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THE EVOLUTION OF TECHNOLOGIES IN TIME AND SPACE: FROM NATIONAL AND REGIONAL TO SPATIAL INNOVATION SYSTEMS

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Complementing existing approaches on national innovation systems (NISs) and regional innovation systems (RISs), the proposed spatial innovation systems (SISs) approach incorporates a focus on the path-dependent evolution of specific technologies as components of technological systems and the intermingling of their technological paths among various locations through time. SISs utilize spatial divisions of labor among several specialized RISs, possibly in more than one NIS. The SIS concept emphasizes the external relations of actors as key elements that transcend all existing systems of innovation. The integrating role of these relations remains inadequately understood to date. This poses a challenge for future research.

This article aims to understand technological development from a perspective that both integrates and transcends contemporary discussions about national innovation systems (NISs) and regional innovation systems (RISs). It approaches technological development as path-dependent processes at the level of specific technologies that evolve in time and space. These technologies are components, or subsystems, of broader technological systems, which makes them interdependent. Furthermore, technological development is spatially bound; technological paths are shaped by the social relations involved in their production as well as consumption (in processes of adoption, adaptation, and rejection) and the interplay between them. This prompts us to pay attention to the role of many RISs (and possibly NISs) in shaping the various components of technological systems: to look at the historical coevolution of interdependent technological paths. Their evolution is inseparable from the

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socioeconomic circumstances in the places in which they take place, as well as the broader competence endowments in their surrounding regions and nations. Technological frontiers create their specific “time geographies” as they evolve so as to take advantage of such circumstances. This makes us observe both the simultaneous evolution of technological paths in many RISs or NISs and their occasional movements in space. Conjointly, these are viewed as forming spatial innovation systems (SIS), which consist of “overlapping and interlinked national, regional and sectoral systems of innovation which all are manifested in different configurations in space” (Oinas and Malecki 1999, 10). Although portions of this argument have been made previously, the notion of an SIS has not been elaborated on in much detail. This article aims to make some progress in this regard.

Much of the thinking on innovation systems in economic geography and regional science is centered on localities or regions. Different places are viewed as manifesting systems—industrial, technological, sociocultural, or otherwise. What we wish to suggest in our approach, in contrast, is that innovation systems are worked out differently in space; they exhibit different spatial configurations. They may originate in one place, but often they are spread beyond local, regional, and even national borders. Technological evolution occurs through the interplay between elements of national, subnational, and transnational innovation systems that produce flows of innovation and are to different degrees able to keep up with state-of-the-art practices in different technological frontiers. Central in the SIS approach are (1) the external relations of actors and (2) the variability of the relative weights of different places or regions as center points of particular technological paths in time. With these emphases, the SIS approach offers a complement to much of the literature on localized learning that emerged toward the end of the 1990s and assumed that proximate relationships are most conducive for learning and innovation (see Oinas 1999, 2000). This assumption has largely prevailed even though it has been observed that production or innovation systems are not necessarily delimited to localities or regions (see, e.g., Storper 1996, 787; Storper 1997, 71; Amin and Cohendet 2000). This issue seems to be drawing more attention in most recent scholarship, however (see Bunnell and Coe 2001).

The SIS approach also complements the earlier literature that paid abundant attention to industrial districts, new industrial spaces, and other specialized industrial agglomerations. While this literature highlighted the specialization of those regions, the SIS approach pays attention to the possibility of various types of regions being part of SISs, whether diverse or specialized. As a related matter, regions whose economies are associated mainly with technologically mature products and processes may also serve a role in SISs in addition to technologically more advanced ones.

The problem is that innovation systems are complex entities, and it is difficult to find clear patterns that would structure our observations on the relative importance of the local versus translocal elements in them. What this article aims to do, therefore, is to open up this complexity for further exploration. While the suggested SIS approach could be applied to innovation in various types of economic activities (such as organizational, financial, and design activities), the discussion in this article is delimited to technological innovations.

