Prometheus, Vol. 18, No. 1, 2000

From Innovation Systems to Knowledge Systems

JEREMY HOWELLS & JOANNE ROBERTS

ABSTRACT *This paper seeks to provide an understanding of knowledge creation and dissemination through an exploration and analysis of knowledge systems. It begins with a brief review of the systems of innovation approach. This is followed by a discussion of knowledge systems in which the nature of knowledge is considered and a definition of knowledge systems is outlined. A conceptual analysis of knowledge systems is provided in which they are compared and contrasted with systems of innovation. The conceptual framework presented is then examined more fully within the context of the computer services sector. Finally, conclusions are drawn and directions for further research are outlined.*

Keywords: knowledge, knowledge systems, systems of innovation, computer services.

Introduction

There has been much interest in the 'systems of innovation' approach in terms of how it shapes and transforms the innovation process in advanced industrial economies. Equally, there has been a desire to provide a better understanding of the role of knowledge in relation to the innovation process and more generally in terms of economic growth and performance. A full appreciation of knowledge in innovation requires a more detailed understanding of its creation and dissemination than that provided by the systems of innovation approach. This paper seeks to contribute to such an understanding through an exploration and analysis of knowledge systems. Drawing on the literature concerning systems of innovation, the paper identifies and evaluates the characteristics of knowledge systems.

For the advanced industrialised countries, knowledge is becoming the only resource capable of offering competitive advantage and continued growth and prosperity.[1] In the emerging knowledge-based economy an appreciation of the creation and dissemination of knowledge is vital for policy makers and business managers.[2] Government action can do much to promote the successful development of knowledge-based activity and the learning economy.[3] Similarly, an understanding of the dynamics of knowledge at the level of the firm, and inter-firm activity, can assist managers in their efforts to maximise efficiency and profitability, and thereby improve economic performance. Consequently, the analysis of knowledge systems presented in this paper will prove useful to policy makers and business managers. It will also stimulate debate among academics studying the role of knowledge in innovation and economic activity.

The paper begins with a brief review of the systems of innovation approach. This is followed by a discussion of knowledge systems in which the nature of knowledge is considered and a definition of knowledge systems is outlined. A conceptual analysis of

ISSN 0810-9028 print; 1470-1030 online/00/010017-15 © 2000 Taylor & Francis Ltd

knowledge systems is then provided in which they are compared and contrasted with systems of innovation. The conceptual framework presented is then examined more fully within the context of the computer services sector. Finally, conclusions are drawn and directions for further research are outlined.

Systems of Innovation

The 'systems of innovation' approach has developed and evolved from the original set of national systems of innovation studies presented by Freeman,[4] Lundvall,[5] and Nelson.[6] It is a useful framework with which to analyse the process of innovation. Consequently, the knowledge systems framework developed here seeks to draw and build upon this approach. It is therefore essential to begin with a brief review of the systems of innovation approach.

Freeman identified a number of vital and distinctive elements in a national system of innovation, such as its model of competition, which could be attributed to its success in terms of innovation and economic growth.[7] The approach has subsequently been applied at a variety of scales and levels, many of which have been outside the original focus of a national setting. Thus, although the national focus remains strong, and rightly so, it has been accompanied by studies seeking to analyse the notion of systems of innovation at an international, sub-national (regional or local) and sectoral or technology level. In this latter context, Carlsson developed the technological systems approach, which indicates that systems can be specific to particular technology fields or sectors.[8] Sectors and technological systems within a nation have a powerful shaping influence on the structure and dynamic of a national innovation system, while national contexts have important influences on sectoral performance and conditioning. Thus, prior institutional endowments of a national system may help or hinder innovative activity and performance within particular sectors of a national economy.[9]

Chris Freeman was the first to attempt to define the concept as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies'.[10] Lundvall makes a distinction between a narrow and a broad definition of a system of innovation.[11] His narrow definition of a system of innovation includes 'organisations and institutions involved in searching and exploring—such as R&D departments, technological institutes and universities'. In his broader definition, a system of innovation includes 'all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring—the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place'. Lundvall stresses that the rational element is not as clear-cut as is often assumed and that nation states, which the concept of national systems of innovation presumes, have two dimensions: the national–cultural and the étatist–political.[12] The ideal, abstract nation state where these two dimensions coincide, controlled by one central state authority, is, as Lundvall adds, difficult, if not impossible to find in the real world. Moreover, this nationally bounded view, at least in geographical terms, has been loosened over time. The approach has now been widened and developed to encompass systems of innovation which are sectoral in dimension and those which operate at different geographical scales, including both what Freeman has coined 'upper' regions ('triad' and continental regions), and 'nether' regions (regional and local systems).[13]

Edquist here has stressed the ambiguity and wide variation in what may be termed 'innovation'.[14] Thus, Nelson and Rosenberg[15] and Carlsson and Stankiewicz[16] have tended to adopt narrower definitions of innovation, mainly (though not wholly) centred

on technological innovations, whilst Lundvall seeks to include what may be termed 'dis-embodied' innovations, in particular institutional innovations.[17] However, Freeman, in his analysis of the Japanese innovation system, also emphasised the role of social and educational innovations,[18] whilst Carlsson and Stankiewicz,[19] in adopting Dosi's definition of innovation,[20] would also seem to include the emergence and development of new organisational set-ups.

