only by technical parameters. Policy imperatives of economic growth in the case of Ofcom and the UK government and strategic ambitions of outdoing competition in the case of BT as an incumbent are also likely to be important factors for more optical fibre deployment. However, despite this ongoing regulatory push for delivering broadband to the Final Third and the attempts to deliver next generation access in the form of fibre investment, the Ofcom Communications Market report 2013 shows that DSL is by far the most widely used broadband technology and will

²⁵ As the bandwidths have continued to increase, the definition of what constitutes superfast/ultrafast broadband continues to change. At the time of writing (late 2013), this is deemed to be 100 Mbit/s in the UK. See the House of Lords Select Committee (2012).

²⁶ Superfast broadband connectivity and its role in enabling better bundling of services and increased revenue for the operators is also perceived as being important from the perspective of the financial markets. See Murdock-Smith et al (2011) and Murdock-Smith (2012a).

remain so²⁷. The ability to deliver more bandwidth on the existing copper in the form of Vectored Very-high-bit-rate DSL (VVDSL), Gigabit DSL, and G.fast solutions, and advanced techniques such as Dynamic Spectrum Management (DSM), means that bandwidths up to 1 Gbit/s are deemed possible on very short copper loops (Cioffi and Ginis, 2002; Lee et al, 2007; Timmers et al, 2013). As a result, any introduction of optical fibre in the last mile and to the end-user premises is likely to be further delayed. With the improvements in copper DSL capabilities, Prof. John Cioffi has argued that DSL remains viable for some time to come:

As long as sufficiently high speeds can be achieved on copper, it [DSL] makes better sense. With latest DSL technologies getting to 100s of Mbps connections for far less investment, DSL then remains the financially more attractive path.

Source: John Cioffi, Unpublished interview conducted by the author. Milton Keynes, 15 December 2011

Ironically, given the significant extent of investment in next-generation of DSL technologies by OLOs and the intense competition for broadband in the retail space, the current scenario makes optical fibre a very viable choice for BT from a competition point of view²⁸. This is because fibre cannot be physically unbundled

²⁷ Out of the total 21.7M fixed-line broadband connections in 2012, 8.8M were LLU ADSL, 7.5M Non-LLU ADSL, 4.3M were cable and 1.1M were Other (including FTTx). Effectively ADSL (LLU and non-LLU) accounted for 75% of the connections. Cable accounted for nearly 20% of the broadband connections. See Ofcom (2013b).

²⁸ The availability of a wholesale fibre broadband product from BT could have important implications for its competitors depending on how it is priced. For a perspective from the financial markets see Fry, Kelly, Kerven, and Johnstone (2012).

like copper. Although solutions such as wavelength unbundling (Hoernig et al, 2010) are being developed, the deployment of fibre itself can take different forms such as point-to-point (P2P) fibre, Gigabit Passive Optical Network (PON), and Wavelength Division Multiplexing (WDM) + PON²⁹. Of these, as of early 2014, only WDM + PON offers the option for wavelength unbundling in a practical manner. However, unlike GPON solutions (which more than handle today's end-user requirements), WDM + PON solutions are not yet viable for mass-market deployments (Hoernig et al, 2010). The result, as the Head of wireless of operations in a European Communications multinational suggests, is that the economics do not favour fibre deployment despite the advantages it may have in a competition-orientated context:

If you think about it strategically, BT wants to invest in fibre. Look at their competitors. Their competitors in the retail broadband sector are the unbundlers. The unbundlers have put a whole load of investments into copper plants and DSLAMs [DSL Access Multiplexers]. So if BT builds a fibre network, they essentially strand the investment of their competitors. [...] the best thing BT could do to hurt CPW [CarPhoneWarehouse, the owner of TalkTalk, one of BT's biggest competitors in the retail broadband space] is to start building fibre. Because that means all these DSLAMs are stranded and wasted as an investment. So strategically BT wants to have superior infrastructure. They want to move to a new technology that cannot be unbundled. But they just

²⁹ The difference between Point-to-point (P2P) fibre networks and passive optical networks (PONs) is that PONs used shared optical fibres to lower deployment costs. In contrast, a P2P fibre network provides a dedicated fibre connection to each end-user's premises. See Hoernig et al (2010) and INCA (2012) for different configurations and architectures possible in a fibre network.

don't have the money to do it. Arguably the business case is [still] very difficult to make.

Source: The Head of wireless strategy in a European communications multinational, Unpublished interview conducted by the author. Milton Keynes, 12 March 2012

The lack of a business case means that an important outcome of unbundling has been the consolidation of DSL as the prime means of broadband delivery, due to which investment in next generation DSL broadband technologies such as Very-high-bit-rate DSL (VDSL) has increased. The deployment of VDSL³⁰ relies significantly on Fibre-To-The-Cabinet (FTTC) solution as a result of which, although the deployment of fibre closer to the end-user premises is likely to happen, the likelihood of Fibre-To-The-House (FTTH) deployment remains very low. As the BSG report on next generation broadband "Pipe Dreams" (2007) suggests, despite the increase in fibre investment, the costs of deploying fibre to the end-user premises in the form of FTTH connections are astronomical. Quoting the Enders Analysis report "Very High Speed Broadband: A Case For Intervention", published in January 2007, BSG has suggested that the incremental costs per household are around €60 (£45) for ADSL₂₊, €300 (£250) for FTTC, and €1000 (£800) for FTTH. This suggests that the cost of delivering FTTH to even 90% of UK households is €14B. Effectively a patchwork of ADSL₂₊ and FTTC-VDSL deployments are likely to

³⁰ The average length of copper loop in a VDSL deployment is likely to be 300 to 1500 metres (BSG, 2007). Given that ADSL solutions still deliver connectivity to 75% of the UK premises (i.e. 16.2M connections. See Ofcom, 2013b), this suggests a significant length of the last mile will be connected by copper even with a rapid increase in FTTC-VDSL deployments.

be the most commonly deployed broadband configurations indicating a long reign for DSL as the most widely used technology to deliver broadband connectivity.

7.7 Discussion and Conclusions

As the events in this chapter show, despite its low cost of deployment, the growth of DSL as the most widely used broadband technology was not straightforward. Not only did BT's parlous financial circumstances play a part in DSL being strengthened as a choice, but the problems in the cable industry and its subsequent reluctance to expand its network also meant that a competitive alternative to DSL did not emerge. Throughout this time, the nature of investment in technology was driven by expected returns on investment in an increasingly competitive market. This focus on commercial returns can be understood in the way the regulatory push for local loop unbundling only succeeded after the terms for access to BT's exchanges were financially viable for the other line operators.

In the light of BT's lack of financial resources, the bankruptcies in the cable industry, BT's DSL registration scheme, and the regulatory policies of functional separation and local loop unbundling it can be seen that the emergence of DSL as the leading broadband technology in the UK is strongly associated with historical decisions and policies made throughout the 1980s and 1990s. The systemic nature of the communications industry combined with the need to maximise investments in physical assets such as network and equipment played an equally important part whether it was a question of extending the footprint of the existing cable network operations or deploying optical fibre in the access network given the continued

demand for higher bandwidths by end-users. In demonstrating this systemic aspect this chapter has continued the themes of chapters 5 and 6.

As section 7.7.2 analyses, the extent to which growth of DSL can be deemed path dependent can be understood by W. Brian Arthur's ideas about how once selected, the adoption of a technology can influence a number of the subsequent decisions related to its development and deployment. The extent to which DSL delivered increasing returns on an existing infrastructure asset is related to the manner which technology diffusion takes place in network industries such as telecommunications. As discussed in section 7.7.3, the adoption and deployment of DSL is increasingly seen to fit the bandwagon effect, a phenomenon as a result of which the benefits available to end-users who had DSL broadband connectivity continued to grow in line with the increase in the number of end-users on DSL broadband.

However, the role of government policy which actively favoured higher bandwidths and linked economic growth with broadband connectivity, needs to be considered first. The changes within the telco space due to the creation of Openreach and the unification of UK cable operations under the 'Virgin Media' brand also need to be analysed in order to understand the dominance of DSL as a broadband technology. The next section examines the changing dynamics of the marketplace and its role in the evolution of broadband technologies in detail.

7.7.1 Broadband as an instrument of government and regulatory policy

The unification of the regulatory bodies for telecommunications, broadcasting (terrestrial and cable), and wireless industry, and the subsequent focus on stimulating investment in broadband technologies via competition underlined the shift in the prevailing regulatory regime from voice/telephony services to the convergence of a wider set of voice, data, and video services. At the same time, a number of decisions related to stimulating investment in the broadband infrastructure were driven by the goals of economic growth and social inclusion. These goals were associated with high bandwidth connectivity. Whether it was the pursuit of local loop unbundling or functional separation, the regulatory instruments remained technology agnostic. The desire to achieve results by increased competition and delivering the best-possible price to the end-users was at the heart of local loop unbundling and functional separation. The influence of both these regulatory policies highlights Hughes' (1987) argument about the way rules of governance i.e. legislative artefacts influence the deployment and adoption of physical artefacts. The physical artefacts in relation to DSL broadband would be the various DSL technologies such as ADSL, ADSL₂, ADSL₂₊, the end-user equipment (splitters, modems, and routers), and the DSL kit installed at various local exchanges. The way in which functional separation shaped the choices of various OLOs and BT (i.e. organisations in Hughes' terminology) is also consistent with Hughes' position about the interaction between legislative artefacts and the organisations and the way it affects the evolution of a large technological system. For example, regulatory policies since the 1980s had long-term consequences for the deployment of DSL, coaxial cable, and optical fibre.

The goal of delivering minimum 2 Mbit/s bandwidth to 100% of the UK premises by 2012 (see the Digital Britain report for more details) via public funds in the form of BDUK, has played an important part in pushing NGA, such as fibre, and thus shaped how the market share of broadband technologies has evolved. The outcome was thus shaped not only by the technical merits, but also by commercial and political considerations of delivering broadband connectivity. As Hecht (2001) points out, in the hands of a technopolitical regime, technology is often an instrument to serve regulatory, political goals. Despite the liberalised nature of the UK communications industry, the pursuit of higher bandwidth and the technology-agnostic outlook adopted by the regulators highlight that the focus of the technopolitical regime was not centred on either the transmission technologies or the services themselves.

The regulatory push for unbundling and functional separation of BT was highly influential in the increased investment in next-generation DSL, such as ADSL₂ and ADSL₂₊. As David Clarkson explained in chapter 6 (section 6.6.3), the first round of unbundling was intended to stimulate investment in broadband infrastructure given BT's cautious approach to DSL deployment. Similarly the second round of unbundling was intended to stimulate competition because the market was considered overly-dependent on BT's wholesale DSL product. Each of these LLU decisions was an instrument for Oftel/Ofcom to achieve its goals of competition and achieving best possible prices for end-users. Although the creation of Openreach led to increased investment in ADSL₂ and ADSL₂₊ by OLOs, Ofcom policy decision was far from achieving a specific technological outcome vis-à-vis either optical fibre or

DSL – a situation which echoes Hecht's argument of how technopolitical regimes often work.

Given that it was cable broadband and not DSL which had an early lead in broadband connectivity, the outcome in favour of DSL also underlines the argument about the uncertainty of outcomes presented in chapters 5 and 6. Similarly the deployment of DSL equipment to exchange on the part of BT was also not a straightforward decision but a choice dictated by regulatory pressure and prospect of competition from cable. The testimonies of Ben Verwaayen, Andy Valdar, and the Head of Wireless strategy for a European communications multinational show that, the choice of DSL was a matter of balancing commercial imperatives against end-user demand. Although as the next sections discuss, historical contingency played an important in shaping the outcome, the result was dictated by not only the cost consideration that favoured DSL at an early stage but also the continued improvements in bandwidth capabilities for copper that even a decade earlier were not considered possible.

7.7.2 DSL as a commercially and politically expedient choice

The way in which the initial DSL adoption took place and then grew displays a form of lock-in, one of the causes of a path dependent outcome as discussed in chapter 3 (section 3.8). Once BT selected DSL as a broadband technology, the possibility of other alternatives being deployed was significantly reduced despite some of the limitations of DSL.

As presented by Arthur (1989; 1990) in his case study of VHS and Betamax (see chapter 3, section 3.8), the ideas of lock-in and increasing returns show how once a technology is in use, it not only delivers increasing returns but also does so at the cost of other technologies being introduced. As the narrative in this chapter shows, once selected, DSL not only delivered increasing returns but its adoption also slowed down deployment of optical fibre. The regulatory policies, although intended to spur investment in broadband infrastructure in a technology-agnostic manner, served to fuel next generation copper DSL such as ADSL₂, ADSL₂₊ being pushed to deliver better bandwidths. The improvements in signal processing, noise cancellation, and cross-talk management techniques furthered lock-in to DSL.

If the extent of DSL deployment by BT and then by the OLOs and how it commits them to DSL in the near future is considered, David's (2007) argument in the 'theory of framing conditions' is also very pertinent. In David's 'theory of framing conditions' he talks about how once a technology is adopted, it can create barriers to reversing the selection of technology. These barriers, whether due to social, economic or other reasons, make switching to other technologies difficult. David essentially discusses the idea of 'framing conditions' to highlight how historical choices can be crucial in relation to selection of technologies and furthers the notion of path dependent outcomes. Having selected DSL for deployment, BT and OLOs now find themselves in a situation where financial barriers exist if optical fibre is to be deployed. An additional barrier is that DSL solutions such as VVDSL, Gigabit DSL, and G.fast reduce the incentive for deploying optical fibre in the light of prevailing end-user demand.

Since in terms of bandwidth capabilities DSL was not always the best technology vis-à-vis optical fibre or coaxial cable/HFC, the role of factors such as regulatory decisions and technology improvements underlines that the outcome was not entirely dictated by technical attributes but cost implications and addressing end-user demand on short-term basis also played a part. The increasing returns possible on DSL can also be seen in terms of the bandwidth improvements delivered by next-generation DSL technologies such as ADSL₂, ADSL₂₊, and even VDSL (although VDSL bandwidth improvements are reliant on being coupled with FTTC solutions). As of 1997-98, the bandwidth of 24 Mbit/s (as possible with ADSL₂₊ now) would have been inconceivable for DSL-based technologies. However, the technical advancements in signal processing and modulation via techniques such as DSM have increased the returns possible on copper in an unexpected way.

