production of equipment. Leif Hommen analyses second- and third-generation mobile telecommunications in chapters 3 and 4, and this is followed by Bent Dalum's account of the part of satellite communications that is related to telecommunication networks – both wireless and wired.

Chapters 6 and 7 are devoted to the Internet services industry, fixed and mobile. Nicoletta Corrocher analyses first the sectoral dynamics of the Internet services industry, where services include both access and content; then she provides an account of country-specific trends in the UK, Italy and Sweden. Finally, chapter 8 is devoted to the policy implications for Internet and mobile telecommunications as well as an account of the future of the sectoral system in Europe, the US and Japan.

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Linköping, 24 June 2002

1. The Fixed Internet and Mobile Telecommunications Sectoral System of Innovation: Equipment, Access and Content

Charles Edquist

1. INTRODUCTION[1]

This chapter introduces the subject of the sectoral system of innovation in fixed Internet and mobile telecommunications. Sections 2 and 3 are mainly conceptual and theoretical discussions of the characteristics, general policy implications and boundaries of the systems of innovation approach. Section 4 deals with Internet and mobile telecommunications: it is part summary, part synthesis, of the following six chapters. Readers more interested in telecommunications and the Internet than conceptual and theoretical issues related to systems of innovation are advised to proceed directly to section 4.[2]

2. SYSTEMS OF INNOVATION (SI)

2.1. Characteristics of the SI Approach

'Systems of innovation' (SI) is a fairly new conceptual framework for the study of innovations. An SI can be defined as including 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations' (Edquist 1997:

[1] I wish to thank Bent Dalum, Nicoletta Corrocher, Jeffrey Funk, Leif Hommen, Per Högselius, Michael Jensen, Martin Kenney and Gert Villumsen for very useful comments on earlier drafts of this chapter.

[2] Chapter 8 draws together the policy implications of the analysis and discusses the future of the sectoral system of innovation and the relations between Europe, the US and Japan within the system.

ing or concerning the relations between managers and employees; many institutions develop inside firms. Hence, there is a complicated two-way relationship of mutual embeddedness between institutions and organizations, and this influences innovation processes as well as the performance and change of systems of innovation (Edquist and Johnson 1997: 59–60).

Some organizations create institutions. Examples are organizations that set standards and public organizations that formulate and implement rules that we call innovation policy (Edquist and Johnson 1997: 60). Institutions may also be the basis for the creation of organizations, e.g., when a government makes a law that leads to the establishment of an organization.

There may also be important *interactions between different institutions*, e.g., between patent laws and informal rules concerning exchange of information between firms. Institutions of different kinds may support and reinforce one another, but they may also contradict and be in conflict with one another.

The relations between organizations and institutions are very complex and often characterized by reciprocity. This emphasis on the complex relations between components constitutes a major advantage of the SI approach. However, it also constitutes a challenge since our knowledge about these relations is very limited. The relations between two phenomena cannot be satisfactorily investigated if they are not conceptually distinguished from each other. It is therefore important to specify the concepts and to make a clear distinction between organizations and institutions in order to be able to address the relations between them. A precise scientific language is a precondition for empirical work; analytical distinctions and conceptual specificity are essential.

When the innovation concept has been specified (as in footnote 3), a crucial issue is to identify all the important 'factors that influence the development, diffusion and use of innovations', i.e., the factors that define a system of innovation. It is not sufficient to identify the main components of SIs and the relations between them. We must also explicitly address what 'happens' in the systems. What do the organizations do in relation to innovation processes? How do institutions constrain or prevent organizations from doing certain things related to innovation processes and stimulate them to do others? What role do the relations between the components in the systems play for innovation processes? What is the overall function of the system as a whole – constituted by the components and the relations between them? Hence, it is important to move beyond descriptions of components of the systems and the relations between them. An obvious way to do so is to deal with the 'activities' and 'functions' of the systems.

At one level, the most important function – i.e., the 'overall function' – of an SI is, of course, to develop, diffuse and use innovations. At a more specific level it is a question of focusing upon factors that *influence* the development, diffusion and use of innovations. Examples might be the production of economically relevant knowledge through R&D or the financing of innovation development. Hence system 'activities' and the 'specific functions' or 'sub-functions' of systems are more or less the same as determinants of innovation processes or factors influencing them (Edquist 2001c: 9).[7]

For national SIs, country borders normally constitute the geographical boundaries. Regional SIs are simply spatially delimited to a certain subnational geographical area. These spatial boundaries of innovation systems are fairly easy to specify. Other kinds of boundaries (sectoral and functional) will be addressed in section 3, where sectoral SIs are discussed further.

2.2. General Policy Implications of the SI Approach[8]

Here I briefly deal with *general* policy implications of the SI approach. They are general in the sense that they are of a 'sign-post' character. They can serve as rules of thumb and point out relevant issues. However, they are not a sufficient basis for designing specific innovation policies. The general policy issues do not tell a policy maker exactly what to do and how in order to improve the functioning of the system. The SI approach as such cannot provide this, but neither can any other approach or theory.[9]

The following lists general policy implications that have been discussed in more detail elsewhere (Edquist 2001b):

- Organizational actors might need to be created, redesigned or abolished.
- Institutional rules might need to be created, redesigned or abolished.
- Innovation policy should focus not only on the elements of the systems, but also – and perhaps primarily – on the relations between them.

[7] The literature has thus far neglected to deal with these sub-functions in systems of innovation in a systematic manner. They were largely ignored in the early literature and have only recently been addressed. Thus, surprisingly, little systematic and detailed research has been done on determinants of innovation. At the same time it is a crucial issue, which should motivate a major effort to increase our knowledge of how to explain innovation (Edquist 2001c: 8, 10). However, one could argue that since Nelson and Winter (1982) there has been a focus on some key functions like 'variety creation' and 'selection' – but these are functions of a fairly general kind.

[8] The discussion in this section is intended to serve as a basis for the discussion of policy implications specific for data communications and mobile telecommunications to be presented in the final chapter of this book.

[9] However, the systems of innovation approach also provides a *framework* of analysis for identifying *specific* policy issues. It is helpful in identifying the 'problems' that need to be the object of policy and in specifying how innovation policies to solve or mitigate these problems could be designed. This discussion is elaborated in Edquist (2001b: 50).

- Innovation policy should ensure that negative lock-in situations are avoided.
- Innovation policy should facilitate changes in the production structure.
- Innovation policy should support structural changes in the direction of production sectors dominated by product innovations rather than process innovations.
- Innovation policy should primarily be proactive, supporting emergence of new product areas and new sectoral systems of innovation.
- Innovation policy should be focused on the early stages in the development of product innovations and new sectoral systems of innovation.

The basis for some of the points above is that the potential for dynamic innovations – and the resulting consequences for productivity growth and employment – varies greatly between sectors of production. For example, annual productivity growth is sometimes 10 to 20 times larger in knowledge-intensive sectors than in other sectors. On this basis it can be argued that the sectoral approach to systems of innovation is central with regard to policy. The changes in and between the sectoral systems of innovation lead to changes in the production structures of national and regional systems – as a *consequence*. Such changes in production structures are crucial for the performance of national and regional innovation systems in terms of productivity growth and employment creation. Sectoral systems of innovation are therefore very important when it comes to understanding dynamics (Edquist et al. 2001).

It could also be added that with globalization, regionalization and the consequent erosion of national boundaries, the sector – just like the region – is becoming a crucial level of intervention for national governments pursuing innovation policy. It therefore becomes important to discuss how different kinds of systems of innovation relate to one another.

3. SECTORAL SYSTEMS OF INNOVATION AND SYSTEM BOUNDARIES

A sectoral system of innovation (SSI) is simply a system of innovation restricted to a certain sector. This means that we must specify what we mean by a sector, and by doing so we immediately enter into a discussion of the boundaries of the (sectoral) systems. The distinction between what is inside and outside the system is crucial, i.e., the issue of the boundaries of systems of innovation cannot be neglected. It is therefore necessary to specify the boundaries if empirical studies of specific SIs – of a national, regional or sectoral kind – are to be carried out. As will be discussed later, one way to

identify the (functional) boundaries of SIs is to identify the causes or determinants of innovations. But first we must address different kinds of innovation systems – national, regional and sectoral.

We saw earlier that the specification 'national systems of innovation' is only one among several possibilities. However, there are strong reasons to talk about innovations in terms of national systems. One reason is the fact that the various case studies in Nelson (1993) show that there are sharp differences between various national systems in such attributes as institutional set-up, investment in R&D and performance. For example, the differences in these respects between Denmark and Sweden are remarkable – in spite of the fact that these two small countries in northern Europe are very similar in other respects such as language, culture, standard of living, lifestyle, consumption patterns, size of the public sector, and strength of trade unions (Edquist and Lundvall 1993: 5–6). Another very important reason is that most public policies influencing innovation processes or the economy as a whole are still designed and implemented at the national level.[10] In other words, the importance of national systems of innovation partly has to do with the fact that they capture the importance of the political and policy aspects of processes of innovation. It is not only a matter of geographical delimitation; the state, and the power attached to it, is also important.[11]

Systems of innovation may be supranational, national or subnational (regional, local) – and at the same time they may be sectoral within any of these geographical demarcations. There are many potential permutations. Whether a system of innovation should be spatially or sectorally delimited – or both – depends on the object of study.[12] All the approaches mentioned above may be fruitful – but for different purposes or objects of study. Generally, the variants of the generic SI approach complement rather than exclude one another. This is because it is a limitation to talk about globalization and regionalization without addressing the national level. Therefore, it is useful to consider sectoral and regional systems of innovation in relation to national ones.

There are three senses in which we can identify boundaries of SIs:

1. spatially/geographically;
2. sectorally; and
3. functionally.

[10] For very large countries the national SI approach is less relevant than for smaller countries – but institutions such as laws and policies are still mainly national, even in a country like the US.
[11] We shall return to the political and innovation policy aspects in section 5.
[12] An 'industrial complex' or 'cluster' as used by Porter (1990) can be seen as a combination of a sectoral and a regional SI if it is regionally delimited. However, such regional/sectoral systems can also be regarded as parts of a national or international sectoral SI.