The article proceeds as follows. We first discuss briefly why the prevalent literatures on NISs and RISs do not provide a full understanding of how technological innovation evolves. We then outline the SIS approach. In subsequent sections thereafter, we discuss key elements of SISs: technological paths, types of RISs involved, proximate and distant relations between actors, and firms and individuals as connectors in SISs. We conclude by reflecting on the main argument of the article and by outlining major challenges related to further theoretical and empirical research in the SIS framework.

LIMITATIONS OF THE NIS AND RIS APPROACHES

The SIS view is a complement to the existing concepts of NISs and RISs. The NIS and RIS approaches largely center on the conditions for innovative activity in a territory—nation or region—at a particular point in time. We propose instead that it helps to put these discussions in a broader perspective by providing an approach to look at the intermingling of technological trajectories among various locations through time.

The NIS approach (Freeman 1987, 1995; Nelson 1993; Edquist 1997) generally focuses on institutional characteristics of innovation systems at the national scale and privileges those at the expense of other scales. The effect of an NIS is seen in the accumulation of specific types and levels of competences in a country. Besides the private sector, this body of research recognizes the involvement of the public sector in innovation, both directly (via universities and government laboratories) and indirectly (by creating incentive structures, education and training systems, and promoting exports through fiscal, monetary, and trade policy packages) (Patel and Pavitt 1994; Nelson 1993). Other factors also can be seen as influencing the emergence of distinct NISs, such as national culture and its effect on policy (Roobeek 1990), business management systems (Hampden-Turner and Trompenaars 1993; Hickson 1993), and financial systems, which configure the relative roles of subsidies, loans, shares, and other prevailing national financial arrangements (Christensen 1992; Guinet 1995).

There is a parallel stream in the NIS literature that focuses on networks and interaction. Indeed, Lundvall's (1992) approach to interfirm networks and interactive learning (see also Gelsing 1992) may be seen as suggesting a focus on a smaller scale, geographically (subnational spaces) or otherwise (e.g., development blocks; Edquist and Hommen 1999)—i.e., to the concrete contexts of the actual interactions where learning and innovation actually occur (Acs, de la Mothe, and Paquet 1996). In line with this observation, the NIS (or NSI) approach has been criticized by, for example, Kumaresan and Miyazaki (1999), whose concern is that

> while the concept of NSI is rich and has a strong foundation, it is too rich, too macro and broad—covering all aspects from institutional set up, interfirm relationships, organization of R&D, educational and training systems, natural resource endowments, financing mechanisms to even culture. Moreover, it is unable to deal with the diversity of industrial situations in one country. In other words it is difficult to analyze NSI without going through in-depth studies at the meso-level. At the micro-level, much of the work on dynamic capabilities has focused on the issue of corporate competencies. In order to analyze dynamic capabilities at the national level, we need to accumulate studies in meso-systems, focusing on the internal dynamics of network evolution. (P. 564)

The meso level has been also highlighted in other recent research, which is attempting to focus on a scale below the national (macro level) and above that of the firm (the micro level) (Braczyk, Cooke, and Heidenreich 1998; de la Mothe and Paquet 1998a). To Foss (1996), the meso level is crucially where nonproprietary and intangible higher order industrial capabilities are developed and maintained by the interactions among firms (cf. also Nooteboom 1999b, 2000). This implies, centrally, that the development of the capabilities crucial for innovation, as well as innovation itself, is a relation-specific process. We adopt the meso level of analysis as most appropriate for a focus on the relations and flows within a spatial innovation system.

Regions within countries share some of the aspects of the entire nation, but they also have different possibilities to "go their own ways" and ultimately end up diverging from a national average (in terms of, e.g., the nature of education and training systems, science and technology capabilities, industrial structure, interactions within the innovation system, and propensities to absorb from abroad; cf. Archibugi and Michie 1997, 127-28). Indeed, within countries, specific regions tend to bring about a large share of the outcomes which, in the NIS framework, would be regarded as the accomplishments of national systems of innovation (Ohmae 1995; Oinas and Malecki 1999; Scott 1998; Storper 1997, 218). Accordingly, an increasing awareness has grown among those sensitive to spatial issues that regions might be an appropriate scale for carrying out analysis on systems of innovations. A focus on regions does not lead to the denial of the importance of the NIS as a key context and facilitator of the smaller scale innovation systems.