The systems of innovation approach is a well established and useful framework with which to analyse the innovative capacities of nations, regions and sectors. However, the approach has so far failed to provide sufficient insight into the role of knowledge in the process of innovation. Lundvall's distinction between a narrow definition of systems of innovation and a broad definition that recognises the importance of a wider range of institutions influencing learning is useful in this respect.[21] However, further development of the approach is required in which full recognition is given to the wide variety of institutional structures which influence the process of knowledge creation and dissemination. The objective of this paper is therefore to take the first steps towards developing a knowledge systems framework which goes beyond the systems of innovation approach in its explanatory capacity. This analysis will hopefully stimulate debate and contribute, in the fullness of time, to a more thorough appreciation of the process of knowledge creation and dissemination.

Knowledge Systems

The Nature of Knowledge

In order to understand knowledge systems, it is necessary to make clear what knowledge is. However, a comprehensive philosophical discussion of knowledge is beyond the scope of this paper. The focus here is on knowledge in the context of the organisation of innovative activity, specifically in relation to the process of knowledge creation and dissemination. The discussion which follows recognises the central role of the individual in this process.

Defining and comprehending knowledge is complex and problematic.[22] A simple definition is that knowledge is what we know. However, more centrally knowledge is 'a mental state that bears a specific relationship to some feature of the world'.[23] Crucially, knowledge has a relational characteristic as it involves a knowing self and an event or an entity. Knowing is an active process that is mediated, situated, provisional, pragmatic and contested.[24] A final element in knowledge is the need for some kind of memory. 'Memory' here involves an enduring brain state which must exist in the case of knowing by the mind, and which allows the bridging of the time gap between events that have occurred and any claim to know about them. It is important to note that memory about events in the past in turn undergoes change and therefore memory forms an unconscious, altering the form of knowing.[25]

There is an important distinction to be made here between knowledge and information. Information relates to individual bits of data or data strands, while knowledge involves a much wider process that involves cognitive structures which can assimilate information and put it into a wider context, allowing actions to be undertaken from it. Thus, knowledge in turn combines the process of learning.[26] The take-up of learned behaviour and procedures is a critical element within knowledge acquisition, both in terms of capturing and moving knowledge between individuals within an organisation,[27] and also in more widely diffusing such competence throughout the organisation,[28] between organisations and indeed within the economy as a whole. It should be stressed

that knowledge cannot be said to flow; although, via information flows and mutual learning experiences which are then assembled or absorbed within a cognitive structure or framework, knowledge can be said to be shared or transferred. As knowledge is transferred through the process of codification, abstraction, diffusion and absorption, it acquires a dynamic quality.[29]

In terms of technological innovation more specifically, the innovation process involves using existing knowledge, but also often requires generating and acquiring new knowledge, which in turn involves the process of learning. Innovation also involves sharing learned knowledge. The process of innovation, by moving from existing knowledge and learning patterns to new ones through invention and discovery, can be termed a 'heuristic' (defined here as a procedure or strategy for solving a problem or moving towards a solution of a problem).[30] To accept this definition and description suggests that knowledge is fundamentally centred on the individual.[31] Even though we may share many characteristics in our knowledge frameworks and intelligence, and in the way we learn and perceive, resulting from common social and educational experiences, knowledge is still intrinsically an individually centred phenomenon. Such a viewpoint also has important implications when we come to discuss what is meant by a knowledge system.

A great deal has been discussed in relation to the important distinctions between tacit and codified knowledge and this distinction has carried through to much wider discussion at the level of the economy as a whole.[32] The distinction between tacit and codified knowledge made by Michael Polanyi is a powerful and useful one, but has all too often been mis-applied.[33] Codified (or explicit) knowledge can be defined here as knowledge which can be written down in the form of a document, manual, blueprint or operating procedure. In contrast, tacit knowledge is disembodied know-how, which is acquired via the informal take-up of learned behaviour and procedures. This bi-polar dichotomy represents a crude characterisation of knowledge within a system. In particular, it misrepresents Polanyi's own thinking, which stressed that tacit and explicit knowledge were not divided and that explicit or codified knowledge required tacit knowledge for its interpretation.[34] Polanyi notes:

> While tacit knowledge can be possessed by itself, explicit knowledge must rely on being tacitly understood and applied. Hence all knowledge is *either tacit* or *rooted in tacit knowledge*. A *wholly* explicit knowledge is unthinkable.[35]

Knowledge is therefore much more complex than this dichotomy portrays, particularly as one moves from the knowledge of the individual to organisational knowledge.