Despite the insights offered by the concepts of increasing returns and lock-in, there seem to be a number of salient differences when Arthur's analysis of VHS vs. Betamax video cassette recorders and the outcome of DSL deployment is considered. The outcome of VHS vs. Betamax was largely a matter of consumer choice. If the case of DSL and other alternatives are considered, the end-users had a choice only in areas served by coaxial cable. The selection of DSL vs. other alternatives was a strategic choice by BT based on its financial condition, market expectations, and regulatory pressure. With the deployment of FTTC solutions, as the length of copper in the last mile is shortened that also increases its bandwidth capabilities of DSL as the development of VVDSL, Gigabit DSL, and G.fast shows. Thus where the quality of copper line is still good enough, fibre is unlikely to

displace it in the last mile. Even with fibre deployment, the returns possible on existing copper line continue to influence BT's choices.

Although being able to deliver higher bandwidths meant that DSL delivered increasing returns, in the early 2000s, the selection of DSL was partly due to the cash-strapped BT's inability to invest in an alternative like optical fibre. The need to reuse the existing copper assets in order to lower cost of deployment and achieve higher returns in line with the expectations of the financial markets also played an important part. Rosenberg's (1994) argument about the systemic nature of the communications industry and the manner in which very high cost of infrastructure investment dictates the technological choices is again very relevant in this context.

The selection of DSL was also aided by a lack of effective competition from coaxial cable. Coaxial cable, despite its technical merits, did not expand significantly beyond its existing UK footprint due to the financial problems in the cable industry during the first half of the 2000s. In the second half of 2000s, although a unified cable operator in the form of Virgin Media exerted significant competitive pressure on the telcos vis-à-vis the bandwidths and capabilities on offer, the cable network footprint still did not extend its previous presence of 50% significantly. The result was that when the share of broadband technologies in the last mile is considered, copper DSL has continued to hold significant share. The resulting share of coaxial cable/HFC in the last mile is a reflection of not only the technological capabilities of coaxial cable but also of the set of economic conditions, regulatory policies, and business decisions that shaped the UK cable industry.

7.7.3 DSL deployment and the bandwagon effect

The bandwagon effect in microeconomics refers to how the benefits of a product or service derived by an end-user increase in relation to the number of end-users who use the product or service (Leibenstein, 1950). In order to understand the importance of the bandwagon effect in relation to the adoption of DSL, the two types of outcome in which the bandwagon effect is manifested need to be considered – network externalities and complementary bandwagon effect. Discussed in detail in chapter 3 (section 3.7.2), network externalities result in increased demand for the products or services. In contrast, complementary bandwagon effects are crucial to increased supply of the products and services influenced by the bandwagon effect. In relation to the growth in deployment and adoption of DSL in the 2000s, both these types of bandwagon effect play a part in addition to the regulatory and financial factors that influenced not only the marketplace but also the end-users (see Deshpande, 2013 for a more detailed analysis of the events in the 2000s from the perspective of the bandwagon effect).

In relation to the events of the 2000s, the bandwagon effect can be evidenced in relation to BT's expansion of DSL capability into the exchanges. BT's cautious approach with the registration scheme mirrors Rohlfs' (1974) argument about using community of interest groups to achieve maximum (equilibrium) demand despite small size of initial user set. As it turned out, the registration scheme proved sufficient demand for broadband connectivity and once the rollouts began, the end-users signing up for the DSL product began to accumulate quickly³¹. Despite the

³¹ As of December 2001, the numbers of end-users on cable broadband and DSL were 196,000 and 136,000 respectively (Ofcom, 2002a). In July 2002, the number of end-users of cable broadband had

higher cost of a broadband connection compared to the existing dial-up products, the early adoption of DSL was partly driven by the fact that the telephone line remained available and the significantly higher bandwidth it offered over dial-up connectivity. With the goals for broadband rollout set by BT during Ben Verwaayen's tenure, the uncertainty around the financial viability of broadband deployment was over-ridden. Effectively the increasing number of end-user registrations led to wider DSL broadband deployments and resulted in a successful supply-demand side equation.

On the one hand, the network externalities can be understood by how the increased end-user registrations and subsequent take-up of broadband connections led to establishing the demand-side of the bandwagon effect. On the other hand, the subsequent deployment of next generation DSL variants and the ubiquity of WiFi show how the supply-side was strengthened in response to the increased end-user demand. This bolstering of the supply-side can be aligned with complementary bandwagon effects which resulted in increased availability of DSL broadband. This increased availability of DSL was also aided by BT's decision to pursue broadband deployment aggressively given the reduced margins on telephony services, regulatory pressure in the form of unbundling, and functional separation. An important influence on the demand-side was the continued growth in the end-user demand of higher bandwidth and better connectivity to the Internet/Web (see Haring et al, 2002 for an engaging discussion on the correlation between broadband

risen to 419,000 compared to DSL which had 290,000 end-users (Ofcom, 2002b). By September 2003, this trend had reversed. The number of DSL end-users had nudged ahead (and have remained ahead) to 1,380,000 to that of 1,232,000 for cable broadband (Ofcom, 2003c). In 2013, the number of residential and small business end-users on DSL (including BT, LLU, and non-LLU) were 16.3M compared to 4.3M for cable (Ofcom, 2013b).

Internet access and the bandwagon effect). An additional factor that led to growth in DSL deployment (supply-side) by BT and OLOs was the potential competition from a unified cable operation by Virgin Media which had the capability to offer not only higher bandwidths but also a vertically integrated product (see footnote 19). The effect was increased adoption (demand-side) by end-users due to not only lowering of retail broadband prices (see footnote 23) but also better bandwidth in the form of deployment of ADSL₂₊ and VDSL technologies by LLU operators and BT. The outcome was a bandwagon effect which not only delivered increased benefits to end-users in the form of lower prices and higher bandwidth but also accelerated DSL deployment to give it a significantly higher share of the market in the last mile.

8 Summary, discussion, and conclusions

8.1 Introduction

Starting with the 1960s when PCM became practical, this thesis has covered events until 2012-13 to show why DSL has become the most widely used technology to deliver broadband connectivity in the UK. The factors that contributed to such an outcome have been examined along with a comparative analysis of the various broadband technologies in contention at different times. The narrative presented in the previous chapters has been based on original, unpublished interviews and documentary sources. For the theoretical discussion, the thesis has drawn from a range of approaches. The previous chapters and their contents are summarised in brief here -

- Chapter 2 defined the research questions, methodology, and objectives that shape the discussion in the remaining chapters.
- Chapter 3 contained a detailed survey of existing literature, various themes, and theoretical approaches within the field of science and technology studies.
- Having identified the theoretical ideas that would be used to discuss and analyse the various events that drove the development, deployment, and adoption of various broadband technologies, chapter 4 covered the events in 1960s and 1970s including the use of PCM being practical and the emergence of 'wideband' connectivity in the form of Datel, Dataplex solutions by the Post Office to deliver data connectivity for mostly business end-users.
- Chapter 5 discussed the events in 1980s including denationalisation of BT, formation of BT-Mercury duopoly, creation of regulatory bodies i.e. Oftel and

Cable Authority, licensing of regional cable franchises for multi-channel transmission, and the various technologies in the fray to deliver high-bandwidth connectivity.

- Chapter 6 examined the disbanding of the BT-Mercury duopoly, further liberalisation of the UK markets, consolidation in the cable industry, and the emergence of the Internet/Web into mainstream consciousness in the 1990s.
- Chapter 7 concluded the narrative by covering the growth in DSL deployment, bankruptcy in the cable industry, regulatory intervention in the form of functional separation of BT, and growth in the unbundling market in the late 2000s that spurred deployment of ADSL₂ and ADSL₂₊ technologies.

The present chapter summarises the various threads of the narrative along with its contribution to scholarship. The chapter ends by discussing the author's personal perspective and the possibilities for extending the various ideas in this thesis with further research. Before providing the summary of key observations, an overview of the main contributions of the thesis is presented first.

8.2 Overview of the main original contributions

The main original contributions of the thesis are -

- The thesis narrates a previously untold story of the evolution of broadband technologies in the UK by combining original, unpublished interviews with secondary sources and archival material.
- The thesis shows that the emergence, selection, and consolidation of DSL as a broadband technology although unheralded was the only realistic outcome in

light of the prevailing situation in the UK communications market. However, despite being the only viable alternative, the dominance of DSL as a broadband technology was neither a deterministic outcome nor was it the intended result from the outset.

- The thesis discusses the changes in the UK communications industry in the wake of BT's denationalisation and the regulatory measures governing those changes. The thesis shows how the unintended consequences of these changes shaped the development, deployment, and adoption of broadband technologies in the UK.
- The thesis establishes that the existing theoretical approaches within historical and sociological studies of technological change enable only a partial picture of the evolution of broadband technologies to be understood. In doing so, the thesis extends and modifies the use of theoretical ideas such as Bijker and Pinch's social constructivism and Hughes' 'technology as a system' approach.

8.3 Summary of key observations

This section covers the research questions identified in chapter 2 and the answers that have emerged as part of the discussion in chapters 4 to 7. The discussion here is intended to summarise the key observations in the light of the narrative presented in the thesis.

8.3.1 The first research question

Why did DSL become the most widely used technology to deliver broadband connectivity in the UK?

The dominance of DSL has its roots in a succession of events that had the unintended consequence of hindering the widespread deployment of technologies that could have competed with DSL. At the time of BT's denationalisation, the regulators were focussed on creating a thriving competitive communications market. As a result, the regulators placed a number of restrictions on BT in relation to cable franchise ownership and broadcasting services throughout the 1980s and 1990s. The cable industry, although expected to provide competition to BT, never developed the required economies of scale and struggled financially in part due to the fragmentation caused by allocation of cable franchises as regional monopolies. With the emergence of BSkyB in the 1990s, the cable operators lacked a unique selling proposition to distinguish their offerings. Once the US-based investors left in the wake of the 1996 Telecommunications Act, the cable operators accumulated unsustainable levels of debt that initially needed restructuring and eventually drove the operators to bankruptcy in the early 2000s. The result was that when the demand for the Internet/Web emerged, despite the capability to deliver better bandwidth, the cable industry could not capitalise on the early lead it had over DSL broadband connections.

Throughout the 1980s and 1990s, ITU-led initiatives such as ISDN and B-ISDN also failed to find acceptance due to lengthy development cycles and mismatch with real-

world requirements. During this time the privatised BT chose to hold back extensive deployment of optical fibre technology in the access network citing inability to achieve financial returns on such an investment. Instead, BT chose to invest its profits in an ambitious plan of expansion outside the UK that ultimately resulted in a huge debt at the start of the 2000s. Given BT's precarious financial position in the early 2000s, DSL offered the best opportunity to respond to the regulatory pressure and capitalise on the end-user demand for higher bandwidth Internet/Web access, a situation that resulted in extensive deployment of DSL kit as chapter 7 established. Although BT initially selected DSL as the most viable alternative, the subsequent investment by unbundlers and the favourable terms created by BT's functional separation contributed to the continued preference for DSL. With the cable network capable of reaching only 50% of the UK premises and lack of extensive optical fibre deployment in the access network, DSL continues to be the most widely used technology to deliver broadband connectivity.

8.3.2 The second research question

How do theoretical insights from historical and social studies of technology help us to understand the evolution of broadband technologies in the UK?

The discussion in chapters 4 to 7 shows that the theoretical approaches about historical and sociological studies of technological change that emerged in the 1970s such as social constructivism, Hughes' large technological system, or social shaping of technology approaches offer only a partial perspective on the way broadband technologies evolved. The thesis shows that this is not a limitation of the theoretical

approaches themselves but a reflection of the way in which broadband technologies differ from the technologies (whether artefacts or systems) studied with these approaches. The use of Bijker and Pinch's (1984; 1987) social constructivist ideas shows how broadband needs to be considered as more than an artefact in the last mile. Hughes' (1983; 1987) 'technology as a system' approach highlights how 'reverse salients' and systemic constraints contributed to the commercial failure of ISDN and B-ISDN. Hughes' ideas also enable analysis of the interaction between various components in the telecommunications system i.e. the organisations (the operators, the regulatory bodies), the legislative artefacts (the regulatory and government policies), and the physical artefacts (the transmission technologies, the exchanges, the networks, and the equipment in exchanges and end-user premises).

However, since the main intent of these approaches was to counter the prevailing determinist and internalist tradition of writing about technology, the thesis also focusses on how the outcomes associated with broadband technologies were often unpredictable and dependent on a number of factors. In order to understand the outcomes, the discussion in chapters 4 to 7 employs a number of additional approaches from economic studies of technological change, Edgerton's (2006) ideas about use-based history and maintenance-based innovation, Hecht's (2001) idea of technopolitical regime, the concept of path dependence as put forward by Arthur (1989; 1990) and David (1985; 1997; 2007), and the bandwagon effect (Leibenstein, 1950; Rohlfs, 1974; 2001). In particular, the idea of technopolitical regime shows how government and regulatory policies, although not aimed at influencing deployment and adoption of specific broadband technologies, often influenced the choices by BT and other line operators. Edgerton's (2006) ideas about use-based history are relevant

to understanding the role of maintenance-based innovation in DSL development. The concept of path dependence highlights how the deployment and adoption of broadband technologies was contingent on a historical sequence of events. In addition to the use of these various theoretical approaches the concept of bandwagon effect enables the initial selection and subsequent growth in the adoption of DSL as a broadband technology to be understood in conjunction with ideas such as lock-in (Arthur, 1989) and the theory of framing conditions (David, 2007).

8.4 Contributions of the study

This section discusses the way in which the narrative and the theoretical discussion in the previous chapters make original contributions to the existing field of science and technology studies, address a gap in existing knowledge, and add to the understanding of the evolution of broadband technologies.

8.4.1 The untold story of broadband

This thesis documents a very recent period of history in the UK communications industry, and one of considerable importance given the economic importance associated with broadband connectivity. Through its analysis of the influence of liberalisation, regulatory policies, changing business priorities of the operators, and the rapid improvements in digital technology, it addresses a key gap in the existing knowledge i.e. the way in which broadband technologies have evolved. In narrating the evolution of broadband technologies and analysing it in terms of the various theoretical ideas in science and technology studies, the thesis adds to the existing

literature on the history of communications industry in the UK and also the scholarship of science and technology studies.

With the use of the original, unpublished interviews, the thesis presents the views of the various stakeholders whether BT, cable operators, regulatory experts or industry consultants. Due to the recent nature of the events surrounding the emergence of the Internet/Web and the fact that broadband connectivity was hardly available as of 2000-01, the use of the interviews offers a previously unavailable account of how various strategy and policy decisions shaped the outcomes associated with broadband technologies at that time. With the use of the interviews the thesis delivers an inside account of the events and as a result makes an important contribution by narrating the previously untold story of broadband technologies.