Those smaller scale systems are variously called clusters, territorial production complexes, productive systems, territorial systems, milieus, and local systems (see, e.g., Acs, de la Mothe, and Paquet 1996; Asheim and Dunford 1997; Cooke 1996; de la Mothe and Paquet 1998a, 1998b; Enright 1996; Feser 1998; Porter 1998; Rosenfeld 1997; Steiner 1998), but they can be seen as belonging under the broad umbrella of RISs. Three features of regional and local systems stand out as important: (1) the collectivity that somehow encompasses—indeed defines—a region in its entirety, (2) the emphasis put on the soft aspects of economic activity, and increasingly, (3) extralocal connections. It is this third feature that has not received due attention in the literature on RISs and needs to be focused on more centrally. The SIS framework seeks to provide a remedy in this regard.

SISs

A technology is an industry-specific, time-specific, and place-specific way of doing things. In clusters of economic activity, developments in several industries become integrated and coordinated through strong links (as, e.g., in industrial clusters producing electronic appliances that involve producers in several industries such as metals, plastics, telecommunications, and electronics). These clusters of interrelated and thus coevolving industry-specific technologies form technological systems (cf. Carlsson and Stankiewicz 1991; Carlsson 1994). *Technological system* refers to sets of technologies in use in specific interlinked industries. Technological systems may be local, regional, or multinational, depending on the nature and extent of the networks involved.

From the standpoint of the dynamics of these technological systems, the evolution of the various technologies in technological systems can be seen as forming technological paths. This notion relates closely to Dosi's (1982) "technological trajectory." Both notions, of course, are metaphorical, but they have slightly different connotations. Dosi defined a technological trajectory as "the pattern of 'normal' problem solving activity (i.e., of 'progress') on the ground of a technological paradigm," where a technological paradigm is a " 'model' and a 'pattern' of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies" (p. 152). Technological paradigms, in his view, embody "strong prescriptions on the *directions* of technical change to pursue and those to neglect" (p. 152). Thus, paradigms form cognitive limits for actors involved in them. While they give direction to activities, they also delimit the options that might actually be available. In addition, institutionalized structures of relations around technological trajectories add inertia to them. Dosi's trajectory, then, appears to be reminiscent of the use of the term in ballistics: a technology develops in the direction to which it is set under initial conditions until, for any reason, a paradigm changes. We regard the metaphor of a "path" more appropriate, yet we share Dosi's idea that broader paradigms give direction to them: technological paths do not move to random directions. Accordingly, the evolution of technologies can actually sometimes be described as trajectories, due to the relatively stable direction in which they seem to be moving, sometimes for relatively long periods of time. Like Dosi, we emphasize that neither trajectories nor paradigms stay unchanged. Paradigms change and new trajectories are set in motion. Thus, technological evolution involves alternating periods of progress along a trajectory (and within a paradigm) as well as periods of change, resulting in settling on a new trajectory based on a new paradigm. Yet, Dosi (1982, 158) seems to suggest that a technology progresses along a trajectory, attaining incremental innovations, until the paradigm changes, due to a radical innovation, and a new trajectory is set in motion. We draw less of a sharp distinction between incremental and radical innovations (cf. Tidd, Bessant, and Pavitt 1997), which allows for the idea of a more evolving technological path. Our emphasis is on the possibility of continuous adjustments. For example, in the case of emerging technologies and in entirely new technological systems, no clear directions of trajectories can be seen but rather an apparently randomly winding path, until the new developments settle onto something that could be called a trajectory. How steady and long lasting such trajectories are depends on the nature of the technologies and on the competitive environment.

The details related to technological change are being revealed in ongoing research, particularly where empirical situations are analyzed with evolutionary conceptual frameworks. Yet, there is a relatively broadly shared understanding of the evolution of technologies as having certain, if unpredictable, life-cycle characteristics (Nelson 1996). Technological development includes stages during which ideas emerge for new products and processes and subsequently standards and dominant designs evolve. We draw on the following in Tushman, Anderson, and O'Reilly's (1997) account on technology cycles and Nooteboom's (1999a, 2000) account on cycles of discovery. Both of these accounts, albeit with some differences, highlight subsequent periods characterized by

- the emergence of variation through technological discontinuity (novel combinations),
- consolidation (following a fermentation period including design competition),
- selection of dominant design and generalization of its application, and
- retention with incremental changes in the dominant design (Tushman, Anderson, and O'Reilly 1997) as well as differentiation as a result of applications in new contexts (Nooteboom 1999a, 2000).