Defining Knowledge Systems

If the above defines and describes what knowledge is, how can a knowledge system be defined? Dominique Foray defines a knowledge system:

> … as a network of actors or entities that assume specific functions for the generation, transformation, transmission, and storing of knowledge … The critical degree of cohesiveness necessary to get a knowledge system is simply defined by some parameters describing the frequency of the knowledge interactions.[36]

Foray continues by noting that:

> A knowledge system includes economic agents (or learning entities) that assume the relevant functions of knowledge generation (by means of cognitive exploration and search) such as the codification and reduction of knowledge to information, the monitoring and perception of information (involving encoding, decoding, transla-

> tion, filtering, and compression), the communication and transfer of knowledge, and its storage, retrieval, and reconstruction. It also includes the institutions that serve to overcome the market's deficiencies in the production and distribution of knowledge.[37]

The description and definition which Foray applies to a knowledge system covers the actors and institutions involved in the generation, transformation, storage and distribution of knowledge. The knowledge system which Foray has described is one which is highly purposeful and specifically centred around economic agents. It is based on the knowledge interactions between these agents, and on the distribution of power. This specificity has been highlighted by Smith, who notes that the David–Foray concept of the knowledge system is complex and narrow in its multi-layered approach to scientific and technological knowledge.[38] It does, though, emphasise the role of learning systems for knowledge.[39]

Foray's definition of the knowledge system, together with the way he and Paul David have articulated this concept, is too narrow and specific. Foray and David specifically focus on the special characteristics of knowledge as an economic commodity.[40] Although much innovation, and indeed new knowledge, comes from purposeful study, learning and action by economic agents in a market-oriented and mediated context, much important knowledge does not. Serendipity and non-market situations are still highly important; social interaction and embeddedness, past historical actions, geographical proximity, trust and chance all play a significant role in knowledge processes. Above all, care should be taken not to take too *ex post* a view of a knowledge system and its impact on innovation and the wider economy. *Ex ante* the knowledge system still remains a fragmented, highly complex and sometimes confusing world. However, if we accept this narrow definition as a starting point, in what way does a knowledge system differ from an innovation system? In an attempt to address this question, the analysis presented below provides a detailed comparison between the two types of system, followed by an elaboration of the knowledge systems framework.

Knowledge Systems: A Conceptual Analysis

The conceptual analysis presented here seeks to promote the knowledge system framework as complementary to, rather than a replacement for, the systems of innovation approach. A number of points are put forward which highlight not only differences between the two types of system, but also their inter-relationship. Several problems associated with using the term 'knowledge system' as a conceptual tool are also raised.

A knowledge system represents a broader and less well-defined system than an innovation system. A knowledge system represents an underlying knowledge and learning framework and pool for the more specific process of innovation and hence systems of innovation. Since an innovation can broadly be seen as application of knowledge, knowledge represents a repository which becomes taken up and applied to invent things and create new ways of doing things. Thus, a knowledge system is bound to be a vague and nebulous system; it may include many elements which are redundant, forgotten, ignored or quite simply wrong. This notion of a knowledge system, acting as the background to the foreground of an innovation system, has parallels with Tassey's notion of a 'technology infrastructure'.[41] Here Tassey envisages knowledge, together with institutional frameworks, as providing the basic infrastructure which acts as a resource and structuring form for technological innovation.

Secondly, education and learning will obviously be central to any knowledge system.

However, Lundvall has noted the clear role that learning plays in binding together production and innovation in a national system of innovation, and the foundation that interactive learning provides for the competitive performance of an innovation system.[42] Indeed, much of what Lundvall lends to the role of learning in an innovation system is pertinent to a knowledge system. Learning is important in Lundvall's conception of systems of innovation because it is a key element in both the dynamic of the system and in binding the whole system together. Here Lundvall notes:

> … many different sectors and segments of the economy contribute to the overall process of interactive learning and the specificity of the elements, as well as the linkages and modes of interaction between them, are crucial for the rate and direction of technical change.[43]

Learning therefore plays a major role in the change and development of both innovation and knowledge systems, while forming the key element in its connectivity. In this framework, learning takes place at all levels from the individual through to the organisation; from inter-firm and inter-organisational learning to institutional learning, cross-institutional learning and so through to the whole system—the 'learning economy'.[44]

Thirdly, the notion of learning leads to a more central concern about how one conceives knowledge as one moves away from the individual to a more aggregate setting, such as a system. Obviously in the context of learning and knowledge generation and sharing, the learning process involves a clear interactive and collective dimension. There are also inter-firm and more general institutional routines which can be set up through this interactive learning process.[45] It is, however, much harder to see collections of firms, organisations and institutions as having a single, clear cognitive process (involving both a decision-making and memory function) associated with knowledge.[46] Knowledge systems can be associated with learning frameworks and parts of the system are involved in collective learning processes, but knowledge itself will reside with the individual. Discussions about knowledge commodities and knowledge assets arise from a profound misconception about the notion of knowledge. Surely knowledge assets are in reality no more than organisational and social mechanisms for the creation, absorption, diffusion and protection of knowledge? They may, for example, result from a firm's investment in a team of workers capable of reading the code through which knowledge, central to the firm's activity, is codified.[47]

Fourthly, it is useful to describe a knowledge system as combining the two elements of tacit and codified knowledge, although it is inappropriate to describe the separate functioning of these two aspects of knowledge. A knowledge system is more complex than a simple bi-polar model of codified and tacit knowledge generation and transfer. As knowledge becomes more codified, it becomes more like information, or what we term 'quasi knowledge', and less like 'real' knowledge. However, all knowledge still depends on a tacit element in its articulation, comprehension and sharing. Knowledge is also firmly rooted in the individual. Thus, as one moves further up the knowledge hierarchy (involving both geographical and socio-economic scales), knowledge radiates outward from the individual through to team/site groupings, to the whole organisation in inter-organisational, local and/sectoral, regional, national and international contexts. Clearly, there may be barriers which, in some circumstances, impede the transfer of knowledge from the individual to the team and beyond. Such barriers may be cultural (such as language differences) or regulatory (relating, for example, to the protection of intellectual property rights). However, as knowledge radiates outward from the individual, it becomes more codified, more information-like, more transferable and more global