8.4.2 The emergence and consolidation of DSL as a path dependent, historically contingent outcome

This thesis has clearly shown that although DSL has the largest market share amongst the broadband technologies deployed in the UK, it has not always been the first choice or the best choice in terms of a number of attributes including bandwidth capability. For a significant duration of time i.e. almost until the mid-1990s copper twisted pair was not considered a good enough medium for high-bandwidth connectivity. Copper-based DSL lacked the bandwidth capabilities of alternatives such as B-ISDN, coaxial cable, and optical fibre. Despite this situation, by 1999-2000 the selection of DSL as broadband technology was the only realistic choice for BT. The thesis not only explains such a paradoxical outcome but also shows that the

triumph of DSL as a broadband technology despite it being the only viable choice at that time was not a foregone conclusion.

The thesis shows that the outcome in which DSL became the most widely used technology to deliver broadband connectivity was neither an intended result from the outset nor was such an outcome impermeable to influences from the society or the market in which it took place. What made DSL the most realistic choice for BT was a sequence of events starting with BT's denationalisation as a result of which the UK communications market evolved in a unique way. The emergence of DSL as a technology of choice in 1999-2000 was dependent on a number of factors such as the problems in the cable industry, the commercial failure of ISDN, B-ISDN technologies, the sheer cost and effort required for optical fibre deployment, and BT's precarious financial position none of which was either inevitable or predictable. Thus the thesis shows that although DSL was the only viable choice at that time, the environment in which such choice had become necessary itself was not inevitable. In showing how the interaction of multiple factors contributed to the dominance of DSL, the thesis not only establishes that the role of cost and the existence of copper in the incumbent's network is over-emphasised but also highlights that the selection and subsequent consolidation of DSL was a path dependent outcome based on a unique set of circumstances in the UK.

8.4.3 The changes in the UK communications industry and unintended consequences for broadband technologies

The thesis establishes how the regulatory approach in the wake of BT's

denationalisation viewed the industry as siloes of functionality in terms of telephony, television and broadcasting, and wireless technologies. The thesis also examines the influence the regulatory policies had on the deployment of broadband technologies. The siloed thinking is reflected in the presence of separate regulatory bodies for telephony, television and broadcasting, and wireless industries. Not only was the network infrastructure central to the regulatory policies but the services were also tied to the nature of infrastructure being deployed. BT was tied to telephony services and restricted from delivering broadcasting services. Cable operators, although permitted telephony, were allocated regional franchises as monopolies to encourage development of local television content. Ultimately however, the UK communications industry developed in a completely different way than originally envisioned resulting in the 'imperfect competition' that added a layer of non-determinism to the emergence of DSL. The changes in the UK communications industry created a dynamic of interaction amongst the various stakeholders that required a significant revision to the regulatory approach.

The demand for broadband Internet/Web access cut across various functional siloes in which the various regulatory bodies operated. The convergence of voice, data, and video functionality enabled by the Internet/Web made the siloed regulatory approach obsolete and it also established the extent to which the choice of services is more important from end-user perspective instead of the choice of infrastructures. Whether telcos such as BT or OLOs, cable operators, or even the mobile operators, it is the bundling of telephony (fixed-line and mobile), television, and broadband and value of the bundle offered that has become the main selling proposition. The thesis shows that despite the best of regulatory intent the original emphasis on

infrastructure competition and price control was instrumental in the way the cable industry did not develop as an effective competitor to BT, the incumbent operator. The thesis demonstrates that although the regulatory policy was a success in terms of creating competition and lowering the prices for end-users, the unintended consequence of that was increased emphasis on ROI which held back the deployment of coaxial cable and optical fibre in the access network.

Although the regulation of the UK communications industry has been covered in varying depth and breadth in other research volumes, the thesis thus contributes to the existing discussion by showing how the unintended consequences of regulatory policies have influenced the deployment and adoption of various broadband technologies.

8.4.4 A different context for social constructivism and the importance of services

The thesis demonstrates how the existing theoretical approaches within historical and social studies of technological change enable only a partial picture of the evolution of broadband technologies to be understood. The thesis establishes that in order to explain the interplay of socio-economic, political, regulatory, and technological factors that influenced development, deployment, and adoption of broadband technologies, more than a single theory, framework, or hypothesis needs to be employed. In particular, as part of the theoretical discussion, the thesis provides a new context for the use of Bijker and Pinch's (1984; 1987) social constructivism and Hughes' (1987) 'technology as a system' approach.

The thesis highlights the unique nature of broadband technology and the way it differs from the technological artefacts that have been studied using social constructivism. The discussion in chapters 4, 5, and 6 shows that broadband technology is more than the artefact in the last mile or the exchange. From this point of view, the thesis extends the context for the application of social constructivist ideas beyond the types of context usually cited. By demonstrating the importance of the changes in the UK communications industry to the evolution of broadband technologies and how that was influential in shaping the function and meaning of broadband, the discussion in chapters 4, 5, and 6 employs social constructivism in an industry-wide, system context unlike other social constructivist studies.

Since the broadband technologies represent more than an artefact, the thesis also shows that it is more rewarding to think from Hughes' (1987) 'technology as system' perspective when understanding the evolution of broadband technologies. As chapter 4 and 5 identified, unlike the large technological systems that Hughes studies, the telecommunications system is not just restricted to telephony and delivers more than one type of service, even more so if broadband connectivity for Internet/Web access is considered. The thesis thus points out a gap in the way the components in a large technological system are defined. Such a definition of a large technological system overlooks the role of services in relation to the components identified by Hughes i.e. legislative artefacts (i.e. rules of governance), organisations (i.e. companies or governments that manage and market the system), and physical artefacts (i.e. objects, tools, offices, and physical networks). The thesis shows how services contribute to the function of the large technological system as understood by

the end-users. Although the services component may not perhaps offer any viable advantages when considering other networked, infrastructure-heavy industries like electricity or railways that Hughes discusses, in case of a telecommunications system, it is a key attribute if the evolution of broadband technologies is considered. By identifying the importance of the services component while discussing the evolution of broadband technologies, the thesis thus contributes an important theoretical construct to Hughes' 'technology as a system' approach.

8.5 Personal perspective of the author

Throughout this thesis, the author's focus has been on presenting the story of broadband in the UK as impartially as possible. This is because with a largely unknown story as this, the credibility of the narrative depends on the extent to which it manages to be impartial. However, in this section, the author provides a personal perspective on broadband deployment in the UK and its relationship to the liberalisation of the UK communications market. In doing so, this section reflects on the equation between some of the key players including the UK government, the regulators, and BT.

Although the policy of liberalisation followed in the UK set the precedent for market-orientated reforms in Europe, the wisdom of allowing infrastructure assets such as water, gas, electricity, and communications networks to be completely owned by non-state, private players is open to question. If the incumbent operators' communications networks are considered, other European countries such as France and Germany have continued to retain some control while denationalising their

public sector monopolies. At the time of writing, the French government has 13.5% stake in Orange (previously France Telecom), the former monopoly operator in France. The German government has 15% stake in Deutsche Telekom and an additional 17% stake through the government bank KfW (originally Kreditanstalt für Wiederaufbau). As a result, although state subsidies are illegal under the European Union rules, the French and German governments are in a much better position than the UK government to push their agenda for next generation broadband infrastructure. In contrast, the UK government cannot influence any decisions about the completely privatised BT's network infrastructure without regulatory or legislative intervention.

In part due to the price competitiveness of the UK market, its communications infrastructure has not kept pace with the UK government's ambitions for building a knowledge economy and achieving higher economic growth. The decision by the UK government to provide funds for broadband deployment to the Final Third demonstrates that liberalisation and competition do not always address all of the market requirements. The fact that the UK government and the regulators whether Oftel or Ofcom, have relied on direct interventions through price control, local loop unbundling, and functional separation suggests that without regulatory oversight, liberalisation is not the panacea it is argued to be.

Given the capital intensive nature of the communications industry and the high cost of deploying and maintaining infrastructure, BT's ownership of the legacy infrastructure gives it a crucial advantage. Other Line Operators cannot match the economies of scale BT is capable of achieving. In consequence, as an incumbent

operator BT continues to have significant market power over the wholesale access network in the UK. This means BT is also in a position to consolidate its significant market power further when funds are made available for rural broadband deployment or Superfast broadband connectivity to urban areas. This outcome is incongruent with the original goals of denationalisation and liberalisation. Although the perceived lack of interest in extensive infrastructure deployment by private players such as BT is aligned with the interests of their shareholders and the stock markets, it poses significant challenges to the UK government's agenda for next generation broadband infrastructure. This situation suggests that further debate and research is needed on the extent to which the communications infrastructure should remain under public ownership and whether the competition should be solely focussed on retail services.

8.6 Scope for further research

As with any PhD research, this thesis has had to balance a range of themes and ideas that could be reasonably covered against the available time. In this section, some of the self-imposed constraints of this research are discussed along with the ways in which the body of work presented here can be extended in the near future.

8.6.1 The coverage of broadband wireless access technologies

Given that close to 90% of the network capacity in a wireless network is actually accounted by fixed-line technologies, this thesis has not considered wireless technologies particularly broadband-capable technologies such as 3G, HSPA,

4G/LTE, and WiMAX in a lot of detail. This has meant that despite significant material being collected in relation to the development of 2G, 3G technologies, the regulatory policy on wireless spectrum, 3G spectrum allocation, the potential of 4G/LTE, and the commercial failure of WiMAX technology, very little space has been devoted to such aspects of the story in the thesis. The richness of the material available points to pursuit of further discussion in another volume.

Part of the reason the focus was on fixed-line technologies has been due to the physical limitations of the wireless spectrum and hence the maximum bandwidth that can actually be achieved via broadband wireless access technologies. As William Webb (2007) points out, the adoption of broadband wireless access (whether fixed or mobile) as an alternative to 'last mile' fixed-line broadband connectivity is most likely to be in rural areas with low population density that require relatively low-cost deployment solutions. Thus broadband wireless access, although important, is likely to play complementary role in the evolution of broadband technologies in the immediate term. Any such developments are likely to be coupled with proliferation of smartphones, smart devices, and the use of white space spectrum (see Webb, 2013 for a discussion on the potential of white space spectrum). When considering such developments, despite its complementary role, the material collected on wireless broadband technologies points to a promising area of research in relation to the evolution of wireless broadband technologies.

8.6.2 Regulation – a subject of expertise on its own

Even though this research covers regulatory policies and their influence on the

broadband evolution in the UK, the author acknowledges that regulation is a separate area of expertise and studies. Although a number of regulatory decisions and their outcomes vis-à-vis the evolution of broadband technologies have been discussed in the thesis, the thesis does not attempt to analyse the merits/demerits of the actual regulatory process and the decision-making at great length. Considering the strength of material and resources on the subject of regulatory economics and the work of experts such as Prof. Martin Cave, Prof. William H. Dutton, Prof. Robin Mansell, and Prof. David Parker, a study of the history of regulation in the UK communications industry and how it has been shaped by socio-economic factors could be another promising area for subsequent research.

8.7 Parting thoughts

Although the thesis is rooted in Science and Technology Studies (STS), the author has chosen to be guided by various ideas including those that have been a peripheral part of STS tradition such as path dependence and economic studies of technological change. The use of multiple theoretical approaches to interpret the outcome is a reflection of the way evolution of broadband technologies differs from other technological changes studied until now. In doing so, the thesis establishes that the emergence of DSL as the most widely used broadband technology was contingent on a number of factors and not an outcome influenced in an autonomous manner by the technologies in contention. By combining social, economic, political, regulatory, and technical strands of studies for a technology that is still evolving, the author hopes to have deconstructed some of the existing disciplinary boundaries and made a small, incremental, and yet valuable contribution to understanding technological changes

and the outcomes associated with them.

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Glossary^{*}

2.5G In mobile telephony, 2.5G protocols extend 2G systems to provide additional features such as packet-switched connections (GPRS) and higher-speed data communications.

2G Second generation of mobile telephony systems. Uses digital transmission to support voice, low-speed data communications, and short messaging services.

3.5G Refers to evolutionary upgrades to 3G services, starting in 2005-2006, that provide significantly enhanced performance. High Speed Packet Access (HSPA) is expected to become the most popular 3.5G technology (see HSPA).

3G Third generation of mobile systems. Provides high-speed data transmission and supports multimedia applications such as full-motion video, video-conferencing and internet access, alongside conventional voice services.

4G The fourth generation of mobile phone mobile communication technology standards, which provides faster mobile data speeds than the 3G standards that it succeeds.

802.11 see Wireless LANs (WiFi)

^{*} Based on Dunlop and Smith (1984), Ofcom (2013b), and Valdar (2006).

Access network An electronic communications network which connects end-users to a service provider; running from the end-user's premises to a local access node and supporting the provision of access-based services. It is sometimes referred to as the 'local loop' or 'last mile'.

ADSL Asymmetric Digital Subscriber Line. A digital technology that allows the use of a standard telephone line to provide high-speed data communications. Allows higher speeds in one direction (towards the customer) than the other.

ADSL₂₊ A technology which extends the maximum theoretical downstream data speed of ADSL from 8Mbit/s to 24Mbit/s.

ARPU Average Revenue Per User. A measurement used by pay-television or mobile companies to indicate the average monthly revenue earned from a subscriber.

ATM Asynchronous Transfer Mode. A networking technology designed to handle high data volumes and low-latency content such as real-time voice and video.

B-ISDN Broadband ISDN. A successor to ISDN that relied on ATM as a networking technology to deliver multi-service capabilities and bandwidths greater than 128 kbit/s.

Bit-rates The rate at which digital information is carried within a specified communication channel.

Broadband A service or connection generally defined as being 'always on' and providing a bandwidth greater than narrowband.

CAP Carrierless Amplitude Phase modulation. A variant of QAM in which relies on filtering two signals instead of modulating them to form a single channel.

CATV Cable television. Originally referred to Community Access TV or Community Antenna Television due to the fact that during the early days of cable television, community antennas were constructed to transmit cable television to areas not reachable due to distance or difficult terrain.

Coaxial cable A type of copper cable where the inner conductor and the outer shield share a geometric axis. The inner conductor functions as the physical channel that carries the signal. It is separated from another concentric physical channel (which serves as ground) by a layer of insulation. In part due to the nature of insulation, coaxial cables suffer far less from signal attenuation in comparison to twisted copper pair.

Contention ratio An indication of the number of customers who share the capacity available in an ISP's broadband network. Figures of 50:1 for residential broadband connections and 20:1 for business are typical.

Core network An electronic communications network which connects two main or local exchanges. Usually used to carry intercity traffic. Does not include the network connection between the end-user and the local exchange.

Data packet In networking, the smallest unit of information transmitted as a discrete entity from one node on the network to another.