To define the spatial boundaries is the easier task, although it also has its problems. These boundaries have to be defined for regional and national SIs, and sometimes also for sectoral ones.[13] The problem of *geographical* boundaries is somewhat more complicated for a regional than for a national SI. One question is which criteria should be used to identify the 'region'.

For a regional SI the specification of the boundaries should not be a question of choosing or using administrative boundaries between regions in a mechanical manner (although this might be useful from the point of view of availability of data). Rather it should be a matter of choosing geographical areas for which the degree of 'coherence' or 'inward orientation' is high with regard to innovation processes.[14] One possible operationalization of this criterion could be a minimum level of localized learning spillovers (between organizations), which is often associated with the importance of transfer of tacit knowledge between (individuals and) organizations. A second one could be localized mobility of skilled workers as carriers of knowledge, i.e., that the local labour market is important. A third possibility could be that a minimum proportion of the innovation-related collaborations among organizations should be with partners within the region. This is a matter of localized networks, i.e., the extent to which learning processes between organizations are interactive within regions.

For a national SI the country borders normally provide the boundaries. However, it could be argued that the criteria for regional SIs are as valid for national ones. In other words, if the degree of coherence or inward orientation is very low, the country might not reasonably be considered to have a national SI.

On what it means to be 'national', Nelson and Rosenberg wrote: 'On the one hand, the concept may be too broad. The system of institutions supporting technical innovation in one field, say pharmaceuticals, may have very little overlap with the system of institutions supporting innovations in another field, say aircraft' (Nelson and Rosenberg 1993: 5).[15] Here they actually argue for a sectoral approach.[16]

Leaving the geographical dimension, we can also talk about 'sectorally' delimited systems of innovation, i.e., systems that include only a part of a regional, national or international system. They are delimited to specific technological fields (generic technologies) or product areas.[17] The 'technological

[13] However, in the latter case it is usually in practice a combination of sectoral and national/regional delimitation.
[14] This is also important with regard to policy, since it is difficult to influence a very outward-oriented system from a political level within the region.
[15] It may be noted that they use the term 'institution' in the sense that we have defined 'organization' in section 3 and that they deal only with 'technical' innovations.
[16] Richard Nelson also takes this perspective in Mowery and Nelson (1999).
[17] They can be, but are not necessarily, restricted to one sector of production.

systems' approach belongs to this category (although it did not initially use language associated with systems of innovation). Carlsson and Stankiewicz state that

> The nation-state constitutes a natural boundary of many technological systems. Sometimes, however, it may make sense to talk about a regional or local technological system. ... In yet other cases the technological systems are international, even global. Where the boundaries are drawn depends on the circumstances, e.g., the technological and market requirements, the capabilities of various agents, the degree of interdependence among agents, etc. (Carlsson and Stankiewicz 1995: 49)

According to Breschi and Malerba, 'a Sectoral Innovation System (SIS) can be defined as that system (group) of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies' (Breschi and Malerba 1997: 131). However, it is not self-evident what a sector is, i.e., the *sectoral* boundaries are partly a theoretical construction. There is a degree of arbitrariness here and we have to be pragmatic (but must still specify the boundaries). We shall discuss this with specific reference to the Internet and mobile telecommunications system in section 4.4.

To summarize: specific technologies or product areas are used to define the boundaries of sectoral systems, but they must also normally be geographically delimited.

However, within a delimited geographical area (and perhaps also limited to a technology field or product area), the whole socioeconomic system cannot, of course, be considered to be included in the SI. The question is, then, which parts should be included? This is a matter of defining the *functional* boundaries of SIs. These have to be defined for all kinds of SIs: national, regional and sectoral. And this is more complicated than in the cases of the spatial and sectoral boundaries.

Actually, the founding fathers of the SI approach did not address this problem in a systematic manner (and they did not use the term 'functional'). They did not provide a sharp guide to what exactly should be included in a '(national) system of innovation' (Edquist 1997: 13–15, 27).[18] Nor have the functional boundaries of the systems been defined in an operational way since then.

At the beginning of section 2.1, a system of innovation was defined as including 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations'. If the concept of innovations has been specified (e.g., as in footnote 3), and if we know the determinants of their development, diffusion and use, we

[18] Nelson and Rosenberg provided 'no sharp guide to just what should be included in the innovation system, and what can be left out' (Nelson and Rosenberg 1993: 5–6). Lundvall claimed that 'a definition of the system of innovation must be kept open and flexible' (Lundvall 1992: 13).

should be able to define the functional boundaries of the SIs. This is one reason why it is so important to identify the functions in SIs and the determinants of innovation processes. Given the satisfactory realization of these tasks we should be able to identify the functional boundaries of SIs, whether they are national, regional or sectoral. Admittedly this is not as easy in practice as in principle and for the time being it is an unresolved problem of a 'catch 22' character (Edquist 1997: 15).

To conclude: all SIs must be functionally delimited; they must be geographically delimited if they are not global; and when we address sectoral systems the boundaries of the SIs must also be sectorally delimited.

4. THE MOBILE TELECOMMUNICATIONS AND FIXED INTERNET SECTORAL SYSTEM OF INNOVATION

4.1. Introduction

Section 4 covers important developments occurring in recent decades in mobile telecommunications and fixed data communications (Internet). It synthesizes other reports produced within the ESSY study of the fixed Internet and mobile telecommunications sectoral system of innovation that are included in this book. It is based on these reports, without always explicitly referring to them. This section also tries to fill in the gaps by covering some important issues that are not dealt with in later chapters. This implies, for example, dealing with the birth of mobile telecommunications as triggered by the NMT (Nordic mobile telephony) standard, i.e., part of the institutional basis for the first generation of mobile telecommunications.

Section 4 addresses some key questions in the ESSY project mentioned in the preface, e.g., the knowledge base of the sectoral system, its organizations and institutions and the boundaries of the (data communications and mobile telecommunications) sectoral system. Public policy, the future of the sectoral system and comparisons with the US and Japan are addressed in chapter 8.

Since the main elements of all systems of innovation – including sectoral ones – are *institutions* and *organizations*, I shall discuss these factors – and changes in them – with regard to data communications and mobile telecommunications. The relations between different kinds of organizations and between institutions and organizations will be a central focus in what follows. Institutions are often created by organizations. At the same time, existing institutions influence organizations as well as the relations between them. I shall try to make a clear distinction between institutions and organizations in order to be able to discuss the relations between them.

In addition there is here a certain emphasis on the *functions* of the sectoral systems of innovation. As argued in section 2.1, it is important to address these, and not only the elements of the systems. The main function of innovation systems is the carrying out of innovations. However, the functions of the SIs also include activities leading to innovations. These secondary functions or sub-functions influence the ability of firms (and other organizations) to carry out innovations. Examples of important functions are knowledge creation (through R&D and in other ways), collaboration in pursuing innovation processes, provision of relevant education, creation of standards, etc.

In section 4.2, the main functions and organizations in the sectoral system(s) are briefly addressed. Section 4.3 focuses on institutions, institutional changes and consequences these changes have for organizations and functions. Different subsections will concentrate on fixed Internet, mobile telecommunications, satellite communications and rate structures. In section 4.4, the boundaries between subsystems and convergence between them are addressed.

4.2. Functions and Organizations in the System(s) and Relations Between Them

As we saw in section 2.1, organizations can be defined as formal structures with an explicit purpose which is consciously created. They may also be called agents, actors or players. Their purpose is to perform certain functions in the system(s). In the fixed Internet and mobile telecommunications sectoral system(s) of innovation (SSI) some of the most important functions are:

- developing equipment (innovation in new equipment, hardware and software);
- conducting R&D relevant to the further development of the system(s);
- providing relevant education and training;
- creating standards and other regulations of importance to the systems(s);
- providing access, e.g., Internet access or mobile telecommunications subscriptions;
- developing new content (introduction of new services, e.g., e-commerce); and
- providing consulting services related to all the above.

The functions of an SSI may refer to the development and diffusion of innovations and how smooth and efficient these processes are. In turn this may be a result or how good the SSI is in creating new knowledge or new combinations of existing (and new) knowledge, in providing education, in creating standards, etc. Other functions could also be mentioned. They might refer to how efficient the financing of product development is, how smoothly new firms are created, how inclined firms in the system are to diversify into new product areas, or how efficiently new markets are created for the new products (goods and services).

On the whole, much more work needs to be done on systems of innovation functions. This is quite similar to studying the determinants of innovation – which in section 3 was also argued to be a useful way to define the (functional) boundaries of the system.

Functions are carried out by organizations (or in some cases by individuals). However, there is not always – or even often – a one-to-one relation between functions and organizations. A certain organization can carry out several functions and one function may be carried out by different kinds of organizations. Below is a list of functions and some corresponding organizations that carry them out:

- The development of equipment, which is increasingly of a software kind, is done by telecommunications and Internet equipment producing firms, such as Siemens, Ericsson, Cisco and Motorola.
- These firms also carry out a large part of the R&D needed for developing new systems. Some R&D is also carried out by public universities and dedicated research organizations.
- Education is of great importance to the sectoral system of innovation and is largely carried out by publicly controlled and funded organizations. However, firms also sponsor further education and provide training. In addition learning-by-using and learning-by-doing take place within organizations.
- There are organizations that create the standards and regulations which are important to decrease the degree of uncertainty for equipment producers and to co-ordinate their relations with various other organizations in the Internet and mobile telecommunications sectoral system of innovation. They have often been of a public character, although private organizations have also been intensely involved in these activities. In addition, there are various industry organizations that have a quasi-public character, but no 'official mandate' from government.
- Access is provided by Internet access providers (IAPs) and mobile system operators. They own (or lease) the physical infrastructure (the network) and in this way provide the backbone of the Internet and mobile telecommunications. This category includes incumbent telecommunications operators, new entrant telecommunications operators, cable TV operators, alternative network providers and 'pure' Internet access providers.[19]
- The access providers may also – and often do – provide (some) content to be transported by the systems, but there are also pure or specialized content providers which own the content (but do not provide access to the systems). There are general content providers, such as companies running portals, and specialized content providers, like news and financial companies. We call these Internet content providers (ICPs). They include traditional media and publishing companies as well as new firms. Often they derive their revenues from advertising but they are increasingly trying to charge a fee for the provision of content. Their ability to do so increases if their content is highly specialized and/or customized. However, consumers tend to want content to be free of charge. Electronic commerce is offered by new firms working only over the Internet, such as Amazon.com, but increasingly old and established firms are also using the Internet as a new marketing outlet. This includes business-to-consumer as well as business-to-business e-commerce.[20]
- Finally, there are consultancy firms – as in all knowledge-intensive sectors – that offer various services related to the Internet and mobile telecommunications. Examples are web design, web hosting, development of platforms for electronic commerce, etc.