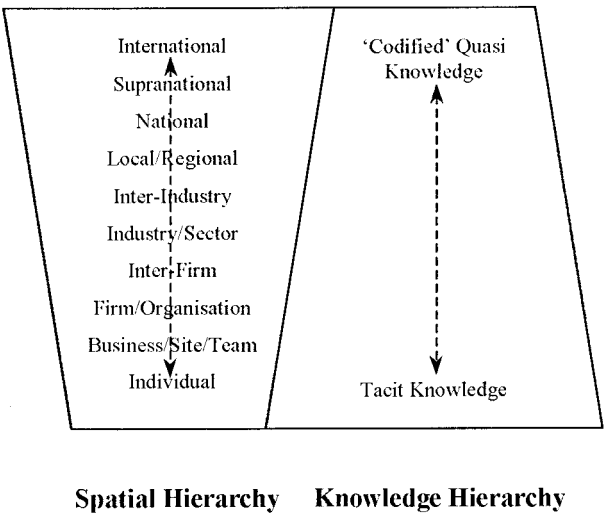


Figure 1. Knowledge: from the individual to the international context.

in its reach, but it still requires interpretation at the individual level. This is illustrated in Figure 1, where the transfer of knowledge from the individual through various spatial scales (spatial hierarchy) is set against the transfer of knowledge from the tacit form through to the codified or quasi knowledge form (knowledge hierarchy). Moving up the knowledge hierarchy, therefore, certain types of codified knowledge become essentially transmogrified into information, which can then be readily transferred. However, its interpretation, comprehension and absorption back into a knowledge state remains at the individual level. Knowledge, as defined here, is embedded within the individual and the social contexts in which individuals interact with one another.

In terms of defining a knowledge system, a distinction must be clearly drawn between individually centred knowledge and what is referred to here as 'quasi knowledge'. A knowledge system, as defined here, consists of two sub-systems. One relates to individually centred knowledge, and can be referred to as the 'knowledge sub-system'. Here knowledge circulates within and between individuals through social interaction. In this sub-system, knowledge is shared and created in a social and organisational context (although in the case of innovation mainly within the wider economic framework of the firm). Consequently, the more important institutional structures are socio-cultural, examples of which are outlined for both national and supra national levels in Table 1. Generally, this knowledge sub-system is specific to the location of the team or group within the firm. Increasingly, however, it is possible to identify such systems operating on various spatial scales. For example, R&D workers in a multinational firm may participate in a geographically dispersed team through frequent travel, enabling face-to-face contact with colleagues, together with the support of information and communication technology services, such as e-mail and video conferencing.[48] In this instance, the knowledge sub-system is international in scope.

The second sub-system within a knowledge system can be referred to as the 'quasi knowledge sub-system'. Here knowledge is shared in codified form, and the full range of institutional factors is relevant, ranging from the socio-cultural through to the economic, legal, political and so on (see Table 1). Although, a distinction is being drawn here between knowledge and quasi knowledge sub-systems, they both have socio-cultural

Table 1. Knowledge systems: institutional structure

Institutional factors	National *Examples:*	Supranational *Examples:*
Socio-cultural	Language; religion; levels of trust; degree of openness/insularity/tolerance; behavioural norms	Degree of cross-cultural harmonisation; international communications through use of common language—English
Legal	Property rights; patent and copyright systems; employment legislation; immigration laws	International law; international patent and copyright regulation; EU-wide employment regulations; international agreements GATT, GATS, IPR, TRIPS etc.
Political	Ideology; political structures; policy communities	Dominant ideology—liberal democracy; the cross-border coordination of policy—OECD; IMF, World Bank, WTO, G7, EU, NAFTA, UN
Economic environment	Level of current and prospective economic growth; business environment and industrial structure; factor endowments; mobility of factors of production	International flows of capital, commodities, labour and information; global business environment—degree of stability and economic growth; sector structures—level of competition in international markets
Policy measures	Competition & industrial policy; science & technology policy; trade and foreign direct investment policy; fiscal incentives: taxes and subsidies relating to innovation; educational policy	Cross-country, science and technology policies, and government sponsored international research programmes; harmonisation of sector wide regulation/standards—International Telecommunications; education—harmonisation of syllabus content across countries and international exchange programmes for both academics and students
Other	National trade associations; privately funded national research programmes; communication infrastructure; local, regional, national interest groups; industrial clusters and centres of excellence	Multinational enterprises; international interest groups; joint ventures, international strategic alliances and other forms of collaborations between national and multinational firms; privately sponsored international student exchanges; international secondments within firms and international organisations; privately funded international research programmes; international private sector scientific organisations; international trade association; internationally mobile scientists and knowledge workers

dimensions. The codification of knowledge may draw on social or cultural conventions; for example, language or traditions, and associated human and organisational capabilities.[49] Moreover, as already noted, the assimilation of codified knowledge requires tacit knowledge, and new tacit knowledge may arise not only from social interaction and learning, but also from the absorption and assimilation of codified knowledge. Importantly, the two sub-systems are inter-linked and, indeed, interdependent. However, whereas the knowledge sub-system usually depends on co-location and co-presence for the sharing of tacit knowledge, the quasi knowledge system is not restricted in this way. The sharing of quasi knowledge does not require co-location or co-presence between the transmitter and receiver. Consequently, when examining knowledge systems in an international context, we might expect to find that the quasi knowledge sub-system has a dominant role whereas in the local context the knowledge sub-system is more significant.