Dial-up see Narrowband.

Digital Britain The government report, published in June 2009, outlining a 'strategic vision for ensuring that the UK is at the leading edge of the global digital economy'.

DOCSIS Data Over Cable Service Interface Specification. An international communications standard that enables an existing cable TV (CATV) system to add the capability of delivering high-speed data transfer. Commonly used by cable operators to provide broadband Internet access over their existing cable transmission systems.

DMT Discrete MultiTone modulation. A method of modulating DSL signals that encodes digital data on multiple carrier frequencies. The use of DMT enables a DSL modem to be rate adaptive (i.e. adjust upstream bandwidth to achieve higher downstream bandwidth). See OFDM

DSL Digital subscriber line. A family of technologies generally referred to as DSL, or xDSL, capable of transforming ordinary phone lines (also known as 'twisted copper pairs') into high-speed digital lines, capable of supporting advanced services such as

fast internet access and video on demand. Asymmetric DSL (ADSL), High-data-rate DSL (HDSL) and Very-high-data-rate DSL (VDSL) are all variants of xDSL.

DSLAM Digital Subscriber Line Access Multiplexer. A network device situated in a local exchange to perform the function of aggregating data traffic from the local loop onto a high-capacity transmission link.

DSM Dynamic Spectrum Management. A set of techniques used to reduce or eliminate the problems of noise, crosstalk, and interference. When used in conjunction to a DSL connection, DSM reduces the loss of signal in a copper line and hence improves its bandwidth capabilities.

Ethernet Family of computer networking technologies for LANs. Defined by the IEEE 802.3 standard.

FRIACO Flat Rate Internet Access Call Origination. A type of dial-up Internet access in which other service providers could offer unmetered flat rate Internet access to subscribers via a specific number (e.g. 0800) set up by BT.

FTTC Fibre-To-The-Cabinet. Access network consisting of optical fibre extending from the access node to the street cabinet. The street cabinet is usually located only a few hundred metres from the subscriber premises. The remaining segment of the access network from the cabinet to the customer is usually a copper pair but could use another technology, such as wireless.

FTTH Fibre-To-The-Home. A form of fibre optic communication delivery in which the optical signal reaches the end user's living or office space.

FTTP Fibre-To-The-Premise. A form of fibre-optic communication delivery in which an optical fibre is run directly onto the end-user's premises.

GPRS General Packet Radio Service. A packet data service provided over 2.5G mobile networks.

GSM Global standard for mobile telephony. The standard used for 2G mobile systems.

HFC Hybrid Fibre Coaxial. This is a type of network configuration employed by cable operators by combining optical fibre and coaxial cable. In a typical configuration, optical fibre cables are used closer to the cable plant to increase transmission capacity while retaining the use of coaxial cable in the last mile or closer to the end-user premises.

HSPA High Speed Packet Access. Jointly, downlink and uplink mobile broadband technologies are referred to as HSPA services.

Incumbent operator/s An incumbent operator usually refers to a market's established provider/s and in the case of the UK fixed market this is BT and Kingston Communications.

Internet A global network of networks, using a common set of standards (e.g. Internet Protocol), accessed by users with a computer via a service provider. See also WWW.

IP Internet Protocol. The packet data protocol used for routing and carrying messages across the internet and similar networks.

ISDN Integrated Services Digital Network. A standard developed to cover a range of voice, data, and image services intended to provide end-to-end, simultaneous handling of voice and data on a single link and network. Sometimes referred to as N-ISDN (Narrowband ISDN) or BR-ISDN (Basic Rate ISDN) in a retrospective way to distinguish it from B-ISDN (Broadband ISDN). See B-ISDN.

ISP Internet Service Provider. A company that provides access to the internet.

ITC Independent Television Commission, one of the regulators replaced by Ofcom in 2003

LAN Local area network. A network for communication between computers covering a local area, like a home or an office.

LLU Local Loop Unbundling. LLU is the process where the incumbent operators (in the UK it is BT and Kingston Communications) make their local network (the lines that run from customers premises to the telephone exchange) available to other communications providers. The process requires the competitor to deploy its own

equipment in the incumbent's local exchange and to establish a backhaul connection between this equipment and its core network.

Local loop The access network connection between the customer's premises and the local PSTN exchange, usually a loop comprised of two copper wires.

LTE Long-Term Evolution. Part of the development of 4G mobile systems that started with 2G and 3G networks.

Mobile broadband Various types of wireless high-speed internet access through a portable modem, telephone or other device.

Multichannel In the UK, this refers to the provision or receipt of television services other than the main five channels (BBC One and Two, ITV1, Channel 4/S4C, Five) plus local analogue services. 'Multichannel homes' comprise all those with digital terrestrial TV, satellite TV, digital cable or analogue cable, or TV over broadband. Also used as a noun to refer to a channel only available on digital platforms (or analogue cable).

Narrowband A service or connection providing data speeds up to 128kbit/s, such as via an analogue telephone line, or via ISD.

NGA Next-Generation Access networks. New or upgraded access networks that will allow substantial improvements in broadband speeds and quality of service compared to today's services. This can be based on a number of technologies

including cable, fixed wireless and mobile. Most often used to refer to networks using fibre optic technology.

NGN Next-Generation core Networks. Internet protocol-based core networks which can support a variety of existing and new services, typically replacing multiple, single service legacy networks.

Ofcom Office of Communications. The regulator formed in 2003 by merging the functions of Oftel, ITC, Radiocommunications Agency (RA), and Cable Authority (CA).

OFDM Orthogonal Frequency Division Multiplexing. A method of digital modulation (i.e. encoding digital data) that uses multiple carrier frequencies.

Oftel Office of Telecommunications, whose functions transferred to Ofcom on 29 December 2003.

Pay-per-view A service offering single viewings of a specific film, programme or event, provided to consumers for a one-off fee.

PCM Pulse Code Modulation. A method of digitally representing sampled analogue signals which is now a standard for digital audio. Invented by Alec Reeves in the 1930s while working at the British Post Office.

PON Passive Optical Network. A type of point-to-multipoint FTTP solution in which a single optical fibre services multiple premises. Subject to the type of services provided and the bandwidth available, multiple variants such as Telephony over PON (TPON), Broadband PON (BPON), and Gigabit PON (GPON) exist.

PSTN Public Switched Telephone Network. The network that manages circuit-switched fixed-line telephone systems.

QAM Quadrature Amplitude Modulation. A method of combining two amplitude modulated (AM) signals into a single channel as a means of doubling the effective bandwidth.

Quadruple-play A form of service bundling where following four services are packaged together – fixed-line telephony, television, broadband, and mobile telephony. See Service bundling and Triple-play.

Service bundling (or multi-play) A marketing term describing the packaging together of different communications services by organisations that traditionally only offered one or two of those services. See Triple-play and Quadruple-play.

Shannon-Hartley theorem Shannon-Hartley theorem (named after Claude Shannon and Ralph Hartley) specifies the maximum rate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise.

$$C = B \log_2 (1 + S/N)$$

where

C is the channel capacity in bits/s;

B is the bandwidth of the channel in hertz;

S is the average received signal power over the bandwidth (often denoted C , i.e. modulated carrier for modulated signal), measured in watts (or volts squared);

N is the average noise or interference power over the bandwidth, measured in watts (or volts squared); and

S/N is the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal to the Gaussian noise interference expressed as a linear power ratio (not as logarithmic decibels).

Smartphone A mobile phone that offers more advanced computing ability and connectivity than a contemporary basic 'feature phone'.

Superfast broadband Sometimes known as next-generation broadband, super-fast broadband delivers headline download speeds of at least 30Mbit/s.

Telecommunications, or 'telecoms' Conveyance over distance of speech, music and other sounds, visual images or signals by electric, magnetic or electro-magnetic means.

TCP Transmission Control Protocol. TCP defines the protocol for communication between the originating and terminating packet switches.

Triple-play A form of service bundling where three services are bundled together as a package to the end-user. Commonly refers to the bundling of fixed-line telephony, television, and broadband. Could also refer to the bundling of any three services out of fixed-line telephony, television, broadband, and mobile telephony.

Unbundled A local exchange that has been subject to local loop unbundling (LLU).

VOD Video-On-Demand. A service or technology that enables TV viewers to watch programmes or films whenever they choose to, not restricted by a linear schedule.

WiFi hotspot A public location which provides access to the internet using WiFi technology.

WiMAX Worldwide Interoperability for Microwave Access. A wireless MAN (metropolitan area network) technology, based on the 802.16 standard. Available for both fixed and mobile data applications.

Wireless LAN or WiFi (Wireless Fidelity). Short-range wireless technologies using any type of 802.11 standard such as 802.11b or 802.11a. These technologies allow an over-the-air connection between a wireless client and a base station, or between two wireless clients.

WLR Wholesale line rental. A regulatory instrument requiring the operator of local access lines to make this service available to competing providers at a wholesale price.

WWW World Wide Web. A system of interlinked hypertext documents accessed via the Internet.

Appendix A - Schedule and mode of research interviews

Date/time	Name	Mode	Interview location	Type of consent
13/Dec/2011 11:00 GMT	David Brown	Face-to-face	Hemel Hempstead	Written
15/Dec/2011 15:30 GMT	John Cioffi	Telephone	Milton Keynes	Verbal
19/Dec/2011 12:00 GMT	William Webb	Face-to-face	Cambridge	Written
19/Dec/2011 16:00 GMT	Peter Cochrane	Telephone/Skype	Cambridge	Verbal
21/Dec/2011 14:30 GMT	A senior Cable & Wireless employee *	Face-to-face	Milton Keynes	Written
22/Dec/2011 11:00 GMT	John O'Reilly	Face-to-face	Cranfield	Written
23/Dec/2011 11:00 GMT	John Midwinter	Telephone	Milton Keynes	Verbal
11/Jan/2012 15:00 GMT	Nicholas James	Telephone	Milton Keynes	Verbal
16/Jan/2012 14:00 GMT	Ian Millward	Face-to-face	Cambridge	Written
19/Jan/2012	Kevin Foster	Face-to-	Ipswich	Written

Date/time	Name	Mode	Interview location	Type of consent
14:30 GMT		face		
19/Jan/2012 14:30 GMT	Peter Adams	Face-to-face	Ipswich	Written
20/Jan/2012 10:00 GMT	Chris Cooper	Telephone	Milton Keynes	Verbal
23/Jan/2012 14:00 GMT	Jon Crowcroft	Face-to-face	Cambridge	Written
27/Jan/2012 11:30 GMT	David Clarkson	Face-to-face	London	Written
01/Feb/2012 11:00 GMT	Graham Knight	Face-to-face	London	Written
01/Feb/2012 15:30 GMT	Gavin Young	Face-to-face	London	Written
06/Feb/2012 12:30 GMT	Niall Murphy	Telephone/ Skype	Milton Keynes	Written/Verbal
09/Feb/2012 11:30 GMT and 13/Feb/2012 11:30 GMT	Graham Sargood	Face-to-face	London	Written
09/Feb/2012 14:30 GMT	Peter Shearman	Face-to-face	London	Written
09/Feb/2012	Managing	Face-to-	London	Written

Date/time	Name	Mode	Interview location	Type of consent
17:00 GMT	Director at an Investment Bank *	face		
10/Feb/2012 11:00 GMT	Mike Pemberton	Face-to-face	London	Written
13/Feb/2012 15:00 GMT	Laurie Cuthbert	Face-to-face	London	Written
14/Feb/2012 11:00 GMT	Ben Verwaayen	Telephone	Milton Keynes	Written (via email)
12/Mar/2012 10:30 GMT	The Head of wireless strategy in a European communications multinational *	Telephone	Milton Keynes	Verbal
27/Mar/2012 11:00 GMT	Malcolm Taylor	Face-to-face	London	Written
27/Mar/2012 15:30 GMT	Bryan Carsberg	Face-to-face	London	Written
29/Mar/2012 15:00 GMT	David Payne	Telephone	Milton Keynes	Verbal
02/Apr/2012 14:15 BST	Martin Cave	Telephone	Milton Keynes	Verbal
11/Apr/2012	Trevor Smale	Telephone	Milton	Verbal

Date/time	Name	Mode	Interview location	Type of consent
14:00 BST			Keynes	
18/Apr/2012 11:30 BST	Andy Valdar	Face-to-face	London	Written
19/Apr/2012 11:00 BST	John Cluny	Telephone	Milton Keynes	Verbal
26/Apr/2012 10:00 BST	Richard Feasey	Telephone	Milton Keynes	Verbal
10/May/2012 13:00 BST	Graham Currier	Face-to-face	London	Written

* Name anonymised at the participant's request

Appendix B - Details of the interview participants

Note – Names appear according to the order in which interviews were conducted

Name	Expertise and affiliation in the communications industry (at the time of the interview)
David Brown	<ul style="list-style-type: none"> • Communications industry expert and consultant • Former Head of consultancy organisation Schema (now Mott McDonald Schema)
John Cioffi	<ul style="list-style-type: none"> • Responsible for OFDM based DMT method being used in DSL that made DSL a practical technology • Founder of Amati Communications Corporation (now part of Texas Instruments) that did pioneering work on the first functioning DSL modems • Spearheaded the development of xDSL technologies and related standards, the latest of which is DSM
William Webb	<ul style="list-style-type: none"> • Former Head of R&D at Ofcom • Industry expert and consultant on wireless communications and a range of strategic, technical, and regulatory issues
Peter Cochrane	<ul style="list-style-type: none"> • Former Head of Research and Chief Technology Officer (CTO) at BT

Name	Expertise and affiliation in the communications industry (at the time of the interview)
	<ul style="list-style-type: none"> • Headed a team of 1000 people at BT engaged in studies related to optical fibre, fixed and mobile networks
A senior Cable & Wireless employee *	<ul style="list-style-type: none"> • Communications industry veteran with nearly 30 years of experience
John O'Reilly	<ul style="list-style-type: none"> • Vice-Chancellor of Cranfield University • Chairperson of UK's NICC for Ofcom and the telecommunications industry • Former Principal Research Fellow with BT
John Midwinter	<ul style="list-style-type: none"> • Emeritus Pender Professor of Electrical Engineering at UCL (1988-present) • Former Head of Optical Communications at BT Research Labs (1977-84) • A consultant on Optical Networks to the EC (Brussels) for the RACE and ACTS programmes
Nicholas James	<ul style="list-style-type: none"> • CEO of UKBroadband, UK's premier wholesale wireless broadband operator
Ian Millward	<ul style="list-style-type: none"> • BT/Openreach employee with extensive experience of exchange-level engineering and a field-level perspective about broadband deployments