Over the last twenty years, we have seen increased functional differentiation and organizational diversity in the telecommunications SSI (in a wide sense). For example, in the past it was common that (monopolistic) access providers were also regulators. Now separate organizations have been created to perform the regulatory functions.

Digitization or 'digitalization' has provided the technological basis for separating telecommunications and Internet network operations (access provision) from content provision. With the emergence of the fixed Internet – and even earlier with the digitization of fixed telecommunications, it has been possible to make this kind of separation between infrastructure, access and content services. This separation was facilitated when the second generation of mobile telecommunications appeared. Nevertheless, this separation was not fully implemented with the second-generation mobile standards such as GSM (global system for mobile telecommunications), despite the best efforts of the

[19] For reasons presented in the Preface to this book, we have chosen not to call these organizations Internet service providers (ISPs) although they certainly provide service products.
[20] E-commerce is dealt with in more detail in Kenney (2001).

European Commission (section 4.3.2.2). This would change with the third generation of mobile telecommunications (section 4.3.2.3).

In telecommunications in the broad sense the set-up and character of organizations has changed tremendously during recent decades.

- Publicly controlled telecommunications operators were transformed into joint-stock companies and privatized so that they were no longer public-sector monopolies (with regulatory power).
- The relations between the most important organizations in the system changed considerably.
- Formerly close ties between 'national champions' in equipment production and monopolistic access providers were progressively loosened.
- Important new organizations emerged in the system, e.g., IAPs and content providing organizations (ICPs).
- Similarly, new regulatory agencies were created, concomitant with privatization of public telephone operators (PTOs).

4.3. Institutional Changes and Consequences for Organizations and Functions

In section 2.1, institutions were defined as sets of common habits, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups and organizations. Relevant examples in this context are laws concerning deregulation/liberalization, technical standards (particularly relevant for Internet and mobile telecommunications), access tariffs, rules with regard to intellectual property rights (IPRs). The institutions constitute the rules of the game that influence the players – or organizations, e.g., firms – when they are trying to achieve their purposes. However, the relations between institutions and organizations are mutual. Institutions are formed and changed by the actions of (some) organizations. I shall now discuss the relations between institutions, organizations and functions in various parts of the sectoral system.

4.3.1. Fixed Internet

As we shall see in section 4.3.2, an institution – i.e., the NMT 450 mobile telecommunications standard – provided the cradle for the development of mobile telecommunications in Europe. But what provided the cradle for fixed data communications or the Internet?

Fixed telephone lines have existed for more than a century. As mentioned in the introduction to this chapter we shall not deal with fixed voice telecommunications here (except occasionally for reasons of comparison). Instead we begin our story when fixed telephone systems started to carry data as well as voice in their cables. As a precondition for this, fixed networks became digitized. There were two technological breakthroughs that made this digitization possible: packet-switching technologies and the Internet protocol.

In packet-switching technology, 'packets' of information share the network lines (bandwidth) with other packets, optimizing the use of the existing bandwidth. In packet-switched transmission protocols any type of information (voice, data, video, etc.) is broken down into packets, which are sent from one computer to another with no chronological order. A 'header' on each single packet directs the routing from the sender to the receiver; the header contains information about the destination. The packages are sent individually and reassembled to a complete message at the receiving end.

In comparison, in the traditional circuit-switched networks, an end-to-end communication path is established before the communication begins and it stays open during the whole connection. With the conventional telecommunications network, each conversation uses a fixed amount of bandwidth for the duration of the call and the available bandwidth is dedicated to the call even if no information is transmitted (e.g., during silences in a voice conversation.)

In early 1969 the US Department of Defense Advanced Research Projects Agency (DARPA) granted a contract to the Cambridge, Massachusetts based engineering firm Bolt, Beranek and Newman to build the first packet switch (Abbate 2000: 55; Mowery 2001: 8). Hence this was a matter of public technology procurement, i.e., a public agency placed a contract to a firm ordering the development of a technology or an artifact which did not exist at the time of granting the contract but which the partners believed could be developed (Edquist et al. 2000b). The resulting switch was called an interface message processor (IMP), and linked several computers to one another. The result was ARPANET, which was the earliest forerunner to the Internet.

In 1973, two DARPA-funded engineers, Robert Khan and Vinton Cerf, developed an improved data-networking communications protocol that simplified routing, eliminated the need for IMP and allowed physically distinct networks to interconnect with one another. The idea of an open architecture that allowed network-to-network connectivity was a key intellectual advance in their design. Kahn and Cerf called the new protocol transmission control protocol (TCP) and openly published the specification in 1974. Later it was split into two pieces and renamed TCP/IP (transmission control protocol/Internet protocol) (Abbate 2000: ch. 4; Mowery 2001: 9–10). Hence these protocols, which were absolutely central to the development of the Internet, were also developed with the help of military research funds.

The TCP/IP is based upon a distributed architecture, within which the IP and the TCP have separate functions: the TCP handles transmission characteristics, while the IP manages routing and network anomalies. The TCP/IP is embedded in distributed customer hosts that are located at the network periphery, therefore reducing the need for centralized control. The software is located on the servers and on the user hosts, which makes possible Internet connectivity and integrated applications.

As a matter of fact, an increasing part of voice is currently sent over IP networks; users may be unaware that a telephone call or a portion of a call is routed over an IP network. The transmission network is today (partly) common for Internet and voice telephone networks. This convergence has also, of course, influenced the telecommunications and Internet equipment industries.

TCP/IP was rapidly adopted. There were several reasons why. It was highly reliable, and it was an open standard that arrived just as the computing research community began to standardize on a common platform.[21] TCP/IP became an integral part of this standard platform. As a result TCP/IP became the dominant protocol for most networking applications in the early 1990s and is now virtually synonymous with the technical definition of the Internet (Mowery 2001: 10).

One reason why TCP/IP became dominant was the National Science Foundation (NSF) decision to adopt it as the standard on its national university network. Beginning in 1985, any university receiving NSF funding for an Internet connection was required to provide access to all 'qualified users on campus' and use TCP/IP on its network (Kenney: 2002: 14). Again, public action was crucial – this time for the early diffusion of TCP/IP.

Other government organizations in the US were also important for the development of the Internet. In the late 1970s, the NSF and DARPA founded a set of organizations to oversee the standardization of the backbone on TCP/IP. The Internet Configuration Control Board (ICCB) was established in 1979. In 1983, when ARPANET switched over to TCP/IP, the ICCB was reorganized and renamed the Internet Activities Board (IAB). The IAB had two primary sub-groups, the Internet Engineering Task Force (IETF) which managed the Internet's architecture and standard-setting processes, including editing and publishing, and the Internet Research Task Force (IRTF) which focused on longer-term research (Mowery 2001: 12–13).

The Internet is not formally standardized as a public telecommunications network. There is no standardization body such as the ITU (International

[21] This platform was the Unix operating system originally put forward by AT&T/Bell labs, but gradually adopted by the main computer firms, initially driven by some of the then newcomers in 'network computing' and work stations, such as Sun Microsystems and later on the dominant incumbents of HP, IBM and DEC.

Telecommunications Union) where all nations participate. The IETF is the closest equivalent to a standardization body. This voluntary organization updates standards, informs about changes and controls the use of global addresses but has no formal power.

As opposed to the standards organizations involved in developing the mobile telecommunications standards, the IETF is mainly a voluntary organization without any central management.[22] To the extent that IETF has management, it is embodied in the working group charters. These working groups are the main drivers in development of Internet standards. The work is voluntary and as such often dominated by large actors (telecommunication operators and manufacturing firms). As a consequence of the Internet's US origin, the protocol has been highly influenced by US actors via IETF. In other words, US firms have dominated the standardization process related to the Internet.

The organizations that managed the establishment of Internet technical standards were informal yet responsive. They developed open standards and rapidly adapted these to new technical and economic challenges – and this contributed powerfully to the quick diffusion of the Internet (Mowery 2001: 42).

An important institutional change that made the rapid diffusion of fixed Internet possible was the deregulation or liberalization of the telecommunications sector. Internet penetration came earlier and was more rapid in countries where liberalization took place early (UK in 1984; US in 1985; Sweden in 1993) than where it has occurred late (Italy in 1998).

Early deregulation in the UK had a significant impact on market structure. It also impacted the rate of technical change, since it opened entry to new companies and forced incumbents to engage in the development of innovations. Further, liberalization of the telecommunications sector resulted in substantially reducing the charges for telephone calls (Corrocher 2002b; and ch. 7, this publication).

As Corrocher notes in chapter 7 (this publication), Sweden has the highest Internet penetration in Europe and the most advanced Internet service sectoral system of innovation. The telecommunications market in Sweden was liberalized in 1993 and Sweden now has the most liberalized telecommunications industry in the world. This has been a major driver for the development of alternative networks to the one of the former incumbent operator (Telia). However, the unbundling of the local loop has not yet been achieved since Telia's price of interconnection is too high to allow others to compete on an equal basis (Corrocher 2002b; and ch. 7, this publication).

[22] Mobile standards are addressed in section 4.3.2.

In contrast to the UK, one of the major obstacles to the development of the Internet in Italy has been the slow process of deregulation of the telecommunications sector, which in turn has been caused by the lack of a clear policy for the implementation of an appropriate competition policy and of an independent regulatory authority. A telecommunications authority was established in 1997 and deregulation occurred in 1998. This delay has hindered not only the development of a competitive industry but also the diffusion of new technologies and applications (Corrocher 2002b; and ch. 7, this publication).