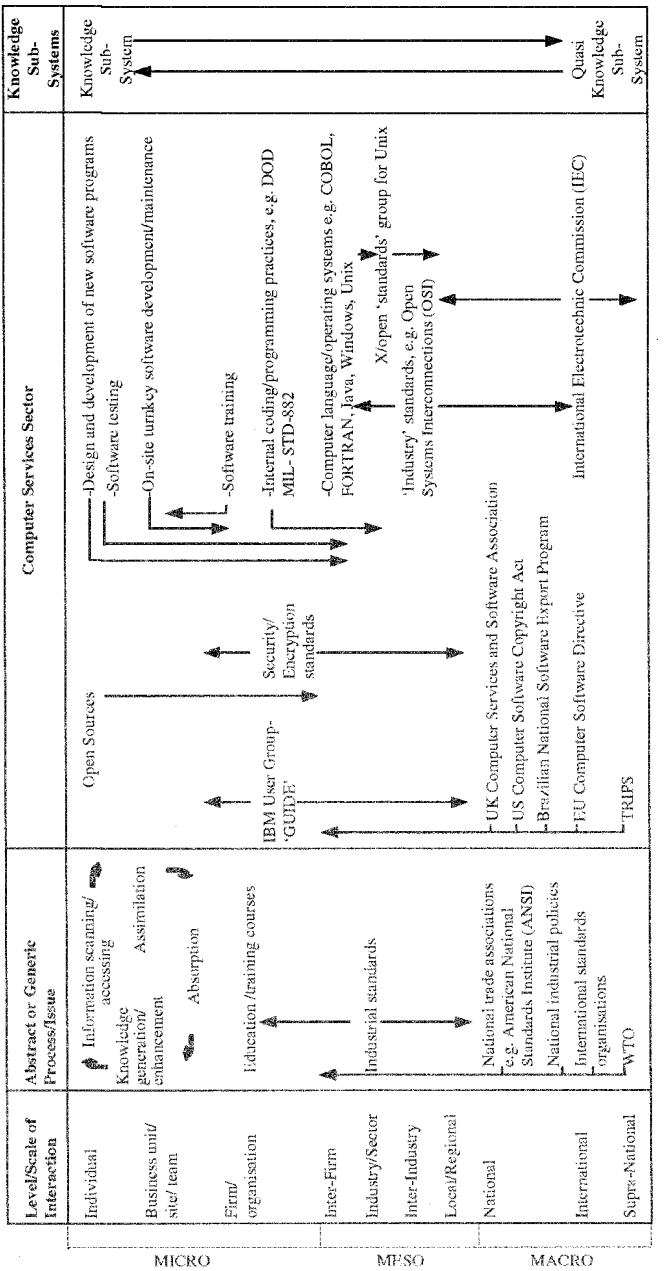
A knowledge system then, is clearly much broader than a system of innovation. The view of knowledge systems outlined here builds on the definition provided by Foray and provides a detailed reflection of the complex institutional structures which influence the process of knowledge creation and transfer on various spatial scales. The operationalisation of this framework presents difficulties and its value lies in its ability to complement the systems of innovation approach, providing an additional dimension for those studying innovation whether in a national or international context.

It should be stressed that the conceptual framework elaborated here is only an initial attempt to reach beyond the systems of innovation approach in search of a deeper understanding of the process of knowledge creation and dissemination. Clearly more theoretical analysis is required. However, such analysis must, if it is to be of value, be informed by empirical research. Consequently, the next section provides a preliminary analysis of the knowledge systems framework in the context of the computer services sector, and forms the basis for a more detailed programme of research in this area.

Knowledge Systems in the Computer Services Sector

The purpose of this section is to explore the complex web of interaction that arises from actions of the various elements that make up a knowledge system. The computer services sector is a useful sector to explore, since it is highly international and dynamic in nature. Moreover, computer services are knowledge intensive in terms of their production and their final output. One can therefore expect to see much interaction between the elements which constitute the sector's knowledge system at various spatial levels. The levels of knowledge interaction in this sector are depicted in Figure 2. The knowledge system within computer services can be seen as operating on all spatial scales. One can move from individual knowledge processing, where programmers work, for example, on the design and development of new software programs, to the more collective process of software project articulation and the subsequent testing and implementation of software programs within the software company and the client's firm. Knowledge and learning activity therefore involves constant circuits and iterations between the individual and the collective; from knowledge work within the individual to knowledge processing between other single individuals, groups of workers, and other firms and organisations. It is at the level of the individual, the team and the organisation that the knowledge sub-system is the most relevant framework for analysis.