These cyclical processes in the evolution of technologies keep technological trajectories or paths moving in one direction for a period of time, but relatively smaller adjustments in that direction are made in periods of retention and differentiation. More significantly, "turns" in a technological path are made during technological discontinuities as major technological discoveries are made (or as novel combinations are brought about).

What is described above refers to the progress that is made in a technological system and that takes place by advancing knowledge at the level of specific technologies (or components, subsystems of technological systems). These components have their own technology cycles, but their development is influenced by developments in other parts of the technological system. As one technology changes, adjustments have to be made in the rest that belong to the same technological system. Different subtrajectories have their own frontiers, which give them new direction. Different frontiers may compete with each other even within the same technological system.

In addition, technological frontiers are developed at different levels of technological sophistication, as older and newer technologies are often developed

FIGURE 1. Hypothetical Evolution of Two Technological Systems (A and B) in the Spatial Innovation Systems Framework

simultaneously to serve the needs of different customer groups. For example, in mobile telephony, the older NMT (*nordisk mobiltelefon*) technology is continuously improved for mobile phones used in remote areas even though most research and development (R&D) effort in Europe is being put into global system for mobile communications (GSM) applications and, increasingly, third-generation technologies. That is, parts of a technology system may make progress by the exploitation of existing technologies at different levels of advancement and incremental improvements in those, whereas the activities in frontiers are aimed at exploration: the search for novel combinations. These parts may be spatially and organizationally separate so as to receive support of suitable sets of actors, capabilities, and institutional environments in different RISs.

Accordingly, no innovation system is located in one place only. This is why it is not enough to focus on particular RISs in trying to understand technological change. Instead, the development of a technological system takes place via the coterminous evolution of its various components in space and time. It is supported by an interlinked set of social relations in a number of RISs of different levels of socioeconomic development, (semi-)integrated by the requirements of a technological system, resulting in a distinct spatial division of labor in that system. Technological systems are not autonomous of the place-specific RISs where they originate or are transferred because local conditions may be decisive for sustaining creative interaction in making progress in specific technologies.

The SIS framework is illustrated in Figure 1, which depicts the hypothetical paths of technological systems A and B. It recognizes the role of multinational corporations (MNCs) as actors who transfer technologies through international flows (e.g., the links from C_1 to C_2) via foreign direct investment (FDI) or strategic alliances. In addition, a small region can originate a technology (T_{B1} in L_3in time period t_2), decreasing its dependence on the principal source of technology (L_2 in C_1).

Summing up the discussion so far, key issues in discussing SISs are (1) the simultaneous and interdependent development of components of technological systems possibly in many places, utilizing spatial divisions of labor among several RISs specialized in different aspects of technologies, possibly in more than one NIS, and (2) the "travels" that technologies make in space and over time as knowledge flows take place along with the progress made in the frontiers of those components. The key elements in the complex spatial innovation systems are the technological paths themselves, the RISs that participate in creating the technologies or parts of them, the actors whose interaction locally and over space ultimately brings technologies about, as well as their (proximate or more distant) relations. These elements will be discussed in the following sections.