In the 1970s and 1980s the data transmitted via the Internet were primarily related to research activities and to communications in large firms having branches in different locations. However, in the 1990s, thanks to innovations made at CERN (European Organisation for Nuclear Research) in Switzerland, data traffic became increasingly demanded by final consumers. Tim Berners-Lee and Robert Cailliau at CERN released in 1991 a new document format called HyperText markup language (HTML) and a related document retrieval protocol called HyperText transfer protocol (HTTP). Together they turned the Internet into a vast cross-referenced collection of multimedia documents. Berners-Lee and Cailliau called their invention the 'World Wide Web' (WWW). Many start-up firms drew upon the protocols. One of them was called Netscape, which was listed on the stock exchange in 1995. Hence, although the HTML and the HTTP were not invented in the US, that is where they were first commercialized – i.e., transformed into innovations.

There were prototype networks designed, which constituted alternatives to the ARPANET, e.g., in the UK and France. 'U.S. dominance thus did not result from a first-mover advantage in the invention or even in the early development of a packet-switched network. The factor that does seem to separate ARPANET from these simultaneous projects was sizeable public funding and flexibility in its deployment' (Mowery 2001: 9). This resulted in a network of a large (continental) scale that included different kinds of organizations: DARPA, universities, consulting firms, research institutes, etc. Its size and inclusion of different kinds of organizations distinguished the ARPANET from its British and French counterparts (Mowery 2001: 9).

In the US, public intervention was crucial for the development of the Internet. Public funds were used to develop many early inventions that spawned the Internet and federal R&D spending played an important role in the creation of the entire complex of 'new' post-war information technology industries. 'The origins of the Internet can be traced back to these efforts' (Mowery 2001: 24).

However, the influence of public policy was not restricted to funding. Federal policies concerning regulation, antitrust, and intellectual property rights were also important. According to Mowery, the overall effect of these policies was to encourage rapid commercialization of Internet infrastructure, services and content by new, frequently small firms (Mowery 2001: 28). As a result, use of the Internet exploded in the US in the 1990s.

From the late 1980s onwards, US firms achieved a dominant position in the production of equipment for the Internet.[23] This occurred very much because of their 'headstart' in serving the large – and early developing – US domestic market just as US packaged computer software firms had benefited from the rapidly growing domestic personal-computer (PC) market during the 1980s. In the Internet field the firms that came to dominate were not large system vendors like IBM or DEC. Instead, a group of smaller firms, most of which were founded in the 1980s, became the most important. Examples are Cisco, Bay Networks and 3Com (Mowery 2001: 16). Cisco is still a very dominant player on this market, although it is certainly no longer a small firm.[24]

As Dalum and Villumsen point out in chapter 2 (this publication), there are currently five ways for consumers (and small business enterprises) to access the Internet:

1. 'Ordinary' modems connected directly on the telephone line.
2. ISDN-modems connected directly on the telephone line.
3. xDSL, primarily ADSL connected directly on the telephone line.
4. TV networks via 'cable modems' for cable TV or 'set-top boxes' forsatellite TV.
5. Fixed wireless access.

Dalum and Villumsen explain that the first three access technologies use a 'twisted pair' of copper wires for the last mile to the consumer, which can be installed as an integral part of an ordinary fixed-line telephone system. In practical terms this means the incumbent telecommunications operators have a clear advantage in delivering access modes. Competing companies must use the existing infrastructure on the last mile to reach the customers, i.e., they must make arrangements with incumbent operators. Dalum and Villumsen (ch. 2) argue that this has preserved the powerful position of the incumbents, which appears to be a major inhibiting factor in the diffusion of high-speed Internet access in many countries.

Because traditional subscriber lines only support analogue transmission, it is necessary to use a modem to transport data. The simple modem access (1) converts analogue to digital signals and does not require changes or enhancements to the network. Maximum speed is currently 56 Kbit/s. A first enhancement of modem technology is (2) ISDN (integrated services digital

[23] As we saw earlier, they also highly influenced the standard creation in the Internet field.
[24] The role of venture capital for the rapid growth of these firms is strongly stressed by Martin Kenney (Kenney 2002).

network), which runs at a higher speed (maximum 144 Kbit/s). In addition ISDN makes parallel connections of data and voice possible.

As demand for faster access increases, several digital subscriber line technologies have made higher speeds possible. Their common name is (3) xDSL, with x indicating the variant. Since demand for sending and downloading is asymmetrical for most users, a technology with higher bandwidth for downloading is required. Currently ADSL (asymmetrical digital subscriber line) is the most common technology for high-speed 'broadband' (above 2 Mbit/s) access over a 'twisted pair'.

An alternative to the telecommunications cables is access via TV networks (4). This option has been growing rapidly in some countries since many telecommunications operators (the previous state monopolies) have been slow to deliver high-speed access solutions. Dalum and Villumsen (ch. 2) note that there has been little incentive since they have been able to acquire enormous revenues due to the low speed generating high telephone bills.[25]

According to one source reporting data for 'broadband' subscriber trends without specifying what exactly broadband is,[26] there were over 40 million subscribers worldwide in 2001 divided among three shares of equal size: ADSL, digital set-top boxes and cable modems (for cable TV). The US lead in the absolute amount of broadband subscribers is, however, concentrated on cable modems and set-top boxes. The TV network-based broadband access share appeared to be around 80 per cent in the US in 2001. It has mainly been the alternatives to the incumbent telecommunications operators – i.e., the TV networks – that have been the 'carriers' of broadband access in the US.

A final access channel is (5) fixed wireless access (FWA), which uses a wireless connection on the 'last mile'. Potentially very large amounts of data can be transmitted through the air over reasonably short distances. Several European countries have recently been through contests of FWA licences, which have attracted much less attention than the recent UMTS (universal mobile telecommunications system) auctions and/or beauty contests for mobile systems.[27]

[25] Rate structures and levels will be discussed in more detail in section 4.3.4.
[26] *The Financial Times*, 13 December 2001.
[27] An emerging – and potentially very important – access method is via wireless local area networks (WLANs) which may become a core part of what is now considered to be 4G communications systems involving a true integration of mobile telecommunications and the fixed Internet. See further in section 4.3.2.3.

4.3.2. Mobile telecommunications

4.3.2.1. First generation (NMT)

The first standard for modern cellular telecommunications began to be specified in January 1970 and was called NMT 450, i.e., the Nordic mobile telephony standard based on the 450 megahertz bandwidth.[28] Important characteristics were that it was an analogue standard, that it was fully automatic and that it had a roaming function within the Nordic countries.[29] The development of the standard was initiated by the Nordic public telephone operators (PTOs), which were state-owned monopolies at the time. A working group, manned by the PTOs in Finland, Norway, Denmark and Sweden, designed the technical specifications. The Swedish PTO had a leading role in this work. In 1971 the NMT group gathered around forty national and international companies that were potential suppliers for NMT 450. They received preliminary specifications. The technical specifications were further developed in discussions within the group and were finalized between 1975 and 1978 (McKelvey et al. 1998: 16, 25).

In 1977–78 the implementation of the project began and the Nordic PTT (post, telephone and telegraph) operators started to look for suppliers of the different component technologies, i.e., radio base stations and switches. The NMT group opened bidding for supplying switches to a number of companies. This means that the mechanism of public technology procurement was used as an instrument to initiate the development of equipment. Bidding was international, but Sweden's Ericsson won the order to deliver switches to Sweden, Norway, Denmark and Finland. Ericsson's main competitor was Japan's NEC. However, Ericsson first offered a computer-controlled switch with electromechanical switch elements (called AXE-13). Then, Televerket (the Swedish PTO) wanted an adapted version of Ericsson's fully digital switch (AXE) and made clear to Ericsson that they would choose the digital switch from NEC if Ericsson did not offer AXE (McKelvey et al. 1998: 26).

The NMT 450 was very specific, which meant that a network operator had the possibility of buying components from different producers and putting them together. NMT 450 was implemented in Sweden in October 1980 and early 1981 in Denmark, Finland and Norway. However, the first implementation occurred in Saudi Arabia in August 1980[30] (McKelvey et al. 1998: 16). In other words, it took ten years to specify the standard and get it functioning.

[28] NMT is not covered elsewhere in this study of the fixed Internet and mobile telecommunications sectoral systems of innovation.
[29] Roaming means locating the mobile phone handset of the person called.
[30] This turned out to be an important order for equipment producer Ericsson.

The NMT 450 was much more successful than expected. It was initially forecasted to have 50 000 subscribers by 1990, whereas by 1992 it had approximately 250 000. Since more subscribers were joining than the standard could handle, the Nordic PTTs developed and added the NMT 900 (megahertz) standard in 1986. The NMT 900 system was developed as an intermediary system, between the NMT 450 and the future European digital standard (which was later agreed to be GSM) (McKelvey et al. 1998: 16).

The Nordic countries had the highest rates of penetration of mobile phones even before the advent of liberalization and before GSM – i.e., during the NMT era. It was about 7 per cent in Sweden in 1992, thanks to high-quality service provision and low tariffs. In 1990 market penetration in the UK was only 2 per cent, despite its much more extensive market liberalization for mobile (and fixed) telecommunications.[31] The rapid penetration in Sweden was largely due to the consolidation of a strong market for mobile telecommunications via concerted action by the Nordic public telephone companies in defining the first-generation NMT standard and through low prices. Sweden's fixed subscription rates were much lower than in the UK, and call charges were about half of what they were in the UK. Rapid subscriber penetration contributed to rapid market growth – which was important for the ability of equipment suppliers to benefit from economies of scale.

NMT 450 can be considered an institution in the sense of being a set of rules. This set of rules decreased the degree of uncertainty and risk for equipment suppliers. The NMT standard was conceived primarily as a regional standard, though it later verged on becoming pan-European.