Moving further up the spatial scale there are the institutions and 'superstructure' organisations which act to provide collective goods to their members and help to facilitate and coordinate the flow of information to 'substructure' firms at the actual core



Note: DOD – US Department of Defense; WTO – World Trade Organisation; TRIPs – Trade-Related Intellectual Property Rights

Figure 2. Knowledge systems: levels of knowledge interaction in the computer services sector.

of the innovation process.[50] These superstructure organisations, which include industry associations and standards authorities (such as the United Kingdom Computer Services and Software Association or the American National Standards Institute), help provide a framework for the knowledge processing activities. Such institutions, together with national, international, and supra national policies (such as the Brazilian National Software Export Program, the European Union Computer Software Directive and the World Trade Organisation's measures concerning Trade-Related Intellectual Property Rights) are key components in the quasi knowledge sub-system active in the computer services sector.

It is also important to recognise the interaction that occurs between the knowledge sub-system and the quasi knowledge sub-system. Actors forming the knowledge sub-system (individuals, firms and organisations) help to shape the quasi knowledge sub-system. The Open Source movement is an example of an initiative originally developed at the level of individual programmers, as a means of freely sharing source codes, which has now been taken up at the level of the firm by such companies as IBM, Oracle and Netscape.[51] This demonstrates how specific innovative development occurring at the level of the individual or team can reach out and have an impact at the level of the firm and sector. Similarly, individual firms or organisations can create *de facto* standards. The US Department of Defense (DoD) helped create the high-order programming language, COBOL, through setting up an industry committee in 1959.[52] Equally, DoD coding and programming standards, such as MIL-STD-882, can become more widely adopted throughout the computing community. More recently, there has been the example of Microsoft with its Windows software creating a global industry software platform. In contrast the Symbian joint venture of Ericsson, Matsushita, Motorola, Nokia and Psion is seeking to establish a world standard for mobile telecommunications operating systems. Thus, firm or inter-organisational knowledge frameworks can 'break out' and be adopted more widely, eventually becoming *de facto* industry or international knowledge standards. Equally, high-level international standards, associated with organisations, such as the International Electrotechnic Commission (IEC), can create knowledge frameworks which have an impact down the spatial knowledge scale. Thus, the quasi knowledge sub-system impacts upon the knowledge sub-system. All these knowledge interactions, combinations and their dynamics create highly complex knowledge systems, which are subject to change and to individual and firm-level interpretation.

The knowledge interactions occurring in the computer services sector are shown in Figure 2, where abstract or generic processes, together with sector specific factors, are set against various spatial scales. The arrows indicate the direction and span of influence relating to the listed factors. The knowledge sub-systems are also illustrated. As noted earlier, the knowledge sub-system will tend to dominate at the local level, particularly in teams or groups within the firm, whereas the quasi knowledge sub-system will have a greater influence at wider, national and international, spatial scales. However, as the arrows illustrate, the influence of both sub-systems will reach across all spatial levels. The knowledge sub-systems are interrelated and interdependent, and the influence of both may impact on certain institutional arrangements within the sector.

The characteristics of the system and the way in which it functions will depend on the nature of the knowledge created, the speed of its evolution, and the extent to which it can be internationally communicated and dispersed. Particularly important is the extent to which the knowledge can be codified. In the computer services sector and other related and high-technology sectors, products are developed rapidly and quickly become obsolete. Furthermore, knowledge may be easily codified and transferred through information and communication technologies. The quasi knowledge sub-system can

consequently be expected to have an important role at the national and international level, where sector-specific knowledge circulates through codified knowledge. The significance of the quasi knowledge sub-system is also evident when examining international production in the sector. Teams of software developers work together even though they are physically located as far apart as California and Bangalore. The fact that computer service firms and workers can collaborate on software development projects with partners on the other side of the world suggests that much of the knowledge that must be shared between the parties involved is highly codified. Yet, informal, uncodified information flows are seen as being important even on an international scale, allowing the multilateral exchange of information to reach into areas and sources of information well beyond the formal systems of the organisation.[53] The difficulty for many international corporations, however, is how to harness and make use of these informal information networks.

Certain types of innovative activity in the sector would seem to be tied to specific locations, making use of informal and personalised information and knowledge circuits.[54] Indeed, the localised qualities of information may not be confined to the informal and tacit elements of knowledge or information flow. Thus, Lamberton sees codification as possibly being effectively achieved only locally rather than internationally because of the human and organisational capabilities required in the effective absorption of codified knowledge.[55] Important clusters of computer service firms do exist in particular geographical locations, for instance, Silicon Valley (California), the M4 Corridor (Berkshire) and Silicon Alley (New York). The computer service activity present in such locations would support the creation and transfer of knowledge in the knowledge sub-system, where the innovative activity is dependent on the creation and transfer of tacit and less easily codifiable knowledge. In such locations, knowledge is transferred through a process of learning which involves social interaction between individuals.