Name	Expertise and affiliation in the communications industry (at the time of the interview)
Kevin Foster	<ul style="list-style-type: none"> • Head of Access Platform Innovation at BT • Chairman of DSL Working Group at NICC • President at Broadband Forum
Peter Adams	<ul style="list-style-type: none"> • Former BT employee and Head of BT Research Labs in Ipswich • Key stakeholder in ISDN, DSL trials and deployments • Spearheaded the development of 2B1Q, a key building block of ISDN and DSL
Chris Cooper	<ul style="list-style-type: none"> • Network strategist to the Joint Academic Network (JANET) • A key member of the SuperJANET programme from 1990 to 2007 specifically SuperJANET, SuperJANET4 and SuperJANET5 • A key member of EU RACE and ACTS projects
Jon Crowcroft	<ul style="list-style-type: none"> • Marconi Professor of Communications Systems in the Computer Lab, at the University of Cambridge • Former professor in the Department of Computer Science University College London
David Clarkson	<ul style="list-style-type: none"> • Competition Policy Director, Ofcom
Graham Knight	<ul style="list-style-type: none"> • A key member of the research team at UCL headed by Prof. Peter Kirstein focussing on data

Name	Expertise and affiliation in the communications industry (at the time of the interview)
	communications and telecommunications
Gavin Young	<ul style="list-style-type: none"> • Head of Strategy and Planning, C&W Worldwide • Advisor, Ofcom Spectrum Advisory Board (OSAB) • Former Board Director/Technical Chairman, Broadband Forum
Niall Murphy	<ul style="list-style-type: none"> • Technologist and entrepreneur, with interests primarily in Internet access, application and services technologies • Co-founder and former Executive Director of The Cloud (now part of BSkyB), the leading public WiFi network in Europe
Graham Sargood	<ul style="list-style-type: none"> • Veteran of the communications industry with previous stints in companies such as AT&T, Telewest, and Bulldog Communications
Peter Shearman	<ul style="list-style-type: none"> • Head of Infrastructure Policy, Broadband Stakeholder Group
Managing Director at an Investment Bank *	<ul style="list-style-type: none"> • Finance industry veteran with a focus on the technology (including communications) sector
Mike Pemberton	<ul style="list-style-type: none"> • Access network architect at Sky Network Services
Laurie Cuthbert	<ul style="list-style-type: none"> • A key member of the Networks research group at QMUL

Name	Expertise and affiliation in the communications industry (at the time of the interview)
	<ul style="list-style-type: none"> • Author of the book "ATM: the broadband telecommunications solution" on ATM technology in 1993
Ben Verwaayen	<ul style="list-style-type: none"> • CEO of Alcatel-Lucent • Former CEO of BT (2002-2008) • Former Vice Chairman of the Management Board at Lucent • Former President and Managing Director of PTT (Staatsbedrijf der Posterijen, Telegrafie en Telefonie), a KPN (originally Koninklijke PTT Nederland) subsidiary
The Head of wireless strategy in a European communications multinational *	<ul style="list-style-type: none"> • Communications industry veteran with a wealth of experience in Europe
Malcolm Taylor	<ul style="list-style-type: none"> • Former President of EuroDOCSIS • Former Director of regulatory and public policy at Telewest (later Virgin Media)
Bryan Carsberg	<ul style="list-style-type: none"> • The first Director-General of Oftel • Oversaw the privatisation of BT and the creation of duopoly

Name	Expertise and affiliation in the communications industry (at the time of the interview)
David Payne	<ul style="list-style-type: none"> • A leading Professor at the University of Southampton and Director of the Optoelectronics Research Centre • Main research interest is high-power fibre lasers • Invented the erbium-doped fibre amplifier (EDFA) along with his team in the 1980s.
Martin Cave	<ul style="list-style-type: none"> • Regulatory economist specialising in the network industries • Deputy Chair of the UK Competition Commission (from January 2012) • Has provided expert advice on regulation to governments, regulators and firms around the world, focussing particularly upon the communications industries • Member of the UK Competition Commission (1996 to 2002)
Trevor Smale	<ul style="list-style-type: none"> • A veteran of the UK communications industry • Regulatory expert and advisor • Lengthy stints in NTL and now Virgin Media
Andy Valdar	<ul style="list-style-type: none"> • Visiting professor in telecommunications strategy with the Dept. of Electronic and Electrical engineering at UCL

Name	Expertise and affiliation in the communications industry (at the time of the interview)
	<ul style="list-style-type: none"> • 30 year tenure in BT where responsibilities ranged from network strategy and planning, international standards, technical aspects of regulation to product management and development
John Cluny	<ul style="list-style-type: none"> • Regulatory economist with a focus on the cable industry
Richard Feasey	<ul style="list-style-type: none"> • Public Policy Director at the Vodafone Group • A veteran of the communications industry with past stints at Ionica and in the cable industry.
Graham Currier	<ul style="list-style-type: none"> • Former Chief Operating Officer at Freedom4, a WiMAX based broadband connectivity provider

* Name anonymised at the participant's request

Appendix C – Information sheet provided to the interview participants

Information sheet



This document detailed information for the following OU research project.

Name of the project

An examination of the evolution of broadband technologies in the UK

The aim(s) of the project

The aim of this project is to examine and analyse the history of development & deployment of broadband technologies in the UK. The project targets an understanding the technical, political, socio-economic and regulatory factors responsible for selection of various broadband technologies such as DSL and optical fibre amongst others. As part of this research, oral histories of various participants i.e. administrators, managers, engineers and researchers involved in relation to broadband technologies will be recorded. Although the participants may be identified in the final research thesis, no personal data apart from their names, organisational affiliation and the nature of their involvement in the industry will be revealed. The nature of histories recorded will be of professional nature and will reflect the opinion of the participants.

The type(s) of data to be collected

The aim of the interview process is to record the oral histories of participants' experience and perspectives in relation to the development & deployment of broadband technologies.

The method(s) of collecting data

The interviews will be recorded in audio files as question & answer sessions in a semi-structured interview process.

Confidentiality terms associated with the data

The participants will have the right to request that any discussion or parts of it be treated confidentially including with anonymity at any point. All the conversations will be subject to the "Policy on anonymising data" as specified in the "Data retention policy" document.

The oral histories recorded in the interviews will not be published either individually or collectively as separate articles in paper/online media. The narratives recorded will be used for analytical purposes in this research project and/or related research articles. Due to the nature of the project, some of the data may be shared with the supervisors. The supervisors will be bound by the same terms of confidentiality as the principal investigator.

Compliance with the Data Protection and Freedom of Information Acts

This project will be fully compliant with the requirements of the Data Protection Act and the Freedom of Information Act.

The time commitment expected from participants

The time commitment expected from the participants will vary on individual basis. The time commitment will be subject to mutual agreement between the participant and the principal investigator.

Policy on the opportunity to withdraw from the study

The participant will have the opportunity to withdraw their participation from the study at any time before the final thesis being submitted with no adverse consequences.

Policy on the opportunity to have any supplied data destroyed on request

The participants will have the opportunity to have the audio recording destroyed on request up at any time before the final thesis being submitted with no adverse consequences.

Details of any risks associated with participation

Since the project involves recording oral histories of professional nature at a location of participants' choice, there are no risks perceived to be associated with participation.

Individuals below the age of 18 will not be participants in the research. As a result, no risks applicable to participation of minors or individuals below the age of 18 are envisaged.

Policy on compensation for time and participation

The participation is expected to be completely voluntary and without any compensation for travel taken or time spent.

The name and contact details of the principal investigator

Advait Deshpande
The Open University,
Walton Hall,
Venables Building
Department of Communication & Systems,
Faculty of Maths, Computing and Technology,
Milton Keynes MK7 6AA
United Kingdom
Email: a.deshpande@open.ac.uk
Ph: +44 (0) 1908 858169 (Extn: 53976)

The name and contact details for the primary supervisor of the research (for matters which cannot be satisfactorily resolved with the principal investigator)

Dr. Allan Jones
The Open University,
Walton Hall,
Venables Building,
Department of Communication & Systems,
Faculty of Maths, Computing and Technology,
Milton Keynes MK7 6AA
United Kingdom
Email: a.jones@open.ac.uk
Ph: +44 (0) 1908 659619

Insurance indemnity for the research

The principal investigator and primary supervisor are indemnified by the Open University for their research activities.

Any debriefing that is planned

No debriefing requirements have been identified.

How the results of the research will be made available to participants

Since the purpose of the project is to record oral histories and does not collect any personal data or samples from the participants, the results of the research are expected to be qualitative in nature. In the absence of any separate quantitative data being published, the best method to get the results of the research will be in the form of the final PhD thesis. The final PhD thesis will be available through the British Library or the Electronic Theses Online System (EthOS) in hard copy or electronic form upon request. Some of the results of the research may be published in the form of articles or papers in research journals and hence will be accessible in either paper or electronic form according to the terms of the publisher. In recognition of the participants' valuable contribution, the recording of the individual interviews will also be made available to each of the participants if requested.

Appendix D – Data retention policy for the research interviews

Data retention policy

This document details the data retention policy for the following OU research project.



Name of the project

An examination of the evolution of broadband technologies in the UK

Contact details for the principal investigator

Advait Deshpande
Email: a.deshpande@open.ac.uk
Ph: +44 (0) 1908 858169 (Extn: 53976)

Terms of compliance with Data Protection Act 1998

The purpose of the research project is to examine the history of development and deployment of broadband technologies in the UK. As part of this research, oral histories of various participants i.e. administrators, managers, engineers and researchers involved in relation to broadband technologies will be recorded. Although the participants may be identified in the final research thesis, no personal data apart from their names, organisational affiliation and the nature of their involvement in the industry will be revealed. The nature of histories recorded will be of professional nature and will reflect the opinion of the participants.

As a consequence, the research does not involve any measures or decisions targeted against specific individuals. No distress or damage any individual is expected from such a research. Within such expectations, the research plans to be fully compliant with the requirements of the Data Protection Act 1998

Process for 'Informed Consent'

As part of the interview process, all the participants will be provided an information sheet detailing the nature of the research project, expected output and contact details of the researchers before beginning the interview. All the participants will be provided and required to sign an "Agreement to participate" as part of the consent process prior to their participation.

Policy on anonymising data

Since the purpose of the interview process is to record oral histories of participant's opinions and perspectives in relation to the history of broadband technologies in the UK, the need to anonymise the participants is not envisaged at this stage. The only personal data involved will be the participant's name, organisational affiliation and the nature of their involvement in relation to the broadband technologies. Depending on an individual participant's wishes, the data may be anonymised on a case-by-case basis either in part or in entirety.

In addition to anonymity, the participants will have the right to request that any discussion or parts of it be treated confidentially at any point. Confidentiality can be requested in the following two ways -

1. The subject matter discussed may be quoted without being attributed to the participant or
2. The subject matter discussed will be completely off-the-record and cannot be quoted / attributed.

Policy on retention of data

The research data collected is intended solely for the purposes of the research. As a consequence the data is planned to be retained indefinitely. Any questionnaires or participants' answers will not be disclosed to a commercial third party and will be secured to avoid any accidental disclosure.

Right of subject access

The participants will have the right to request the recording of their individual interviews.

Process for security of data collected

The interview data and audio recordings will not be shared with any commercial third party in either paper or electronic media. Any CDs or physical media created during the research process will be subject to security procedures aimed at avoiding accidental disclosure.

Policy on the use of data for other research projects

The data collected may be used for analysis in other related research projects. Any use of the collected data in other related research projects will be subject to the requirements of the Data Protection Act 1998.

The name and complete contact details for the principal investigator

Advait Deshpande
The Open University,
Walton Hall,
Venables Building,
Department of Communication & Systems,
Faculty of Maths, Computing and Technology,
Milton Keynes MK7 6AA
United Kingdom
Email: a.deshpande@open.ac.uk
Ph: +44 (0) 1908 858169 (Extn: 53976)

The name and contact details for the primary supervisor of the research (for matters which cannot be satisfactorily resolved with the principal investigator)

Dr. Allan Jones
The Open University,
Walton Hall,
Venables Building,
Department of Communication & Systems,
Faculty of Maths, Computing and Technology,
Milton Keynes MK7 6AA
United Kingdom
Email: a.jones@open.ac.uk
Ph: +44 (0) 1908 659619

Appendix E – Agreement to participate provided to the interview participants



An examination of the evolution of broadband technologies in the UK

(Name of the project)

Agreement to participate

I,

(Print name)

agree to take part in this research project.

I have been provided with an information sheet explaining the purpose of the project and the data retention policy that governs the research project.

I have read the documents and confirm that –

1. I have had the purpose of the project explained to me.
2. I have been informed that I may refuse to participate at any point by simply saying so.
3. I have been assured that my confidentiality will be protected as specified in the information sheet and the data retention policy.
4. I understand that -
 - a. I have the right to request that any discussion or parts thereof be treated confidentially.
 - b. I may request that any such parts be either not used in research material based on the interview, or, if used, be attributed anonymously.
5. Subject to requests specified in 4(a) and 4(b) being fulfilled, I consent to being identified in non-confidential matters in the research material.
6. I agree that the information that I provide can be used for educational or research purposes, including publication.

I understand that if I have any concerns or difficulties I can contact:

Advait Deshpande

at:

The Open University,
Walton Hall,
Venables Building,
Department of Communication & Systems,
Faculty of Maths, Computing and Technology,
Milton Keynes MK7 6AA
United Kingdom
Email: a.deshpande@open.ac.uk
Ph: +44 (0) 1908 858169 (Extn: 53976)

(Name of the researcher)

If I want to talk to someone else about this project, I can contact the Associate Dean (Research) at:

Prof. Uwe Grimm
Associate Dean (Research),
Deanery, Faculty of Maths, Computing and
Technology,
The Open University,
Walton Hall,
Milton Keynes MK7 6AA
United Kingdom
Email: u.g.grimm@open.ac.uk
Ph: +44 (0) 1908 659991

I assign the copyright for my contribution to the Faculty for use in education, research and publication.