The institution of NMT 450 provided the cradle for the development of pan-European mobile telecommunications. It actually spurred the development of a whole new industry – or sectoral system – of very large economic significance. Public-sector organizations dominated the development of the standard. The development was actually initiated and led by a few Nordic national public telecommunications operators.

In techno-economic development there has often been an institutional lag, i.e., institutions (rules and regulations) lag behind technical change (innovation) and constitute an obstacle to such change. This was the case with the diffusion of fixed Internet in Italy (see section 4.3.1). However, in the case of NMT 450 the opposite happened. When this institution was created it pushed – or rather pulled – the whole development, e.g., by decreasing uncertainty for equipment producers and operators. We might call this an 'institutional push' (or 'pull') instead of an 'institutional lag'.

[31] As mentioned earlier, liberalization was initiated in the UK in 1984 and in Sweden in 1993.

The development and implementation of NMT was actually an example of the importance of user–producer relations in innovation processes, which is stressed so strongly in the systems of innovation approach. The public organizations provided a technical framework for private equipment producers and decreased uncertainty. The Nordic equipment producers, Ericsson and Nokia greatly benefited from this, which is an important contributing factor for their leading role in mobile telecommunications equipment production today.

However, NMT was not the only standard that was developed in the proto-period of mobile telecommunications. In the 1970s cellular systems R&D gained similar momentum in a few countries (with the US, the Nordic countries and Japan as forerunners).[32] This resulted in the introduction of as many as eight cellular standards between 1979 and 1985[33] (Lindmark and Granstrand 1995: 386).

The advanced mobile phone system (AMPS) was developed by Illinois Bell Telephone, Bell Labs and Motorola. The first AMPS system was launched in 1983 (as opposed to 1981 for NMT), delayed by arguments over access to radio frequencies and a complicated licensing procedure. NMT 450 was the first standard adopted by multiple standards and by the end of 1993, 36 countries had introduced the system (Funk 2002: 41). AMPS was quite successful; it was diffused to a larger number of countries than NMT and had a larger number of subscribers worldwide (Funk 2002: 40).[34] However, NMT in the Nordic countries showed the highest penetration rates in the world, constantly outstripping forecasts (Lindmark and Granstrand 1995: 386–8). In addition, NMT was the basis for the development of GSM – which became the globally dominant standard in second-generation mobile telecommunications.

4.3.2.2. Second generation (GSM)

A. Europe Introduced in 1992, the GSM standard is also an institution. It was conceived from the start as a pan-European standard intended to cover many countries. And it came to do so. In 1992 commercial GSM services were initiated in 15 countries, but by 1996 GSM operated in 103 countries. It was possible to make phone calls between countries – even between continents – thanks to the fact that the national systems could be integrated in order to

[32] Bell Labs is usually credited with having invented the design concept of cellular mobile telecommunications (in 1947), the main idea being to overcome radio spectrum congestion by combining space division with radio spectrum division (Lindmark and Granstrand 1995: 386).
[33] The standards were: NAMTS, NMT, AMPS, TACS, C-450, RC-2000, RTMS and Comvik, although some experts argue that RC-2000, RTMS and Comvik were not fully functional cellular systems.
[34] This is explained not only by the size of the home market (in the US), but also by the diffusion to some large markets in the Asia-Pacific region and Canada (Lindmark and Granstrand 1995: 392).

trace where a certain terminal was located (roaming). This means that the development of the GSM standard was characterized by the involvement of a far greater number of organizations than the NMT standard(s) and a far greater complexity in the relations among them. There were other differences. Until the 1980s, public telecommunications companies in Europe often had monopolistic positions with regard to network operation and service provision. They also had the role of regulating the telecommunications sector. By the mid-1990s, they were much more oriented towards network operation. Separate regulatory organizations had been created and in turn these new organizations created new institutions.

In Sweden, the National Telecommunications Council was created in 1990, followed by the National Telecommunications Agency in 1992. This ended the double role of Televerket (the former PTO) in the area of frequency management and it meant the creation of an independent telecommunications regulator capable of ensuring competition in the non-monopoly telecommunications sector, which now included the mobile sector. As a network operator, Televerket was increasingly exposed to competition from new entrants, domestic and foreign based.

As in the case of NMT, public-sector organizations were crucial to the development of GSM (see Hommen in ch. 3, this publication). For instance, national telecommunications agencies were central in initiating and developing the new standard. However, there were now more numerous organizations of this kind than was the case with NMT's development. The development of GSM occurred within the formal organizational framework (and not in an ad hoc consortium) provided by two European standards development organizations: CEPT (Conference on European Post and Telecommunications) and ETSI (the European Telecommunications Standards Institute). CEPT was an association of European telecommunications organizations while ETSI – which gradually took over the role of standard creation – was a European Union organization.[35] In addition, equipment suppliers and public research organizations actively participated in this work. This reflected the fact that the (former) public monopolies no longer had a monopoly of knowledge and expertise in the telecommunications field (Hommen 2002a; Glimstedt 2001).

The Swedish former monopoly Televerket/Telia was very active in GSM's implementation, along with other Nordic operators and equipment production firms like Ericsson and Nokia – which formed a 'Nordic coalition'. Televerket – which later transformed from a public enterprise to a joint-stock, limited liability company and in due course partly privatized in the form of Telia – effectively led the Nordic alliance. This consortium was based on his-

[35] For an account of the European Commission's role in the development of GSM, see Glimstedt (2001).

torically close collaborations between Nordic PTOs and Nordic equipment producers. In competition with a Franco-German group the Nordic proposal was selected and supported by 13 of CEPT's voting members. In this way GSM may be said to have developed out of NMT – i.e., along the same trajectory (Hommen 2002a). ETSI adopted GSM without German and French support, but the two countries were still forced under EU law to use GSM as the basis for the public mobile telecom network (Glimstedt 2001).

Although Ericsson produced equipment for all three major international standards, it developed and tested the first prototype of a full GSM system in collaboration with Televerket/Telia. This consolidated Ericsson's technological leadership. However, Nokia benefited even more from the GSM decision, since it produced the standard's base stations and switches. The way GSM developed contributed significantly to increasing impressive advantages already enjoyed by Ericsson, Nokia and other Nordic firms in relation to equipment manufacturers elsewhere.

However, the Nordic proposal was based upon well-established technologies to which a number of non-Swedish firms held the IPRs; Motorola held many (50 per cent) of the important patents, and it licensed them selectively to the main Nordic equipment manufactures, Nokia and Ericsson. The second largest share (16 per cent) was claimed by AT&T. Bull and Phillips claimed 8 per cent each. Hence, at least 82 per cent of the patents for the GSM standard were of non-Nordic origin. In this light, it is quite surprising that Nordic firms attained such a dominant position as GSM equipment producers. A relevant question is why Motorola did not (successfully) push their technology in the US. Motorola sold licences to Ericsson and Nokia and thereby benefited directly by collecting licensing fees. However, Motorola was not in the position to produce equipment for GSM to any large extent. A possible explanation for Motorola's behaviour is that it felt unable to compete with European equipment producers in Europe, and perceived GSM as a European standard that would not necessarily develop into a world standard[36] (Hommen 2002a; and ch. 3, this publication).

In the first generation of mobile telecommunications, telephony and radio were combined. In the second generation, digital technology was fully implemented, creating possibilities for data transmission, in addition to voice transmission. In GSM data transmission was first introduced through SMS or short messaging service, a two-way variant of the previously existing paging system, which has become unexpectedly popular. GSM can also provide Internet access through HTML compatibility, currently developed in the form of wireless applications protocol.

[36] But at the time no one could foresee that GSM would evolve to become the world's dominant standard.

Finally, a remark on the role of deregulation for the diffusion of GSM. As Hommen points out (ch. 3), GSM was developed and implemented before large-scale liberalization took place in Europe, and hence the deregulation process did not play a major role. The relation was rather the reverse. GSM was actually used as a 'spearhead' of the EU strategy for telecommunications deregulation in the 1990s; it was used as a tool to change the telecommunications sector in Europe.

B. US and Japan In the US, one standardization agency, the CTIA (Cellular Telephone Industry Association), chose the digital advanced mobile phone system (D-AMPS) standard which was compatible with existing first-generation (analogue) systems. The idea was to facilitate a gradual shift between generations.[37]

Another relevant regulatory agency, the Federal Communications Commission (FCC), decided there would be no national digital standard for the US as a whole; rather operators were free to adopt any standard. On this basis another digital standard came into use, the CDMA (code division multiple access). It emerged later, but attracted more operators.[38] These two main standards were not directly compatible with each other; they were so only through the use of analogue channels. This was the so-called 'backwards compatibility' insisted upon by the FCC (Hommen 2002a; and ch. 3, this publication).

Partly because of this, both digital standards diffused relatively slowly in the US. The US had a mobile phone penetration rate of 20 per cent in 1997 – as opposed to 40–50 per cent in the Nordic countries. In addition, 60 per cent of subscriptions were to the analogue standard, while Europe was almost completely digital. The slower diffusion of digital systems in the US was due to the presence of several standards and a weaker migration from the first generation to the second because of backwards compatibility. Furthermore, the structure of tariffs on mobile services was different in Europe and roaming and caller pay issues were resolved much earlier[39] (Hommen 2002a; and ch. 3, this publication).

The two main US digital standards diffused to Latin America and Asia only to a limited degree, and never became a serious international competitor to GSM. Foreign standards were used to a very small extent in the US. But during 2000 and 2001 the most important US operators transferred to GSM,

[37] This is in contrast to Europe, where the standard creators did not need to worry about backward compatibility with a first-generation standard.
[38] CDMA was technically superior to D-AMPS, but CDMA had limited availability of terminal equipment and was implemented differently by each operator.
[39] The tariff structure will be discussed in section 4.3.4.

beginning with AT&T wireless in late 2001 and followed by six mobile operators. Among the reasons for switching was the fact that GSM accounted for 60 per cent of the world market even before the transfer and that economies of scale and thus lower prices could be realized. In addition, the transfer to third generation (W-CDMA) would be facilitated. GSM has thereby effectively become a world standard. The transfer has also strengthened the position of Ericsson and Nokia.