Conclusion

Building on the literature concerning systems of innovation, this paper has explored and analysed knowledge systems. It is argued here that knowledge systems are a broader, more nebulous concept than the systems of innovation model. Consequently, when considering knowledge activity as a system, it is necessary to look beyond those factors usually associated with systems of innovation. Knowledge is highly complex and cannot be separated from the individual. Hence, knowledge systems must give particular attention to the mechanisms through which knowledge is transferred, and especially to the process of learning. More generally, though, a knowledge system includes a variety of organisational and institutional factors. Since it is argued here that knowledge is fundamentally centred on the individual, social relations and context will be of great significance in the creation and dissemination of knowledge. A major research challenge concerns the exploration and analysis of individual and social relations in an international context. Here interactions are complicated by the diversity in cultural and social norms between countries and regions.

This paper presents an initial attempt to analyse knowledge systems. The framework presented here of a knowledge system composed of two sub-systems, relating to knowledge and quasi knowledge, has proved to be a useful mechanism from which to start to explore knowledge in the computer services sector. The framework provides a tool which can assist policy makers and business managers in their efforts to analyse knowledge and the systems within which it is created and disseminated. In particular, an improved understanding of the management of knowledge activities requires the recogni-

tion of a wide range of institutional arrangements and the interactions which occur between and within institutions. The application of an improved appreciation of knowledge creation and dissemination by managers and policy makers alike can do much to promote efficiency and prosperity in the emerging knowledge-based economy.

Clearly, though, a deeper understanding of knowledge systems and how the sub-systems interact on various spatial scales is required. Further research is needed to develop our initial findings. The analysis presented provides a foundation upon which the authors, and perhaps others, will build with the aim of extending understand of knowledge in innovation and economic activity. In particular, the validity of the knowledge systems framework needs to be tested more rigorously within the computer services sector and within other sectors. Moreover, efforts to identify, measure and assess a wider range of knowledge interactions (as well as the barriers to such interactions) at a national and international level are required.

Notes and References

1. Peter F. Drucker, *Post-Capitalist Society*, Butterworth-Heinemann, Oxford, 1993, p. 40.
2. OECD, *Employment and Growth in the Knowledge-Based Economy*, OECD, Paris, 1996.
3. B.-Å. Lundvall and B. A. Johnson, 'The learning economy', *Journal of Industry Studies*, 1, 2, 1994, pp. 23–41; Geoffrey Hodgson, *Economics and Utopia: Why the Learning Economy is not the End of History*, Routledge, London, 1999.
4. Chris Freeman, *Technology Policy and Economic Performance*: *Lessons from Japan*, Pinter, London, 1987; Chris Freeman, 'Japan: a new national system of innovation?', in Giovanni Dosi, Christopher Freeman, Richard Nelson, Gerald Silverberg and Luc Soete (eds), *Technological Change and Economic Theory*, Pinter, London, 1988, pp. 330–48.
5. Bengt-Åke Lundvall, 'Innovation as an interactive process—from user–producer interaction to National Systems of Innovation', in Giovanni Dosi *et al.* (eds), *op. cit.*, pp. 349–69; Bengt-Åke Lundvall, 'Introduction', in Bengt-Åke Lundvall (ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, Pinter, London, 1992, pp. 1–19.
6. R. R. Nelson, 'National innovation systems: a retrospective on a study', *Industrial and Corporate Change*, 1, 2, 1992, pp. 347–74.
7. Freeman, *op. cit.*, 1987, 1988.
8. Bo Carlsson (ed.), *Technological Systems and Economic Performance: The Case of Factory Automation*, Kluwer, Dordrecht, 1995.
9. Jeremy Howells and Ian Neary, *Intervention and Technological Innovation: Government and the Pharmaceutical Industry in the UK*, Macmillan, Basingstoke, 1995.
10. Freeman, *op. cit.*, 1987, p. 1.
11. Lundvall, *op. cit.*, 1992, p. 12.
12. *Ibid.*, pp. 2–3.
13. Chris Freeman, 'The national system of innovation in historical perspective', *Cambridge Journal of Economics*, 19, 1995, pp. 5–24.
14. Charles Edquist, 'Systems of innovation approaches—their emergence and characteristics', in Charles Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations*, Pinter, London, 1997, pp. 1–35.
15. Richard R. Nelson and Nathan Rosenberg, 'Technical innovation and national systems', in Richard R. Nelson (ed.) *National Innovation Systems: A Comparative Analysis*, Oxford University Press, New York, 1993, pp. 3–21.
16. Bo Carlsson and R. Stankiewicz, 'On the nature, function and composition of technological systems', in Bo Carlsson (ed.), *Technological Systems and Economic Performance: The Case of Factory Automation*, Kluwer, Dordrecht, 1995, pp. 21–56.
17. Lundvall, *op. cit.*, 1992.
18. Freeman, *op. cit.*, 1988, pp. 339–41.
19. Bo Carlsson and R. Stankiewicz, *op. cit.*, 1995, p. 28.