Technological Paths in Time and Space

In line with the above, we portray technological evolution at the level of specific technologies that coevolve as part of a wider technological system along their specific paths. The directions that technological paths take are influenced, but not entirely determined, by each technology's frontier. A frontier is advanced by actors within sets of social relations, for example, in one (or several) RIS. It is in the idea of a frontier that it is brought about by unique knowledge and skills: exactly the same frontier (or a part of it) cannot be in two places at the same time. Thus, the collective action of those sets of interdependent actors at a technology's frontier is subject to the basic constraints identified by time geography: movement takes time, and the same actor cannot be in more than one place at the same time (Hägerstrand 1970). They are subject to situated interdependence (Jackson and Thrift 1996, 214) with others working with a specific technology. In other words, they are locally dependent on the RISs, which are able to support a particular level of and progress within a specific technology. As a result, the advancement of each particular technology has its own time- and space-specific developmental path behind (and ahead of) it. For many innovations, technological development proceeds simultaneously but focused on different specializations, in several places. Lasers, for example, are the result of research efforts in Germany, Japan, and the United States (Grupp 2000). In aircraft, innovation is the fruit of a complex web of producers in many places, as Frenken (2000) showed by tracing 863 aircraft models. Each firm, in its own location(s), has its unique design specialization (Frenken and Leydesdorff 2000).

The cyclical patterns of technological development referred to above also need to be seen as having spatial patterns that are part of their evolution: technological frontiers may change places. Spatial discontinuities, or shifts, in technological trajectories or paths do not necessarily (or even often) happen because the sets of social relations advancing them change places but rather due to reasons related to the dynamics of technological progress, as discussed above. What is different about the time geographies of technological paths compared to the more customary idea of individuals' time geographies is that technologies may change form and multiply. Even if a frontier moves ahead in space, the path that it leaves behind does not remain entirely unchanged, that is, there is a period of retention (Tushman, Anderson, and O'Reilly 1997). Besides, new developments are set in motion as adapters of the technologies created by a frontier remain along the path and may be successful in further developing the technology—giving rise to new paths, which either go their own way or start competing with the frontier, that is, there is a period of differentiation (Nooteboom 2000). As a product moves from R&D to production, firms (and places) that specialize in economies of scale play a more important role, as firms in Singapore and Taiwan do in semiconductors (O'hUallachain 1997).

Spatial discontinuities may relate to specific phases in technological cycles. Technological frontiers are in operation in the RISs that are involved in creating novel combinations and that are able to build local structures around emerging dominant designs and exploit them commercially. If those structures become too rigid in time, they cannot change as new variation emerges, beginning a new cycle of technological change. At this time, the actors at the frontier of technology may move to areas that fulfill their locational specifications (cf. Storper and Walker 1989). Alternatively, new technological frontiers may emerge in new areas as a result of the previous dominant design having been applied in a new context, possibly in a new region, where it becomes differentiated and may give rise to a new subtrajectory and maybe later to another novel combination beginning a new cycle with a different set of actors involved.

In sum, technologies have their specific, path-dependent time geographies: technologies emerge somewhere, in a place—or sometimes similar technological solutions are invented in more than one place simultaneously (shown, e.g., by patent applications for similar technical solutions of different origins being received one after another by patent authorities)—and the further development of those technologies may take place in a new context and in a new place, where possibly new qualities are added to them. Technological development is the result of the intermingling of such technological paths, overlapping in content and possibly also in space. Each path is part of an industry- or product-specific technological system and epitomizes its developmental phases. An example is found in the hard disk drive industry (Christensen 1997), in which customers in different markets place priority on different types of performance (e.g., size, weight, speed, capacity). The industry has evolved to meet new needs, often through the emergence of new firms, taking advantage of skills and networks in new locations, such as Singapore and

Penang (Malaysia). The production skills in these new locations helped to shape the trajectories of several producers as new products were introduced (McKendrick, Doner, and Haggard 2000).

TYPES OF RISs

So far, we have aimed at giving a dynamic, albeit metaphorical, account of technological development as paths that the frontiers of specific technologies create as they evolve in time and as they travel and make connections in space. This section discusses the different kinds of places: the different, interlinked RISs that are involved in producing those paths. The RIS literature usually fails to provide distinctions between types of RISs, which may be top-down and poorly integrated regionally (regionalized NISs) or bottom-up, with considerable regional networking (territorially integrated innovation systems; Asheim and Cooke 1999; Hassink 2000). For our purposes, such distinctions are important, as SISs consist of various kinds of activities with different levels of sophistication organized in space (within and between different RISs) according to a division of labor that is specific to each SIS (cf. Figure 1). Our typology of RISs evolves out of a discussion on the relative technological advancement of regions and on the relative specialization versus diversity of their economic activities.