The US standard regulatory organizations seemed to have wanted to secure competition between standards as well as between operators in the US. In Europe competition only took place between operators.

In Japan the adopted digital mobile telephone standard, PDC (Pacific digital cellular), never diffused outside Japan and was incompatible with all other standards. The Japanese market remained closed to other (foreign) standards.

4.3.2.3. Third generation (UMTS/WLAN)

Unlike the NMT 900 and GSM standards, the development of the universal mobile telecommunications system standard was not driven primarily by the need to accommodate unexpectedly rapid growth in the number of subscribers. Instead, as Hommen points out in chapter 4, improved functionality seems to have been the main driving force behind UMTS.

Although UMTS is a standard supported by ETSI, i.e., it is a European standard, it also has the official sanction of the ITU, an organization 'with truly world-wide coverage and authority' (see Hommen, ch. 4, this publication). At the same time, ETSI chose NTT DoCoMo's W-CDMA (wireless code division multiple access) technology in January 1998 as the European third-generation standard[40] (Funk 2002: 78–82; 206–8). The previous development was pursued within ETSI in very general terms. When it came to an actual decision W-CDMA was chosen because ETSI believed that standard offered greater capabilities than an enhanced version of GSM and because W-CDMA included the evolution of the GSM network interface (Funk 2002: ch. 6: 6). Hence UMTS can be seen as an extension of GSM, and the two systems are intended to be compatible.

The choice of W-CDMA has been seen as a major victory for Japanese manufacturers and its two European supporters, Ericsson and Nokia. The decisions made by ETSI and ITU also made W-CDMA a global standard. The 'UMTS alliance' includes the European Union and some national operators, such as Japan's NTT DoCoMo. It also includes multinational telecommunications equipment manufacturing firms such as Ericsson and Nokia. The choice

[40] NTT DoCoMo is the largest mobile phone operator in Japan. It is a spin-off of NTT; the former operator monopoly. NTT is still a majority equity holder in DoCoMo.

of W-CDMA was a blow to supporters of other standards such as TDMA (time division multiple access) and CDMA2000.

UMTS will be, in important respects, a significant departure from existing mobile telecommunication systems, and will constitute a 'third-generation' system. It involves several important breaks with GSM:

- the use of broadband, as opposed to narrow-band, radio frequencies;
- full integration of voice and data communications;
- full integration of 'fixed' and 'mobile' telecommunications networks; and
- provision of 'seamless' global roaming, in addition to high functionality.

However, a certain level of wireless data transmission is already possible within GSM. For example, the further development of GSM technology (and other, second-generation counterparts) has proceeded for some time within a framework consistent with UMTS objectives. A case in point is the wireless application protocol (WAP) created in 1998. WAP constitutes an intermediate stage of development between existing GSM capabilities for wireless data transmission and the UMTS goal of making 'wireless Internet' a reality through an integration of fixed and mobile communications networks. WAP is HTML compatible since Internet material is in HTML format. WAP allows a great advance in GSM wireless data transmission by enabling Internet information to be delivered on mobile devices that already support GSM-based SMSs.[41] WAP was in operation by 2001 in many countries, but it had not become a success in terms of number of users until early 2002.

Another 'intermediate' solution – between 2G and 3G – is GPRS (general packet radio service). It brings the IP into the GSM network and thus enables data to be sent in small packets, with users to be charged for these packages as opposed to connection times, and data transmission speeds up to 115 Kbit/s. GPRS also makes multimedia services possible (Funk 2002: 211–12). Many GSM operators introduced GPRS during 2001.

The first operator to put UMTS in operation was NTT DoCoMo in Japan, who initiated the service in October 2001.[42] DoCoMo was a natural first mover since the company has operated the I-Mode mobile Internet system since February 1999. Like WAP, I-Mode is somewhere between second- and

[41] As mentioned before, SMS is data transmission of a 'paging' character, but in both directions. Here there is a direct link between mobile phones and fixed Internet, i.e., SMS can be sent to and from fixed computers as well as mobile phones.

[42] However, the system has suffered from a number of technical problems that have made many potential subscribers hesitate. Therefore the 3G system had fewer than 55 000 subscribers in March 2002, which was well below DoCoMo's objective.

third-generation mobile telecommunications, and had 31 million subscribers by March 2002.[43] The fact that UMTS was first introduced in Japan might provide Japanese equipment manufacturers with an advantage over other manufacturers.

Reasons for the success of I-Mode in Japan include low fixed Internet usage and DoCoMo's effective strategy. The reasons why DoCoMo has the largest number of subscribers and content sites are its early release of compatible handsets, a packet service, a clearinghouse, and its use of compact HTML. The packet service enables small packets of information to be sent inexpensively. In the clearinghouse, DoCoMo collects money for the content provider's fee-based services and takes 9 per cent as a handling charge. This organizational or managerial innovation is crucial since it makes it easy for content providers to earn money without actually being responsible for collecting the charges from the users themselves (Funk 2002: ch. 6).

In Europe, auctions for UMTS licences were held in many countries during 2000 – and operators in some cases agreed to pay enormous fees. This has created financial difficulty for some operators and will be an obstacle to the diffusion of UMTS in Europe. Some people believe that shortsighted governments thought they could finance the increasing costs of an ageing society by taxing new economy agents, such as the mobile telecommunications operators, and that this may hurt an important part of European high-tech industry. In some countries – e.g., Sweden – licences were allocated by means of 'beauty contests', i.e., a comparison of the characteristics of the proposed systems was the basis for granting licences and no fee was paid. The investments in 3G systems will be very large and are expected to be carried out during 2002 and 2003 in Europe. The US will be a laggard (also) with regard to UMTS, partly because other users, e.g., the military, tie up the relevant radio frequencies.

Whether third-generation mobile telecommunications systems (including mobile Internet access) will diffuse rapidly or slowly will depend on:

- the quality and importance of the services provided (as evaluated by those who pay);
- the structure and rate of the tariffs; and
- the cost of accessing similar services in other ways.

If operators want to enhance rapid diffusion of third-generation mobile telecommunications subscriptions they must ensure the services are good and probably offer flat subscription rates of a limited size. In addition, cultural

[43] I-Mode is a transitional system, based on narrow-band frequencies and a development of the Japanese PDC standard. DoCoMo established I-Mode in the Netherlands, Germany and Belgium in early 2002.

differences between countries may be important, as in the way everyday life is organized. For example, lengthy commuting via public transportation as in Tokyo may contribute to rapid diffusion of 3G.

The European success in NMT and GSM will not necessarily be repeated for the third generation of mobile telecommunications because some conditions contributing to the success of the first and second generations no longer apply. In particular, liberalization has reduced the central role of monopolistic PTOs, diminishing their close interaction with equipment producers. Consequently, producers may find that large domestic markets are initially more difficult to obtain for new products.

There are also alternatives and supplements to 3G. As Dalum and Villumsen (ch. 2, this publication) point out, 3G systems will not provide users with the full range of broadband services available to fixed Internet users. 3G systems are based on rather low-speed data communications. The absolute maximum speed for UMTS is currently 2 Mbit/s and speeds lower than 400 Kbit/s will be the norm at least for the next few years. Much higher speeds will be provided by a complement to UMTS, called WLAN. This began with the development of customer premises networks (CPNs) or wireless local area networks (WLANs) for professional users (firms). Recently WLANs also started to be installed in public areas. Public WLANs can cover only small geographical areas or 'islands', e.g., an office, an airport or an Internet café. In these islands a PC or a Palmtop can be used to access the Internet at speeds of 10 to 50 Mbit/s.

Dalum and Villumsen argue that WLAN will rapidly diffuse in the near future (ch. 2, this publication). By April 2002, there were some 300 public areas covered by WLAN in Sweden (Ny Teknik 2002). A 4G mobile telecommunications system may be considered an integration of a 3G mobile telecommunications system and WLAN access to the 'traditional' fixed Internet (and integrated with other wireless options such as GPRS, Bluetooth,[44] etc.). The customer will be automatically connected to the network with the highest capacity and the same subscription is used for all. The standard now emerging as the winner within WLAN is the American IEEE 802.11a and b. The 802.11a operates in the 5 GHz band with a potential speed of 50 Mbit/s, while 802.11b operates with 10 Mbit/s in the 2.4 GHz band. As Dalum and Villumsen state, ETSI's HiperLAN 2 standard appears the loser in this standardization game.[45]

[44] Bluetooth is a mode of transmitting data and voice over very short distances using radio signals instead of cables.
[45] HomeRF is yet another variant while Bluetooth-based solutions basically operate only within 10 metres of distance and act more as substitutes for cables. See, e.g., Garber (2002); Mannings and Cosier (2001); and *The Financial Times* (2002), FT Review 'CEBIT 2002 and beyond'.

The frequencies used by WLAN are unlicensed, i.e., free, and therefore encounter interference from other WLAN systems or from different applications. The 2.4 GHz band currently mainly used for WLANs is also used by – and can therefore be disturbed by – Bluetooth, microwave ovens and car-parking sensors. The 5 GHz band, which is the frequency proposed for new WLAN systems, is free from interfering competitors and allows many operators to co-exist.

Currently the US is probably most advanced in private and public WLAN installations, with Cisco strongly supporting the 802.11 standard. At the same time 3G is delayed because no radio spectrum has been allocated. For these reasons it is highly probable that WLAN will become more important than 3G in the US than in other countries (although WLAN cannot, of course, cover large areas). In Europe 3G licences have been awarded in most countries and will be installed fairly soon. However, operators who did not get 3G licences may be pushing WLAN. The country most committed to 3G is Japan, where 3G is already operating, and where there is very little discussion about WLAN (Wireless Web 2002).

Within the mobile telecommunications sector the number of categories of actors as well as the number of actors in most categories will increase. Currently the dominant categories are suppliers of equipment and access providers (operators). The vendors of systems (base stations and switches) are not likely to be threatened, since economies of scale and barriers to entry are very large. They need only wait until the current crisis is over and the operators start investing again. On the handset side we are, however, likely to see additional producers, probably with niche strategies focusing on cheap mass-market phones or very advanced ones. This increased competition will mainly influence Nokia, Motorola and Siemens.