20. Giovanni Dosi, 'The nature of the innovative process', in Goivanni Dosi *et al.* (eds), *op. cit.*, pp. 221–38.
21. Lundvall, *op. cit.*, 1992.
22. John Sparrow, *Knowledge in Organizations: Access to Thinking at Work*, Sage, London, 1998, p. 24.
23. H. Plotkin, *The Nature of Knowledge: Concerning Adaptations, Instinct and the Evolution of Intelligence*, Allen Lane, London, 1994, p. 40.
24. F. Blackler, 'Knowledge, knowledge work and organizations: an overview and interpretation', *Organization Studies*, 16, 1995, pp. 1021–46.
25. Plotkin, *op. cit.*, p. 8.
26. Michael Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy*, Routledge and Kegan Paul, London, 1958, p. 369.
27. D. H. Kim, 'The link between individual and organisational learning', *Sloan Management Review*, Fall, 1993, pp. 37–50.
28. D. Urlich, T. Jick and M. A. von Glinow, 'High-impact learning: building and diffusing learning capability', *Organizational Dynamics*, 22, 2, 1993, pp. 52–66.
29. Max H. Boisot, *Knowledge Assets: Securing Competitive Advantage in the Information Economy*, Oxford University Press, Oxford, 1998; Ikujiro Nonaka and Hirotaka Takeuchi, *The Knowledge-Creating Company*: *How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, Oxford, 1995.
30. Plotkin, *op cit.*, p. 250.
31. Jeremy Howells, 'Knowledge, innovation and location', in John R. Bryson, Peter W. Daniels, Nicholas D. Henry and Jane S. Pollard (eds), *Knowledge, Space, Economy*, Routledge, London, 2000, forthcoming.
32. Boisot, *op. cit.*
33. Polanyi, *op. cit.*; M. Polanyi, 'The logic of tacit inference', *Philosophy*, 41, 1966, pp. 1–18; M. Polanyi, *The Tacit Dimension*, Routledge and Kegan Paul, London, 1967.
34. Howells, *op. cit.*, forthcoming.
35. Polanyi, *op. cit.*, 1966, p. 7.
36. Dominique Foray, 'Generation and distribution of technological knowledge: incentives, norms and institutions', in Charles Edquist (ed.) *Systems of Innovation: Technologies, Institutions and Organizations*, Pinter, London, 1997, pp. 64–85 (quote pp. 64–5).
37. *Ibid.*, p. 65.
38. K. Smith, 'Interactions in knowledge systems: foundations, policy implications and empirical methods', *STI Review*, 16, 1995, pp. 69–102.
39. P. A. David and D. Foray, 'Accessing and expanding the science and technology knowledge base', *STI Review*, 16, 1995, pp. 13–68.
40. *Ibid.*, p. 20.
41. G. Tassey, 'The functions of technology infrastructure in a competitive economy', *Research Policy*, 20, 1991, pp. 345–61.
42. Bengt-Åke Lundvall, 'The global unemployment problem and national systems of innovation', in Dermot P. O'Doherty (ed.), *Globalisation, Networking and Small Firm Innovation*, Graham and Trotman, London, 1995, pp. 35–48; B.-Å. Lundvall and B. A. Johnson, *op. cit.*
43. Lundvall, *op. cit.*, 1995, p. 40.
44. Björn Johnson, 'Institutional learning', in B.-Å. Lundvall (ed.), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, Pinter, London, 1992, pp. 23–44.
45. Geoffrey Hodgson, *Economics and Institutions*, Polity Press, Cambridge, 1988.
46. Howells, *op. cit.*, forthcoming.
47. R. Cowan and D. Foray, 'The economics of codification and the diffusion of knowledge', *Industrial and Corporate Change*, 6, 3, 1997, pp. 595–622.
48. Jeremy Howells, 'Going global: the use of ICT networks in research and development', *Research Policy*, 24, 1995, pp. 169–184.
49. D. Lamberton, 'The knowledge-based economy: A Sisyphus model', *Prometheus*, 15, 1, 1997, pp. 73–81.
50. L. H. Lynn, N. M. Reddy and J. D. Aram, 'Linking technology and institutions: The innovation community framework', *Research Policy*, 25, 1996, pp. 91–106.

50. L. H. Lynn, N. M. Reddy and J. D. Aram, 'Linking technology and institutions: The innovation community framework', *Research Policy*, 25, 1996, pp. 91–106.
51. Chris DiBona, Sam Ockman and Mark Stone, 'Introduction', in Chris DiBona, Sam Ockman and Mark Stone (eds), *Open Sources: Voices from the Open Source Revolution*, O'Reilly and Associates Inc., London, 1999, p. 8.
52. D. C. Mowery and R. N. Langlois, 'Spinning off and spinning on(?): The federal government role in the development of the US computer software industry', *Research Policy*, 25, 1996, pp. 947–66; Edward Steinmueller, 'The U.S. software industry: An analysis and interpretive history', in David C. Mowery (ed.), *The International Computer Software Industry: A Comparative Study of Industry Evolution and Structure*, Oxford University Press, Oxford, 1996, pp. 15–52.
53. S. Macdonald, 'International information flow and strategy in the international firm', *International Journal of Technology Management*, 11, 1/2, 1996, pp. 219–32.
54. Jeremy Howells, 'Regional systems of innovation?', in Daniele Archibugi, Jeremy Howells and Jonathan Michie (eds), *Innovation Policy in a Global Economy*, Oxford University Press, Oxford, 1999, pp. 67–93.
55. Lamberton, *op. cit.*, p. 77.