Signed:

Date:

Appendix F - The timeline of key events

Timeline	Key event(s)
1967	The Post Office began to envisage the use of PCM to deliver telephony, data, and television in an integrated manner via the same network.
1969	The Post Office was changed from a government department into a public sector corporation.
1975	The Post Office began to operationalise an all-electronic digital transmission system named 'System X' in its exchanges.
1978	The Post Office introduced an optical fibre link carrying telephone calls in public service.
1978	The review of Post Office operations from a committee headed by Prof. Charles Carter recommended that the postal and telecommunications operations should be split.
1979	The Conservative Party government came to power and began an official scrutiny of the functioning of state-owned monopolies in telecommunications and utilities industries with a view towards denationalisation of the industries and introducing competition.
1983	BT was privatised with the UK Government retaining golden shares as a minority shareholder. A regulatory body, the Office of telecommunications (OfTel) was created to oversee BT's transition into the private sector.
1984	The Telecommunications Act 1984 came into effect, introducing competition to BT and requiring BT to offer access in the last mile

Timeline	Key event(s)
	to its competitors. The Cable and Broadcasting Act 1984 paved the way for setting up multi-channel cable transmission systems.
1987	The concept of Broadband ISDN underpinned by Asynchronous Transfer Mode (ATM) technology was unveiled for the first time.
1989	The first prototype systems for High-bit-rate Digital Subscriber Line (HDSL) technology were developed at AT&T Bell Laboratories and Bellcore.
1991	As part of the duopoly review BT-Mercury duopoly was disbanded. The cable operators were permitted telephony by default.
1992	BT began its early trials for DSL as a means to deliver video-on-demand services.
1994	The UK government sold off its remaining golden shares in BT. BT was listed on the stock market and subsequently pursued an ambitious strategy of global expansion.
1997-98	BT did its first DSL trials for broadband Internet access.
1999	In order to spur investment in broadband infrastructure Oftel initiated its first round of consultations on local loop unbundling. However, these consultations failed to deliver the expected growth in unbundling.
2003	With Ben Verwaayen as its new Chief Executive Officer (CEO), BT committed to delivering 5M broadband lines by 2006.
2004-06	NTL and Telewest merged their operations post-bankruptcy to create Virgin Media, a single cable operator capable of quad-play of services.

Timeline	Key event(s)
2006	Ofcom reached an agreement with BT to functionally separate BT's network operations into a new division named 'Openreach'.
2008-09	The success of the second round of unbundling saw the retail broadband market share almost equally divided between BT and OLOs.
2011-12	The UK government and regulators unveiled a number of measures to increase investment in Next Generation Access (NGA) technologies.

Annexure – Published journal article

The following article has received the commendation below

Advait.Deshpande

From: Emma Hollindrake [EHollindrake@emeraldinsight.com]
Sent: 26 March 2014 10:46
To: Advait.Deshpande
Subject: Your paper published in 2013 has been named as a Highly Commended Paper
Dear Mr Deshpande

Congratulations, your paper "Broadband deployment and the bandwagon effect in the UK" published in *Info* has been selected by the journal's Editorial Team as a Highly Commended Paper of 2013.

The *Info* Editorial Team were asked to nominate an Outstanding Paper and up to three Highly Commended Papers. "Broadband deployment and the bandwagon effect in the UK" was chosen as a Highly Commended Paper winner as it is one of the most impressive pieces of work the team has seen throughout 2013.

We aim to increase dissemination of such a high quality article as much as possible and aim to promote your paper by making it freely available for one month. I will contact you again with further details once the paper is freely available.

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Broadband deployment and the bandwagon effect in the UK

Advait Deshpande

Advait Deshpande is based at the Communication and Systems Department, The Open University, Milton Keynes, UK.

Abstract

Purpose – *The aim of this paper is to look at the extent to which the bandwagon effect played a part in digital subscriber line (DSL) broadband adoption combined with the regulatory measures, the slowdown in the cable industry and the changes within the telecommunications industry in the United Kingdom (UK). The dynamics of broadband deployment, broadband adoption against a real-world supply-demand equation and the factors that influenced the outcome in the UK are examined in detail.*

Design/methodology/approach – *This paper combines historic facts and socio-economic analysis done from archival research and interview material to examine the outcome in which the less-heralded copper DSL technology outpaced cable broadband adoption. The analysis delves into the influence of the bandwagon effect and the two types of outcome associated with it i.e. network externalities and the complementary bandwagon effects.*

Findings – *The paper argues that the deployment of broadband technologies in the UK has not taken place solely on the merits of the technology or factors such as speed, end-user demand and costs. A combination of factors related to regulatory decisions, status of industry finances, commercial expediency, short-term technical benefits and the bandwagon effect are argued to be at work.*

Originality/value – *The paper is useful for historians, policy makers, regulators and communications industry analysts given its focus on broadband deployment in the UK in correlation to the bandwagon economics.*

Keywords *British Telecom, Broadband networks, Telecommunications industry, Regulation, The bandwagon effect, United Kingdom, Telecommunication*

Paper type *Research paper*

Introduction

As of 2001, the broadband market in the UK was in its nascent state. In the early to late-1990s, the term “broadband” mostly referred to broadcast television and video content that was carried by cable networks (hence the mention of broadband cable in some of the literature (see Fox, 1990). Telecom industry initiatives like Integrated Service Digital Network (ISDN) and Broadband ISDN (B-ISDN) were in part aimed at bringing such high-bandwidth, video capabilities to the telecom networks (Kano *et al.*, 1991). Video-on-demand (VOD) and pay-per-view were seen as the premium services that would provide additional revenue-earning opportunities in an increasingly competitive market (see BT, 1994a, 1998a) for BT’s forays into the on-demand and broadcasting services; Young, 2012). In the mid to late 1990s, with the growth in the narrowband (i.e. dial-up) subscriptions for Internet access, telecom operators began to consider the alternatives to delivering high-speed data to the end-users.

In this context, British Telecom (BT) conducted Digital Subscriber Line (DSL) trials in 1997-1998 to decide whether copper-based DSL was a good enough conduit for delivering internet access. BT however remained uncertain about whether a market existed that would deliver a return on the investment for enabling the existing copper networks to deliver DSL

Received 18 September 2012
Revised 25 October 2012
Accepted 29 October 2012

The author wishes to acknowledge the valuable inputs and advice from Dr Allan Jones in preparing the paper. The author would also like to thank the staff at BT Archives and Porthcurno Telegraph Museum for providing access to the BT annual reports and Cable & Wireless annual reports respectively.

connectivity. This question of return on investment (ROI) and what kind of services such high speed broadband[1] would deliver was also critical to the cable industry. The UK cable industry had consolidated into two major players, NTL (originally National Transcommunications Limited) and Telewest. Both cable operators needed an additional source of revenue to compete with British Sky Broadcasting (BSkyB) Corp., the premier satellite broadcasting services provider in the UK, on the content front. On the telephony front, NTL and Telewest had to contend with the significant market power (SMP) of BT. In addition, the extent to which such broadband connectivity could be monetised, and the kind of premium services it would enable, was unclear. With close to 10 million end-users already using dial-up internet access (Office of Telecommunications i.e. OfTel, 2001a), the extent and speed with which such end-users could be switched to a broadband connection that cost significantly more was also difficult to ascertain.

All these factors created an uncertain environment for telecom operators such as BT and the cable operators such as NTL and Telewest in relation to rolling out broadband. This paper discusses the eventual outcome in relation to the deployment of copper-based DSL and coaxial cable broadband during the period from 2001 to the present day. Such deployments are considered in the context of the supply-and-demand dynamics for broadband technologies and the role of bandwagon effect on their adoption. The paper uses archival research and interviews with industry experts (see Table I) to argue that in the deployment and adoption of broadband technologies, technical merits or economic feasibility were not the only factors that influenced the outcome. This argument is crucial since the success or failure of technologies is often attributed to benefits relative to their price or technical merits. The paper examines a range of factors associated with regulatory policy, industry circumstances and the bandwagon economics[2] to present a detailed analysis of the events.

Bandwagon economics and the supply-demand equation

The bandwagon effect in microeconomics refers to the situation where the benefits of a product or service derived by an end-user increase relative to the number of end-users who use the product or service (Leibenstein, 1950). Such an accumulation of end-users creates a strong demand for the product or service and influences the supply-side significantly. The bandwagon effect is one of three complementary effects in the theory of demand along with the Snob effect (which focuses on the exclusivity of a product/service driving the demand) and the Veblen effect (which focuses on the increase in the pricing of a product/service driving the demand) (Leibenstein, 1950).

The bandwagon effect is manifested in two types of outcomes that influence the accumulation of end-users. The first type of bandwagon effect is the network externalities. Due to the network externalities, the benefits available to end-users increase or multiply because of the additional end-users who use or sign up for the product or service (see Rohlfs, 1974) which specifically discusses interdependent demand in the communications industry and its relation to an increase in the number of end-users). The network externalities are associated with the demand-side equation of the bandwagon effect. The second type of bandwagon effect is known as the complementary bandwagon effects. As a result of the complementary bandwagon effects, the supply of the product or service increases in response to the cumulative demand for competitively priced complementary products or services created by the bandwagon effect (Haring *et al.*, 2002; Rohlfs, 2001). In contrast to the network externalities, the complementary bandwagon effects are associated with the supply-side of the bandwagon effect.

Part of the argument presented by the theory of demand and the bandwagon effect is that the end-user demand is not just driven by the pricing of products or services but also by the value and quality. The events throughout the 2000s show that the technical merits and pricing are just one of the factors that influenced the end-user demand and the deployment of broadband technologies. For a better understanding of the outcome, the factors that influenced the supply-side of the broadband deployment also need to be considered. To understand the influence of the bandwagon effect, the next two sections look at the factors

Table 1 Details about the interview participants

<i>Name</i>	<i>Expertise and affiliation in the communications industry (at the time of the interview)</i>
John Cioffi	Responsible for Orthogonal Frequency Division Multiplexing (OFDM) based Discrete MultiTone (DMT) method being used in DSL that made DSL a practical technology Founder of Amati Communications Corporation (now part of Texas Instruments) that did pioneering work on the first functioning DSL modems Spearheaded the development of xDSL technologies and related standards, the latest of which is Dynamic Spectrum Management (DSM)
David Clarkson	Competition Policy Director, Ofcom
John Cluny	A veteran of the UK communications industry Regulatory economist with a focus on the cable industry
Jon Crowcroft	Marconi Professor of Communications Systems in the Computer Lab, at the University of Cambridge Member of Technical advisory board at Max Planck Institute for Software Systems (MPI SWS), Institutos Madrileños de Estudios Avanzados (IMDEA) Networks, Korea Advanced Institute of Science and Technology (KAIST), Onelab and the Foundation for Information Policy Research Advisory Council Former professor in the Department of Computer Science University College London (UCL)
Richard Feasey	Public Policy Director at the Vodafone Group A veteran of the communications industry with past stints at Ionica and in the cable industry
John O'Reilly	Vice-Chancellor of Cranfield University Specialist advisor to the UK Government and the European Commission Chairperson of UK's Network Interoperability Consultative Committee (NICC) for Ofcom and the telecommunications industry Former Principal Research Fellow with BT Former Chief Executive of the Engineering and Physical Sciences Research Council (EPSRC) Former President of the Institution of Electrical Engineers (now the Institution of Engineering and Technology (IET))
Mike Pemberton	Access network architect at Sky Network Services
Peter Shearman	Head of Infrastructure Policy, Broadband Stakeholder Group (BSG)
Trevor Smale	A veteran of the UK communications industry Regulatory expert and advisor Lengthy stints in NTL and now Virgin Media
Malcolm Taylor	Former President of EuroDOCSIS Former Director of regulatory and public policy at Telwest (later Virgin Media)
Andy Valdar	Visiting professor in telecommunications strategy with the Dept. of Electronic and Electrical engineering at UCL 30 year tenure in BT where responsibilities ranged from network strategy and planning, international standards, technical aspects of regulation to product management and development
Ben Verwaayen	Chief Executive Officer (CEO) of Alcatel-Lucent Former Chief Executive of BT (2002-2008) Former Vice Chairman of the Management Board at Lucent Former President and Managing Director of PTT Telecom, a KPN (Koninklijke KPN N.V., originally Koninklijke PTT Nederland) subsidiary
Gavin Young	Head of Strategy and Planning, Cable & Wireless Worldwide Advisor, Ofcom Spectrum Advisor Board (OSAB) Former Board Director/Technical Chairman, Broadband Forum

that drove the rollout of broadband connections based on coaxial cable and copper DSL technologies respectively. This discussion is then followed by an analysis of the socio-political and regulatory factors that influenced such rollouts.

Coaxial cable

Following significant consolidation in the cable industry in the late 1990s, there were two major players left in the UK – NTL and Telewest. Despite the consolidation however, the coaxial cable network reached only 50 per cent of UK households and businesses (Ofcom, 2002a). On the other hand, the copper-based Public Switched Telephone Network (i.e. PSTN used by telecom operators such as BT) had a near universal reach to the UK households

and businesses. Although cable operators could carry BSkyB content through a wholesale agreement, and they were allowed to carry telephone services, they still sought a product that would be their unique selling proposition. With the narrowband market approaching saturation (OfTel, 2001a)[3], the demand for higher speeds and higher bandwidths was visible and suggested that a consumer market existed for broadband connectivity. The problem faced by the cable industry was of being unable to decide the extent of the rollout for such connectivity and its pricing.

Compared to the telecom operators, the cable industry had one critical advantage when it came to broadband rollouts: its network was built on coaxial cable and hybrid-fibre coax (HFC) technologies. In addition to being able to carry high-speed and high-bandwidth data, the cable networks were also superior to the copper PSTN in suffering far less from signal attenuation. A copper DSL broadband connection would decrease in bandwidth and speed as the distance of the end-user premises from the local exchange increased. The cable networks were not affected by this limitation and could deliver nearly the same bandwidth over the entire distance. In subsequent years, as the cable industry worked to minimise its legacy problems, such as fragmentation of standards, systems and services, the inherent technical merit of its network allowed the cable operators to position themselves as providers of a combined bundle of telephony, television and broadband services (Taylor, 2012). Effectively, on the back of the HFC investments made in the 1990s and the Data Over Cable Service Interface Specification (DOCSIS) standards, cable operators could offer a superior, vertically integrated broadband product. The telecom operators, in turn, saw an opportunity to counter the cable operators' broadband proposition by delivering next generation DSL capabilities. The intervention by the regulatory bodies for the UK telecommunications sector (OfTel, and later the Office of Communications i.e. Ofcom) proved crucial at this juncture. From 2004 onwards, Ofcom re-worked its unbundling strategy (Clarkson, 2012). The functional separation of BT (described below), achieved in 2006, further fuelled the competition for copper DSL as the next section explores.

Copper DSL

Compared to coaxial cable/HFC, copper DSL was mostly an unheralded technology. Although the DSL technology and some of its modulation techniques had been conceptualised as early as 1993[4] (Cioffi, 2011a), it was not until 1997-1998 that BT considered DSL for delivering broadband internet connectivity (BT, 1998b). With speeds of 2 Mbit/s that dropped progressively beyond the initial 3 km length of the copper wire from the end-user premises, DSL was perceived to be a short-term solution (Starr *et al.*, 1999). As a result, DSL was expected to tide over the limitations of narrowband connectivity until the eventual deployment of optical fibre.