The number of access providers will increase in many markets in the near future. In Sweden, for example, two new large mobile operators will enter when the 3G networks start to operate during 2002 and 2003. In addition, operators who own networks may start renting capacity to others, i.e., operators without networks will enter. Hence competition will increase in several ways.

A major obstacle to the breakthrough and growth of 3G is the supply of mobile Internet content. Just as in the fixed Internet sector, content providers independent of access providers will have to mitigate the obstacle of the supply of content for mobile Internet. This pertains to content such as games, music, news, information, financial services, etc., where the division of labour and the relations between access providers and independent content providers are not clear and have to be sorted out. How, for example, should the final customer pay? Via the invoice from the access provider, via a bank account or via some other intermediate actor? There is a struggle here between various interests.

An even more difficult issue to resolve is how the cake will be divided between providers of access and of content. Currently the operators appropriate most of this cake, and it is probably necessary that more be handed over to content suppliers in order to create stronger incentives for the development of content for mobile Internet. This conflict must be resolved no later than when handsets with larger displays in colour (3G phones) have emerged, i.e., in late 2002 or 2003. When discussing NTT DoCoMo's I-Mode, I stressed that organizational and managerial innovations are important in this field. 3G will not become successful without content that is so attractive the final customer is willing to pay! Such content will not be developed if its providers cannot charge for it.

4.3.3. Satellite communications

Wireless access to the Internet and to telephone lines can also be achieved via satellite communications (see Dalum, ch. 5, this publication). A communications satellite is basically a microwave repeater revolving around the earth in a specified orbit. On earth the signals can either continue in cable or mobile systems or be transferred to private houses by means of small discs. The satellites are primarily used for TV and radio transmission. For example, the European EUTELSAT system was broadcasting 750 analogue and digital TV channels and 450 radio channels by the end of 2000. In 1999, however, 20 per cent was used for a range of broadband services, including Internet backbone and access and corporate networks. EUTELSAT was initially government based but in 2001 was in the process of being privatized. At the start, members of US-dominated INTELSAT were also national governments, with privatization measures beginning during 2001 (Dalum 2002; and ch. 5, this publication).

So-called 'set-top boxes' may facilitate high-speed Internet access in remote areas. These represent an alternative solution if incumbent telecommunications operators are reluctant to make high speed available. They also make it easier for people without computer skills to reach the Internet through their TV screen. This convergence between TV broadcasting and Internet access represents an enormous potential for television networks (Dalum 2002; and ch. 5, this publication).

At the beginning of the 1990s four large consortia announced plans for mega projects of satellite-based mobile telecommunications systems. Iridium, Globalstar and ICO are the best-known examples. All became established, but in the first half of 1999 Iridum and ICO went bankrupt and Globalstar significantly adjusted its plans. Operations were geographically focused on areas

where there were no terrestrial mobile communications systems available – which decreased the number of customers as well as their purchasing power.

The success and vigorous growth of cellular mobile telecommunications was significantly underestimated, bringing commercial failure to many enterprises. The 'new millennium' fostered huge ambitions for voice and data transmission among global mobile satellite-based systems that have been drastically scaled down (Dalum 2002; and ch. 5, this publication).

With widespread 3G mobile communications – or WLANs – within reach in the next five to ten years, satellite-based mobile phone systems will serve complementary roles in areas with weak coverage of terrestrial mobile communications networks. They will also play a role in maritime communications and perhaps also in systems intended to be used by the airline industry.

4.3.4. Rate structures and levels

The structure and level of rates and tariffs may also be considered to be 'rules of the game', i.e., a form of institution. In this case, it is an institution created, to a large extent, by firms, i.e., at the micro level – although firms are also influenced by other institutions, e.g., regulations. The quality and value of a telecommunications or Internet service, as perceived by the user, influence the rate of the service's diffusion. The cost of the service also influences diffusion. This implies that comparative prices of different modes of accessing certain services are important – and so are comparative prices of content provided over the networks.

In GSM there was agreement that calling charges were to be billed to the caller. However, when calls were placed to a mobile handset located in another country at the time of calling, the caller was charged the local rates, and the cost for forwarding the call outside the home country was paid by the receiver.[46]

In the US, however, the receiver has traditionally been charged. If a call is placed from a fixed telephone line to a mobile phone, only the receiver is charged (if the receiving handset is located in the vicinity). This is because there is normally no variable cost for local phone calls from fixed lines in the US, but only a fixed subscription fee. For long-distance calls there is also a variable cost. If the receiver is located outside the local area, then both the caller and the receiver pay. If a call is placed between two mobile phones, both are also paying a variable fee. This posed an obstacle to diffusion of mobile telecommunications in the US that Europe did not experience. It constituted a disincentive to subscribe to mobile services while creating an incentive for users to switch off the handsets – which led to non-availability. There was also a disincentive to give out mobile numbers because of this.

[46] This decision was taken since the caller would otherwise not know the cost of calling.

The importance of the level of charges (related to quality and value of service provided as well as to the cost of alternatives for access to the same or similar service), can be illustrated by the fact that mobile subscriptions diffused rapidly in Sweden (as compared to the UK), because of low tariffs even in the analogue era (see section 4.3.2.1).

The introduction of the prepaid card was also instrumental in increasing the diffusion in those countries where it became available. In Sweden these cards were first introduced in 1997 by Comviq – one of the three operators (now called Tele 2). The prepaid cards are, for example, used by people not able to subscribe, e.g., young people and those without credit for other reasons.

The structure and level of access costs to the fixed Internet also vary between countries and continents. In the US a flat rate is all that is normally charged, which makes possible unlimited Internet access. Local dial-up is not metred.[47] In the UK and also in Italy, Internet access has been provided to a large extent free of charge, although this phenomenon might be gradually disappearing in the near future. In Sweden most consumer Internet access has been mediated by a modem and a variable cost has been paid (in addition to the subscription fee). However, the US pricing structure is currently becoming increasingly common in Sweden. In Japan the cost structure is similar to that in Sweden, i.e., both fixed and variable costs are charged.

The rate structure probably explains in part the high penetration of Internet access in the US – and the low ratio in Japan. However, rapid diffusion in Sweden cannot be explained by rates. Nor is the slow Internet penetration rate in Italy a consequence of pricing structure, but rather a lack of familiarity with information and communication technology (ICT) applications, the inertia of Italian consumers and their limited knowledge of English.

The low diffusion of fixed Internet in Japan – together with the low density of home PCs – may, in turn, partly explain the rapid diffusion of the I-Mode mobile Internet operated by NTT DoCoMo. Further, this may be a reason why DoCoMo was the first operator to install a full-scale third-generation mobile telephone system in October 2001 (as discussed in section 4.3.2.3).

4.4. Boundaries Between Systems and Convergence Between Subsystems

What is the sectoral system of innovation in the telecommunications field? Is there one sectoral system or are there several systems? The telecommunications sector – in a wide sense – is growing rapidly and there is convergence

[47] Other OECD countries with unmetred local telecommunications services are Australia, Canada and New Zealand. In these countries and the US there is also a high penetration of Internet hosts (Mowery 2001: 37).

between various parts or subsystems. It is possible to talk about convergence in several senses and respects.

First, we saw convergence between information technology (IT) and communication technology into information and communication technology, which occurred in the 1980s. There was then convergence between ICTs and the broadcasting/audiovisual technologies in the 1990s. This constituted the starting point of the so-called multimedia revolution.

The transfer to digitized mobile telecommunications systems in the 1990s implied a convergence of formerly separate technologies. The technological base had broadened to include innovations from outside the traditional telecommunications sector, mainly from computer and software firms. This meant that telecommunications equipment producers in essence became IT and software firms, although with a specialization in telecommunications. It also meant that traditional telecommunications firms had to confront new entrants whose competence had originated in other sectors. In addition, standard-setting organizations became important. There has also been considerable growth of publicly funded research in telecommunications in Europe during this past decade.

In the 1990s we have experienced convergence between traditional telecommunications and the Internet. The emergence of the Internet meant that another subsystem entered the telecommunications sector. This implied that new functions had become important, and new kinds of organizations entered the sector – new Internet access providers (such as telecommunications operators and cable TV operators), Internet content providers (such as e-commerce companies) and consulting companies specializing in software and the Internet.

In the near future we are bound to see a convergence between fixed Internet and mobile telecommunications with the emergence of third-generation mobile telecommunications. This convergence has already started with SMS and with WAP and GPRS (and with UMTS in Japan). What WLANs will mean in terms of convergence is still unclear.

We have also seen a convergence process with regard to receiving devices or customer premises equipment. For example, third-generation cellular phones offer Internet connection and narrow-band services. Similarly, desktop computers can be used to make telephone calls or to watch a video, and set-top boxes are also starting to become an alternative device for Internet access. Palm pilot organizers may also be used for Internet access. There are combinations of these devices. In 1994, Nokia introduced one of the first data interface products – a 'PC' card that could be inserted into a portable computer connected to a mobile handset by means of a cable.

All this has meant that the knowledge base for the telecommunications sectoral system has become increasingly complex. Convergence means that boundaries are changing and that sectoral systems may be moving targets, becoming larger and more complex. However, boundaries may also change in the opposite direction and sectoral systems may become more specialized, more isolated from other (sub)systems because of increasing specialization, and smaller. Therefore, both convergence and divergence might occur.

In section 3, we concluded that there is a certain degree of arbitrariness when it comes to specification of sectoral boundaries. Therefore, we can consider data communications to be one sectoral system, and mobile telecommunications to be another. However, we can also see both as belonging to one combined system (particularly if they are converging). It is partly a matter of choice and convenience. Some minimum degree of coherence is nevertheless required to make it useful to talk about a sectoral system. We would not regard paper pulp and telecommunications to be the same sectoral system of innovation.

Here, we take a very pragmatic view of whether we are talking about one sectoral system of innovation or about several within telecommunications in a wide sense. Sometimes it may be useful to regard the whole field as one system. Other times it might be more fruitful to consider the Internet or mobile telecommunications to be separate sectoral systems of innovation. It depends upon the context – e.g., on the purpose of the study to be carried out. In addition, equipment production, network operation (access provision) and content provision can be regarded as separate systems or as one common system.