Despite its limitations however, DSL had other advantages. Not only would copper DSL allow the telecom operators to make the most of their existing copper assets (Cioffi, 2011b; Shearman, 2012), the technology also enabled efficient utilisation of the bandwidths that copper could deliver. At the time of its conception in 1993-1994, DSL was considered by incumbent telecom operators as a technology that would allow VOD services to be run on copper networks (see Cioffi, 2011a). Given the asymmetric nature of digital applications (covering video and data), Joseph Lechleider, one of the architects of the DSL concept, suggested using more bandwidth downstream than upstream, a concept that was equally applicable to the nature of Internet traffic (Cioffi, 2011a). Such Asymmetric DSL (ADSL) meant that a copper pair could be effectively used to deliver speeds of 2 Mbit/s downstream and 128 kbit/s upstream (Starr *et al.*, 1999), a capacity previously inconceivable in relation to copper. However, despite the subsequent improvements that allowed it to carry higher speeds over longer distances, the DSL broadband would still remain comparably slower than cable broadband on most occasions.

An advantage of DSL was its relative ease in delivering broadband to existing telecommunications end-users. When the local exchange was equipped with DSL capability, the end-user's premise only needed to be fitted with a modem and a

micro-filter device (more specifically an ADSL splitter) that would separate the data and voice traffic and deliver the promised broadband connectivity (Valdar, 2006). The self-installation of such equipment by the end-users avoided the need for an engineer to visit the end-user premises and further lowered the cost of deployment for a telecom operator such as BT (Starr *et al.*, 1999). When the prevailing economic and regulatory environment is considered, all these factors could be seen to have added up in favour of copper DSL technology despite its limited technical merit. These prevalent economic and regulatory factors are discussed in the next three sections.

Narrowband and the network congestion

Up to 2000-2001, most of the Internet connectivity in the UK was provided by narrowband connections based on the PSTN. Several Internet Service Providers (ISPs) used an unmetered wholesale access product from BT called Flat Rate Internet Access Call Origination (FRIACO). As a result of FRIACO, fully unmetered retail packages (giving unlimited data usage and no call costs) were available for £12.99 - £14.99 a month (OfTel, 2001a). With 10 million narrowband end-users and the internet traffic doubling every ten months, the end-user experience was soon expected to be plagued by network congestion and significantly lower speeds as a consequence (O'Reilly, 2005, 2011). Such congestion pointed to a need to upgrade the existing copper-based technology and to better manage the increasing demands on BT's switches in the core network. The resolution depended not only on ascertaining the end-user demand but also on determining whether the end-users would be willing to pay the additional cost of upgrading to broadband.

By this time, OfTel needed to align its policies with the European Union (EU) regulatory framework. OfTel also needed to achieve the goals set by the Labour government for internet access and speeds^[5] (OfTel, 2001b). As a consequence, OfTel considered measures such as local loop unbundling (LLU). With LLU, OfTel aimed to lower consumer prices, increase competition in the access network and infuse additional investments in the network infrastructure (OfTel, 1998). Part of the reason to push unbundling was to accelerate the deployment of broadband technologies by telecom operators, particularly BT (OfTel, 1998). Despite the fact that BT had conducted its most recent trials of copper-based DSL technology in 1997-1998, uncertainty prevailed in the fixed-line market about not just the potential of DSL but also the returns on such an investment due to demand constraints (OfTel, 2001b; Haring *et al.*, 2002; Verwaayen, 2012).

An important impetus to BT's decision making in relation to a DSL broadband rollout was the competitive threat from the cable industry which, with the consolidation into NTL and Telewest, had the potential for scale it lacked before. With regulatory price caps on its telephony revenue, BT also needed to create new revenue streams (Feasey, 2012). Despite the technical superiority of the cable network, one of its main limitations was that it had at the most 50 per cent market reach and broadband could not be delivered to about 5 per cent of these premises due to technical limitations (OfTel, 2002a). Effectively only 45 per cent of the UK households and businesses could get cable broadband (OfTel, 2002a). In addition, the cable network suffered from significant fragmentation in terms of the network equipment, implementation of standards, end-user equipment, information systems and end-user services issues (Taylor, 2012). These problems were due to the original nature of cable franchise allocation in the late 1980s and 1990s as a result of which more than 100 cable franchise areas existed in the UK^[6] (ITC, 1997). The presence of such disparate franchise structure led to the implementation of incompatible standards and equipment in these franchises (Taylor, 2012; Cluny, 2012). Most importantly such fragmentation meant that until the consolidation, the cable industry lacked the capability to rapidly build the economies of scale in order to compete with the telecom operators on pricing and upgrading the cable plants for delivering broadband. Some of these difficulties were exacerbated by the events related to the 2000-2001 dotcom crash, the subsequent recession and the changes in the US market (Feasey, 2012).

Dotcom crash, recession and bankruptcy

A significant amount of investment in the UK cable industry throughout the late 1980s and 1990s was made by cable and telecom companies such as Comcast, Bell Cablemedia, Nynex and Videotron which had parent operations in the USA and Canada (ITC, 1997). Some of these companies looked for opportunities in the UK, partly because of the regulatory restrictions in the USA which limited investment opportunities. Since the cable industry in the UK was significantly less regulated than the USA, the UK was an attractive investment destination (Feasey, 2012). By the mid to late 1990s, there were ten cable companies operating in the UK, with more coming later (ITC, 1997). In addition, not all of these operators functioned in contiguous franchise areas (Cluny, 2012). All of this resulted in the significantly fragmented nature of cable operations in the UK. With the dotcom boom in the late 1990s and the subsequent dotcom crash, some of these companies were severely stretched financially (Curwen, 2002). In the subsequent years, as the regulatory restrictions in the USA eased, the North American cable and telecom companies largely exited the UK market either by systematic withdrawal or by selling their UK cable assets completely (Feasey, 2012; Smale, 2012; Taylor, 2012). An example is Cable & Wireless Communications which was created in 1997 with the merger of Mercury Communications and the UK cable operations of Nynex, Bell Cablemedia and Videotron (C&W, 1997; ITC, 1997). These events meant that although the UK cable industry could finally operate on a regional scale it had previously been incapable of, it no longer had the financial wherewithal to do so. The outcome of this financial crunch, combined with the costs of integrating the fragmented UK cable operations and the pressure from BSkyB and BT, was the near-collapse of the UK cable industry (Smale, 2012; Taylor, 2012). The two companies that had emerged in the consolidation, NTL and Telewest, went into administration in 2002 (Curwen, 2002, 2003) and had to undergo financial restructuring. Consequently, the UK cable industry did not have the financial strength to push for cable broadband in the nascent stage of the broadband market. As a result, despite the technical advantages of cable broadband, its deployment was significantly constrained.

Similar financial constraints also affected BT which had made large investments outside the UK throughout the 1990s. Most of these investments were made on the back of its annual profits to the tune of £1-2 bn in the UK in the early 1990s[7] (BT, 1992; 1993a; 1994b). Since BT was prohibited from carrying television content on its main network until 1999, it had continually argued an inability to invest in deploying optical fibre in its UK access network, citing lack of opportunities to recoup its costs (BT, 1993b). In addition, although BT had retained SMP in a number of market segments, it faced increasing competition with the introduction of mobile telephony. Another factor responsible for the increased competition was the disbanding of BT's duopoly with Mercury Communications and the resultant full liberalisation of the UK telecommunications industry in 1992. Some of BT's major investments during this period were the costly 3G licence in the UK (£4.03 billion in 2000, see BT, 2000, p. 14), 3G licence in Germany (for Viag Interkom purchased at the cost £5.13 bn in 2000-2001, see BT, 2001a, p. 14), Netherlands (BT paid £1.2bn to acquire Telfort in April 2000 and paid £267 million for a Dutch 3G licence, see BT, 2001a, p. 14) and France (BT acquired a 26 per cent stake in Cegetel in September 1996 for £1 billion, see BT, 1997, p. 19). This meant a significant amount of BT's financial resources were tied up not just in the UK but outside the UK as well. Although BT made tidy sums of profit on some of these ventures[8], by 1999 BT losses from its ventures outside UK grew to £342 mn (BT, 1999, p. 31). By March 2000, BT's net debt grew to £8,700 million with an increase of £7,747 million in the financial year 1999-2000 (BT, 2000, p. 36). In the financial year 2000-2001, the net debt rose to £27.9 billion and BT had to take measures to reduce its debt (BT, 2001b, p. 2). Part of the subsequent restructuring led to demerger and eventual sell off of BT's mobile services business in Europe[9]. Although the £17.7bn generated enabled BT to reduce its debt significantly, BT would miss out on the higher Average Revenue Per User (ARPU) earned by mobility companies over the next decade (Crowcroft, 2012). BT would also have to endure low revenue streams in the existing saturated fixed-line telephony market in which its prices were capped (Feasey, 2012). The outcome was that BT not only lacked the justification for investment into optical fibre but also that DSL was the most expedient option in economic

and commercial terms for delivering broadband. The drive for DSL deployment was further spurred by the regulatory measures adopted by Oftel/Ofcom and some of the key decisions made by BT as the next section examines in detail.

Regulation, further consolidation and unbundling

Aside from the financial problems faced by the cable companies, the focus of their activities after the consolidation remained on reducing the problems of fragmentation, incompatible systems and standardising equipment across regions (Cluny, 2012). The cable industry was unsure of the potential of broadband and the extent to which internet-based premium services could be monetised (Cluny, 2012). As a result, NTL and Telewest chose to focus on improving their operations to achieve better economies of scale. In March 2006, the operations of NTL and Telewest were consolidated to create "NTL:Telewest". A further merger with Virgin Mobile in July 2006 led to the creation of a rebranded, single entity – "Virgin Media". In effect, Virgin Media became the first UK company to offer a quadruple play of services i.e. television, broadband, fixed and mobile telephony (Smale, 2012).

During this period of further consolidation in the UK cable industry, the DSL rollout had given BT and the other telecom operators wider reach in the UK for their broadband products by 2006[10]. Although the process of unbundling had been initiated in 1999, very few operators showed any interest in unbundling until the mid-2000s (Ofcom, 2004). This was partly due to the unfavourable economics of unbundling for the other line operators (OLOs) (Oftel, 1998; Sandbach and Durnell, 2002). The OLOs, as a result, had mostly relied on the wholesale line rental (WLR) services to rent the capacity and DSL connectivity from BT instead of building their own routes into the BT exchanges. By the mid-2000s, the market was deemed to be over-reliant on BT's wholesale products (Ofcom, 2004, 2005). The increased end-user demand suggested that the deployment of next generation DSL equipment in the form of ADSL2 and ADSL2+ technologies was needed. This led to an increased interest in unbundling and spurred an intervention on the part of Ofcom (see Stern (2004) for changes in the regulatory approach with the transition from Oftel to Ofcom). Because of the limited success of the earlier unbundling initiative, Ofcom's focus this time centred on enabling equal access and ensuring that the OLOs' broadband products were not disadvantaged by BT's wholesale pricing (Ofcom, 2004, 2005, 2006).

Another aspect of the increased DSL rollout was that in 2002, BT had set an ambitious agenda for rolling out DSL connectivity to the exchanges and the end-users' premises. This agenda was set in motion by BT's then Chief Executive Ben Verwaayen. He also devised specific time-bound targets for BT to achieve these goals. Combined with the take up of wholesale connectivity, the aim was to deliver five million broadband connections in the UK by 2006 (BT, 2002, p. 13). This rollout relied on the legacy copper infrastructure which was mostly owned by BT. As a result, BT held SMP in the wholesale broadband market segment and led the retail broadband segment[11] (Ofcom, 2006). In consequence Ofcom decided to intervene in order to inject more competition into the broadband market.

With the possibility of Ofcom taking BT to the Competition Commission (CC) and recommending a structural break up of BT, an agreement was reached between BT and Ofcom for functional separation of BT operations (BT, 2006; Ofcom, 2006; see Stern, 2004 for discussion on the policy of structural separation in the UK regulatory regime). Under this agreement, BT would create a separate division named "Openreach" for its network operations and ensure equality of access and pricing for the OLOs. This meant the charges paid by BT's Retail division and the OLOs for Openreach services would be the same without any cross-subsidy, prioritisation or preference to BT's operations. The creation of Openreach and the related equality of access conditions played a significant part in fuelling the competition for delivering broadband (Pemberton, 2012; Young, 2012). By 2009, TalkTalk, Virgin Media and BT Retail had almost similar market share within the retail broadband space with Sky also registering double digit market share[12]. The outcome was that the broadband tariffs continued to reduce in favour of the end-user[13] and provided further incentives to DSL broadband adopters. By this time, the near universal adoption of the Institute of Electrical and Electronics Engineers (IEEE) 802.11 WiFi standards in devices

such as laptops, mobile phones and customer premise equipments (CPEs) had made broadband adoption an easier and more attractive prospect for end-users. The improvements in the speeds delivered by the 802.11 standards and the increased availability of wireless connectivity via WiFi hotspots provided an important benefit for the growing number of end-users. The reliance of these WiFi hotspots on DSL broadband combined with the increased demand and competition was one of the factors that led to the introduction of ADSL2 and ADSL2+ products. Effectively, the average actual residential broadband speeds in the UK increased up to 7.6 Mbit/s by November 2011 (Ofcom, 2009, 2011, 2012a; Shearman, 2012; Young, 2012).

The impact of this race within the DSL broadband space was that the cable broadband adoption numbers lagged behind the DSL broadband numbers throughout this period[14]. With the cable industry focused on consolidation and integrating their operations, BT's introduction of DSL broadband via a registration scheme successfully overtook the cable numbers by 2003-2004 (see note 14). Considering the near-ubiquitous reach of the copper PSTN, the availability of DSL broadband connections was also significantly higher than the cable broadband technology (see note 10). However, with the creation of Virgin Media, the threat from the cable industry became more credible (Cluny, 2012). Since then the increasing broadband speeds delivered by Virgin Media have led to additional investments in Very-high-bit-rate digital subscriber line (VDSL), Fibre-To-The-Cabinet (FTTC) and, potentially vectored VDSL deployment by BT and investments in ADSL2+ by the LLU operators (Clarkson, 2012; Ofcom, 2009). The next section discusses these events and the extent to which the relative success of DSL broadband was influenced by the bandwagon effect.