However, *when* an empirical study is to be carried out it is absolutely necessary to identify the boundaries of the sectoral system to be scrutinized. The boundaries have to be specified in a sectoral as well as functional sense (and in a geographical sense, if the system is not global).

In section 3, we discussed the functional boundaries of systems of innovation and identified them with the determinants of the relevant innovation processes. If we can identify the determinants of different kinds of innovations in fixed Internet and mobile telecommunications, then we can say that these determinants constitute the functional boundaries of the relevant SSI. However, we do not know these determinants in detail, given the present state of the art. Hence, this is a clear example of the 'catch 22' problem mentioned in section 3.

REFERENCES

Abbate, J. (2000), *Inventing the Internet*, Cambridge MA: MIT Press.

Braczyk, H.-J., P. Cooke and M. Heidenreich (eds) (1998), *Regional Innovation Systems: The Role of Governance in a Globalised World*, London and Pennsylvania: UCL Press.

Breschi, S. and F. Malerba (1997), 'Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries', in C. Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations*, London and Washington: Pinter/Cassell Academic.

Carlsson, B. (ed.) (1995), Technological Systems and Economic Performance: The Case of Factory Automation, Dordrecht: Kluwer.

Carlsson, Bo and Rikard Stankiewicz (1995), 'On the Nature, Function and Composition of Technological Systems', in B. Carlsson (ed.), *Technological Systems and Economic Performance: The Case of Factory Automation*, Dordrecht: Kluwer.

Cooke, P. (1998), 'Introduction: Origins of the Concept', in H.-J. Braczyk , P. Cooke and M. Heidenreich (eds), *Regional Innovation Systems: The Role of Governance in a Globalised World*, London and Pennsylvania: UCL.

Corrocher, N. (2002a), 'The Internet Services Industry: Sectoral Dynamics of Innovation and Production', report written within the study of the 'Fixed Internet and Mobile Telecommunications Sectoral System of Innovation' carried out within the EU-financed TSER project 'Sectoral Systems in Europe – Innovation, Competitiveness and Growth' (ESSY), co-ordinated by Franco Malerba, Bocconi University.

Corrocher, N. (2002b), 'The Internet Services Industry: Country-specific Trends in the UK, in Italy and in Sweden', report written within the study of the 'Fixed Internet and Mobile Telecommunications Sectoral System of Innovation' carried out within the EU-financed TSER project 'Sectoral Systems in Europe – Innovation, Competitiveness and Growth' (ESSY), co-ordinated by Franco Malerba, Bocconi University.

Dalum, B. (2002), 'Data Communication – The Satellite and TV Subsystems', report written within the study of the 'Fixed Internet and Mobile Telecommunications Sectoral System of Innovation' carried out within the EU-financed TSER project 'Sectoral Systems in Europe – Innovation, Competitiveness and Growth' (ESSY), co-ordinated by Franco Malerba, Bocconi University.

Dalum, B. and G. Villumsen, (2002), 'Fixed Data Communications – Challenges for Europe', report written within the study of the 'Fixed Internet and Mobile Telecommunications Sectoral System of Innovation' carried out within the EU-financed TSER project 'Sectoral Systems in Europe – Innovation, Competitiveness and Growth' (ESSY), co-ordinated by Franco Malerba, Bocconi University.

Edquist, C. (1997), 'Systems of Innovation Approaches – Their Emergence and Characteristics' in C. Edquist, (ed.), *Systems of Innovation: Technologies, Institutions and Organizations*, London: Pinter/Cassell. (Also published in Swedish.)

Edquist C. (2001a), 'Innovation Policy – A Systemic Approach', in D. Archibugi and B.-A. Lundvall (eds), *The Globalising Learning Economy: Major Socio-Economic Trends and European Innovation Policy*, Oxford: Oxford University Press.

Edquist, C. (2001b), 'Innovation Policy in the Systems of Innovation Approach: Some Basic Principles', in M.M. Fischer and J. Fröhlich (eds), *Knowledge Complexity and Innovation Systems*, Berlin: Springer Verlag.

Edquist, C. (2001c), 'The Systems of Innovation Approach and Innovation Policy: An Account of the State of the Art', paper presented at the DRUID Conference, Aalborg, 12–15 June.

Edquist, C., M.-L. Ericsson and H. Sjögren (2000a), 'Collaboration in Product Innovation in the East Gothia Regional System of Innovation', *Enterprise & Innovation Management Studies*, 1.

Edquist, C., and L Hommen (1999). 'Systems of Innovation: Theory and Policy from the Demand Side', *Technology in Society*, **21**: 63–79.

Edquist, C., L. Hommen and M. McKelvey (2001), *Innovation and Employment: Process versus Product Innovation*, Cheltenham: Edward Elgar.

Edquist, C., L. Hommen and L.Tsipouri (eds.) (2000b), *Public Technology Procurement: Theory, Evidence and Policy*, Boston/Dordrecht/London: Kluwer Academic Publishers.

Edquist, C. and B. Johnson (1997), 'Institutions and Organisations in Systems of Innovation', in C. Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations*, London and Washington: Pinter/Cassell Academic.

Edquist, C. and B.-Å. Lundvall (1993), 'Comparing the Danish and Swedish Systems of Innovation', in Richard R. Nelson (ed.), *National Innovation Systems – A Comparative Analysis*, Oxford: Oxford University Press.

Edquist, C. and M. McKelvey (eds) (2000), Systems of Innovation: Growth, Competitiveness and Employment. An Elgar Reference Collection (two volumes), Cheltenham: Edward Elgar.

Edquist, C. and C. Riddell (2000), 'The Role of Knowledge and Innovation for Economic Growth and Employment in the IT Era', in K. Rubenson and H. Schuetze (eds), *Transition to the Knowledge Society*, Vancouver: Institute for European Studies, UBC.

Edquist, C. and F. Texier (1996), 'The Growth Pattern of Swedish Industry, 1975–91', in O. Kuusi (ed.), *Innovation Systems and Competitiveness*, Helsinki: Taloustieto Oy in collaboration with ETLA (The Research Institute of the Finnish Economy) and VATT (The Government Institute for Economic Research).

Fagerberg, J. (2001), 'The Economic Challenge for Europe: Adapting to Innovation-based Growth', in D. Archibugi and B.-Å. Lundvall (eds), *The Globalising Learning Economy: Major Socio-Economic Trends and European Innovation Policy*, Oxford: Oxford University Press.

The Financial Times (2001), 'Broadband's slow start hides its potential', 13 December.

The Financial Times (2002), 'Wireless world offers true laptop mobility',13 March.

Freeman, C. (1987), Technology Policy and Economic Performance: Lessons from Japan, London: Pinter.

Funk, J.L. (2002), Global Competition Between and Within Standards. The Case of Mobile Phones, New York: Palgrave.

Garber, L. (2002), 'Will 3 G Really be the Next Big Wireless Technology?', *IEEE Computer*, **35** (1).

Glimstedt, H. (2001), 'Competitive Dynamics of Technological Standardization: The Case of Third Generation Cellular Communications', *Industry and Innovation*, **8** (1): 49–78.

Hommen, L. (2002a), 'The Global System for Mobile Telecommunications (GSM) – Second Generation', report written within the study of the 'Fixed Internet and Mobile Telecommunications Sectoral System of Innovation' carried out within the EU-financed TSER project 'Sectoral Systems in Europe – Innovation, Competitiveness and Growth' (ESSY), co-ordinated by Franco Malerba, Bocconi University.

Hommen, L. (2002b) 'Universal Mobile Telecommunications System (UMTS/MBS) – Third Generation', report written within the study of the 'Fixed Internet and Mobile Telecommunications Sectoral System of Innovation' carried out within the EU-financed TSER project 'Sectoral Systems in Europe – Innovation, Competitiveness and Growth' (ESSY), co-ordinated by Franco Malerba, Bocconi University.

Kenney, M. (2002), 'The Growth and Development of the Internet in the United States', in B. Kogut (ed.), *The Global Internet Economy*, Cambridge, MA: MIT Press.

Lindmark, S. and O. Granstrand (1995), 'Technology and Systems Competition in Mobile Communications', in D. Lamberton, (ed.), *Beyond Competition: The Future of Telecommunications*, London: Elsevier Science B.V.

Lundvall, B.-Å. (ed.) (1992), National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter.

Malerba, Franco (2000), 'Sectoral Systems of Innovation and Production', ESSY Working Paper No. 1, Milan.

Mannings, R. and G. Cosier (2001), 'Wireless Everything – Unwiring the World', *BT Technology Journal*, **19** (4).

McKelvey, M., F. Texier and H. Alm (1998), 'The Dynamics of High Tech Industry: Swedish Firms Developing Mobile Telecommunications Systems', Department of Technology and Social Change Working Paper No. 187, Linköping University, Sweden.

Mowery, D. (2001), 'Is the Internet a U.S. Invention? An Economic and Technological History of Computer Networking', paper presented at the DRUD Conference, Aalborg, 12–15 June.

Mowery, D. and R. Nelson (eds) (1999), *Sources of Industrial Leadership: Studies of Seven Industries*, Cambridge: Cambridge University Press.

Nelson, R. and N. Rosenberg (1993), 'Technical Innovation and National Systems', Introductory chapter in R.R. Nelson (ed.), *National Innovation Systems: A Comparative Study*, Oxford: Oxford University Press.

Nelson, R.R. (ed.) (1993), *National Innovation Systems: A Comparative Study*, Oxford: Oxford University Press.

Nelson, R. and S. Winter (1982), *An Evolutionary Theory of Economic Change*, Cambridge, MA: Harvard University Press.

North, D.C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge: Cambridge University Press.

Ny Teknik (2002), '290 heta platser för surfning med datorn', 4 April.

Porter, M. (1989), *The Competitive Advantage of Nations*, Macmillan: London.

Wireless Web (2002), 'Battling a mindset: WLAN could threaten 3G future', http://wireless.iop.org/article/feature/3/2/5, April.