The bandwagon effect on the broadband race

One of the problems faced by the telecom operators was that without a critical mass of end-users, broadband could not be delivered at prices comparable to the existing narrowband connections. Another difficulty faced by the operators was that of converting the existing narrowband end-users to sign up for broadband. This meant convincing the end-users of the superiority and advantages of the broadband connections offered by telecom or cable operators. Having realised the importance of broadband, Oftel wanted to promote competition in the broadband market by enabling unbundling of local loop and allowing OLOs to deliver copper-DSL to end-users. It can be argued that BT's approach until this time had been cautious and effectively hedged on the basis of the volume of dial-up connections and a lack of clear demand for broadband at a higher price than dial-up (Pemberton, 2012). This is crucial in that although the end-users arguably wanted higher-speed, the extent to which they were willing to absorb the cost of copper DSL rollout and the higher monthly charges was uncertain. Thus BT's position depended on the justifiability of investments in the face of this uncertainty. Its solution was the ADSL registration scheme (described below) which eventually resulted in a rapid DSL rollout throughout the UK and left cable broadband adoption behind in its wake[15].

In particular, the bandwagon effect can be observed to be at work in relation to BT's rapid expansion of DSL capability into the exchanges. When BT launched the ADSL registration scheme, it was in part to justify the investment in DSL, gauge the demand for higher-speed and more expensive service (than dial-up), to enable a deployment plan for BT's broadband products and position its response to BT shareholders and Oftel. As part of this ADSL registration scheme, subject to the cost of DSL deployment being viable, BT promised to rollout DSL equipment to exchanges in those areas which had achieved a minimum threshold of end-user registrations (Oftel, 2002b). The minimum threshold varied depending on the size of the exchange and the area under consideration. Such a strategy was arguably in line with BT's traditionally cautious approach towards rolling out new technologies (Cioffi, 2011b) and in part influenced by the need to justify investments given its financial position in 2001. BT's approach also mirrors Rohlfs' (1974) argument about using community of interest groups to achieve maximum (equilibrium) demand despite small size of initial user set. Despite field-trials during the later 1990s, DSL was a relatively untested product in actual deployments and the speeds offered by copper varied significantly depending on the

distance of the end-user from the exchange and the quality of the line. In the context of the 2000-2001 economic recession, a short-term benefit of DSL to the embattled telecommunications operators (including BT) was that it would allow higher speeds to be delivered without the significantly higher investments of fibre. The registration scheme proved that sufficient demand existed and once the rollouts began, the end-users signing up for the DSL product began to accumulate quickly (see note 14).

The initial DSL broadband product was costlier than the existing narrowband products[16]. However, the speed benefits of DSL broadband were significant[17]. In addition, unlike the narrowband connection, a DSL connection also allowed the telephone line to be available while the internet was being used. It is arguable that the early adoption of DSL broadband was driven by both these advantages over the existing narrowband connections. Having managed to ascertain the demand for DSL, BT's push for installation of DSL equipment was also set apace by the goals set by its then chief executive Ben Verwaayen (BT, 2002; Valdar, 2012; Verwaayen, 2012). As a result, the uncertainty around the financial viability of broadband deployment was successfully over-ridden. These factors resulted in a positive supply-demand side equation in which the increasing number of end-user registration led to wider DSL broadband roll-out. The subsequent DSL roll-out in turn was spurred by the increased demand.

Such a situation demonstrates both the types of the bandwagon effect at work. The network externalities are evidenced by the increase in the end-user registrations (see note 14). It became obvious that the DSL rollout would indeed take place subject to registered end-user interest and that it clearly delivered benefits over the existing narrowband connections. In consequence, the demand side of the bandwagon effect was firmly established[18]. On the other hand, the complementary bandwagon effects are evidenced by the extent to which better speeds and the ubiquity of WiFi accelerated the DSL broadband rollouts[19]. Each of these supply-side effects contributed to the increased availability of DSL broadband. This rollout was also aided by a supply-side push on BT's part in response to regulatory pressure, reduced margins on the telephony services revenues and the availability of BT wholesale DSL products. The reliance of the OLOs on the BT wholesale DSL product as a means of competing, pointed to BT's stranglehold on the broadband market. As a result, Ofcom pursued unbundling and the functional separation of BT to promote more competition.

Throughout this period, the capability of the cable networks to offer higher speeds and the possibility of market loss kept the telecom operators motivated and resulted in deployments of ADSL and ADSL+ by the LLU operators and BT (Clarkson, 2012; Young, 2012). The cable operators, in turn, needed to distinguish their services since the telephony services were mostly commoditised. Their reliance on the wholesale content from BSkyB meant that delivering higher-speed broadband was a potentially important revenue stream. With the purchase of Virgin Mobile and the final consolidation into the "Virgin Media" brand, the cable network could deliver potentially quadruple-play of services and allow Virgin Media to position itself as an end-to-end service provider instead of just being a television or telephony operator (Cluny, 2012). Thus, although the adoption of cable broadband lagged behind DSL broadband in the long run, the competitive threat of cable broadband was one of the key factors that influenced DSL broadband rollout and the bandwagon effect that accelerated it.

Conclusions

Until the mid-1990s, broadband was mostly associated with the delivery of broadcast television and on-demand video. The communications industry's expectations centred on delivering premium content services over the networks and the innovation was driven by the projected demand for such services. These expectations about delivering video as a revenue stream are seen to persist until late 1990s. By 1999-2000, the demand for the internet had become evident as witnessed by the dial-up adoption numbers. This opened up an unforeseen revenue opportunity for the communications industry. The focus of delivering a broadband service shifted to delivering a high-speed connection to the internet instead of delivering just television or video-on-demand.

The copper-based PSTN had significant limitations when it came to delivering a high-speed connection. The alternatives available for the fixed-line operators (including cable) were DSL, coaxial cable and optical fibre. In the short term, optical fibre was ruled out due to the costs involved and the fact that the financial resources available were limited. That left DSL and cable broadband as the options in contention. DSL allowed the telecom operators to deliver broadband by sweating the existing copper assets. While it cost significantly less compared to optical fibre, DSL still required an investment that a company like BT would need to justify to its shareholders and investors. Although some trials had been done with DSL technology, it remained an untested technology in terms of large field-deployments.

However, the early adoption of DSL broadband was not driven by pricing benefits but the advantages it offered over the prevalent narrowband market. The speed and convenience of broadband effectively meant that as the DSL rollout gathered momentum, the number of end-users jumping on the DSL bandwagon also increased in proportion. At the same time, due to the prevailing market and economic circumstances, cable broadband, a superior technology, lagged behind DSL broadband in end-user adoption.

The bandwagon effect propelled the subsequent DSL adoption due to the demand for better Internet speeds and was also aided significantly by the falling prices. Cable broadband, despite the head-start in end-user adoption, was plagued by legacy issues within the cable industry. Although the telecom operators were also faced with financial problems, the DSL broadband did not suffer from the problems of fragmentation and incompatible standards. This meant that the rollout of DSL equipment was easier to accomplish. The uncertainty and questions around return on DSL investment faced by BT were partly answered by the registration scheme which clearly demonstrated a demand for higher speeds. The subsequent reduction in prices can be attributed to a combination of the competitive threat from cable, regulatory pressure from Ofcom in the form of unbundling and the increased economies of scale due to the wider rollout of DSL equipment. The growth in end-user demand, increased rollout of DSL equipment and the introduction of next-generation DSL technologies that delivered higher speeds were the benefits of the bandwagon effect. The growth in end-users and the impact on pricing of broadband connections being offered indicate the network externalities that drove the demand-side of the DSL bandwagon. On the other hand, the subsequent acceleration in the rollout of DSL equipment at the BT exchanges, increased speeds due to the push for ADSL2, ADSL2+ deployments by LLU operators, ubiquity of WiFi-capable devices and wider availability of WiFi hotspots illustrates the complementary bandwagon effects that influenced the supply-side of the DSL bandwagon.

That the bandwagon effect worked in DSL's favour was a result driven by the prevailing technical, regulatory and socio-economic factors. The commercial and political expediency of DSL was aided by the combined influence of such factors along with the benefits that increased with end-user adoption (thus echoing the premise of the bandwagon effect). In the UK, the bandwagon effect led to positive supply-demand equation between the end-users, the incumbent operator (BT), OLOs and the regulator (Ofcom).

A critical catalyst for the acceleration of DSL broadband adoption was the unbundling initiatives and landmark agreement in 2006 that created Openreach. The arrangements for equality of access and transparent retail-wholesale pricing triggered by the functional separation of BT were unique in the telecommunications regulatory environment. Its influence on the outcome can be evidenced by the lowering of broadband tariffs and entry of LLU operators such as TalkTalk and Sky into the UK market. This particular regulatory intervention meant that Ofcom's goal of delivering the best price environment for the end-users (including wholesale customers such as OLOs that rented capacity from BT) and developing a competitively priced market was fulfilled for a short term. Effectively, the bandwagon effect worked in tandem with regulatory decisions, status of industry finances, commercial expediency and short-term technical benefits of DSL over optical fibre and the competition from cable and LLU operators. The combination of all these factors stimulated broadband deployment and adoption in the UK. As a result, although cable broadband had led in terms of end-user numbers and technical merits as of 2001, by the end of the 2000s, DSL broadband deployment and adoption was firmly in the lead.

Notes

1. As of November 2001, dial-up or narrowband access was defined as “speeds up to and including 128 kilobits per second (kbps)” (Of tel, 2001a, p. 3). Broadband was defined as “higher bandwidth, always-on services, offering data rates of 128 kbps and above.” (Of tel, 2001a, p. 3). Although Of tel/Of com still defines broadband as minimum 128 kbit/s, in practice the minimum speeds delivered have risen to 2 Mbit/s (Of com, 2006, 2009).
2. This paper uses the term bandwagon economics to denote the superset of ideas associated with the bandwagon effect, network externalities, complementary bandwagon effects and their influence on the economics of technology deployment and adoption.
3. The November 2001 Of tel report estimates that there were over 400 ISPs operating in the UK. 80 per cent of the online households and 63 per cent of the small and medium enterprises (SMEs) with internet access relied on narrowband connections. With ten million homes and two million SMEs using narrowband, the market was arguably saturated.
4. Joseph Lechleider from Bellcore, proposed the use of ISDN's improved echo-cancelled 2B1Q line code for each of T1's two twisted pairs thus yielding a speed of 800 kbit/s per pair i.e. 1.6 Mbit/s in total. He termed this high-speed digital subscriber line (HDSL), generally considered the first variant of DSL (see Cioffi (2011a) for further details).
5. The stated goal was for the “UK to have the most extensive and competitive broadband market in the G7 by 2005” (Of tel, 2001b, p. 3)
6. The Independent Television Commission (ITC) Annual Report 1997 mentions that 124 franchise areas had been awarded by Cable Authority before 1991. In the same report, ITC mentions 39 additional franchises being advertised or licensed in 1997.
7. BT's profits after tax for the financial year ending in 1992, 1993 and 1994 were £2.07bn, £1.24bn, £1.8bn respectively (BT, 1992; 1993a, b).
8. e.g. BT agreed to sell Airtel in Spain to Vodafone for £1.1 billion (BT, 2001b, p. 31). BT also sold its 34 per cent stake in Sunrise communications in Switzerland to Tele Danmark for the equivalent of £464 million in cash, realising a profit of over £400 million. (BT, 2001a, p. 10)
9. The demerger was completed in November 2001 when mmO2 plc was created. The mobile services provided by mmO2 would be under the “O2” brand (Curwen, 2009). In 2005, Telefónica, the Spanish Telecommunications operator agreed to buy mmO2 and BT Group's mobile business in the Europe for £17.7 bn (Curwen, 2006).
10. The cable network footprint mostly remained the same at 50 per cent of the UK homes and businesses. On the other hand, the DSL broadband reach grew from 60 per cent as of 2001 (Of tel, 2001a) to 99.7 per cent of homes and businesses by 2006 (BT, 2006, p. 9)
11. As of 2005, BT's portfolio of wholesale products accounted for 70 per cent of the broadband connections (Of com, 2006, p. 146). In 2005, BT's share of the retail broadband market was 24 per cent, the highest among all broadband providers (Of com, 2006, p. 147). In the retail segment, BT's nearest competitors were NTL and Telewest at 20 per cent and 10 per cent market share respectively (Of com, 2006, p. 147).
12. In 2009, the market share in the retail broadband segment for BT, Virgin media, TalkTalk and Sky was 25.9 per cent, 22.5 per cent, 24.7 per cent and 12.4 per cent respectively (Of com, 2009).
13. The average monthly cost of DSL for residential and small business end-users in November 2001 was £40 (Of tel, 2001a). The average monthly cost of DSL for residential and small business end-users in September 2003 was £22-£24 (Of tel, 2003). By 2012, when bundled with landline (excluding line rental) the monthly costs were as low as £6.49 depending on the contract length, speed and data usage (Of com, 2012a).
14. As of December 2001, the numbers of end-users on cable broadband and DSL were 196,000 and 136,000 respectively (Of tel, 2002a). In July 2002, the number of end-users of cable broadband had risen to 419,000 compared to DSL which had 290,000 end-users (Of tel, 2002b, p. 1). By September 2003, this trend had reversed. The number of DSL end-users had nudged ahead (and have remained ahead) to 1,380,000 to that of 1,232,000 for cable broadband (Of tel, 2003). In Q1 2012, the number of residential and small business end-users on DSL (including BT, LLU and non-LLU) were 16,173,000 compared to 4,165,000 for cable (Of com, 2012b).

15. More than 560,000 potential end-users registered for the BT ADSL registration scheme by September 2003 (OfTel, 2003). This indicated a potential 50 per cent increase in the number of end-users. See note 14 for further details of the increase in the DSL numbers.
16. In November 2001, the average monthly cost of DSL for residential and small business end-users was £40. Compared to this the average cost of a FRIACO-based, fully unmetered narrowband connection was only £12.99-£14.99 (see OfTel, 2001a, pp. 4-7)
17. The basic rate offered by modern narrowband connections was 64 kbit/s. With pure text transmission, a narrowband connection could deliver 320 kbit/s but with significant reduction in the web experience. DSL broadband connections were required to deliver minimum speeds of 128 kbit/s (OfTel, 2001a).
18. The registrations started in June 2002 when the number of DSL end-users were 290,000 compared to 419,000 end-users for cable broadband (OfTel, 2002b). By September 2003, the scheme had received 560,000 registrations during which time the DSL end-users had increased to 1,380,000 (OfTel, 2003).
19. At the start of the registration scheme, the number of UK households covered by DSL was 66 per cent with 1115 exchanges being DSL-enabled (OfTel, 2002b). By September 2003, the availability of DSL had increased to 80 per cent with 1,708 exchanges being DSL-enabled (OfTel, 2003).

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