We start with a basic tenet of evolutionary accounts on technological development: that innovation requires diversity (Nelson and Winter 1982). In spatial analysis, the need for diversity has been documented in recent research showing that diverse locales (i.e., locales with relatively large numbers of different industries) are more important for promoting innovative firm behavior (Feldman and Audretsch 1999; Harrison, Kelley, and Gant 1996; Quigley 1998) than specialized ones (of, e.g., the industrial district type, as often assumed in the course of the 1990s). Small firms in particular benefit from regional industrial diversity (Kelley and Helper 1999) because they cannot create it internally.

These are important findings for the spatial analysis of technological change. The SIS perspective, however, prompts us to raise three additional issues.

Diversity and actual (innovative) relationships. As pointed out above, a meso-level approach to innovation pays attention to relations between actors. With regard to that, simple claims made at the level of numbers of industry sectors (whichever ISIC digit level) miss the point about the critical nature of relations within and between industries for innovation. This is the case even in regions with a broad diversity of industries. The mere presence of a variety of industries in a region obviously does not make a region a "territorially integrated innovation system" (Asheim and Cooke 1999); it does not reveal the basis of the relations between firms in any of those industries. Rather, this basis has to be seen in the potential relatedness between firms' knowledge and capabilities that may trigger their engagement in innovative interaction (Oinas and van Gils 2001).

Diversified and specialized regions complement each other (via external relations). While diverse regions may be more conducive to regional innovation relative to specialized ones, the SIS approach helps to point out that diversity as food for innovation is not always locally available in the right form and thus needs to be complemented by interaction with more distant actors—actors that can bring in specialized expertise based on their participation in another RIS. Within the SIS framework, there is no reason to think, ceteris paribus, that diversity originating locally is drastically different in terms of its potential input into innovation as compared to diversity originating elsewhere.

In line with our discussion of technological paths above, we regard it as one of the key functions of technological frontiers to search for diversity: to direct and redirect technological paths to regions where they can find suitable diversity to support innovation. When actors in one region do not provide enough diversity for innovativeness, a technological frontier either puts effort into making regional actors effectively connected to sources of diversity elsewhere, or the technology gradually loses its edge and the frontier moves to another region (yet, as discussed above, it may be another frontier, with a different set of actors and their specific social relations).

This does not exclude the possibility that even narrowly specialized regions may have a role in the evolution of technologies, by creating leading-edge specialized knowledge that supports a larger innovation system. Specialized regions do not operate in isolation but receive impulses for renewal and innovation from interaction with other innovative actors who are part of the same system even if they are not located in the same place. Thus, even a narrowly specialized region may be a substantial contributor if the part of the technology that it creates happens to be crucial at some point in time (Frenken 2000; Frenken and Leydesdorff 2000). This may be the result of the (possibly slow and incremental) evolution of specialized knowledge through local adjustments in a region that leads to a strong (possibly leading-edge) expertise in a narrow area of knowledge. It is possible that such a small region will not stay central for a long time, and the technology may or may not create spillover effects in its regional environment, but it may still be relevant for the historical evolution of the technological path.

Within regions, thus, each sector has its specific connections to extraregional partners, which enhances the innovative potential of those sectors' actors. In the case of diversified regions, external relations are likely to add to the total innovative potential of the region's actors by helping to sustain continuously higher and more diversified technological capabilities. In the case of specialized regions with a more narrow range of economic activities, external relations compensate for the lack of regional diversity.

Diversity versus specialization and technological advancement in SISs. What is important in the SIS framework, accordingly, is the variety of regions involved in whole innovation systems. Yet, regions differ not only in terms of their relative specialization but also in terms of their relative technological sophistication. The RISs that are involved in SISs range from genuine innovator regions (which may tend to be more diversified on the average) to regions that merely imitate or adopt innovations. Yet, each has a function in the SIS. We make a simple distinction in the following between three types of regions in SISs in terms of their ability to bring about innovation: adopters, adapters, and genuine innovators (Oinas and Malecki 1999) (these types still leave outside the large swath of the world which is technologically excluded; Sachs 2000).

1. Genuine innovators. These are the RISs in which genuinely novel combinations ("new to the world" innovations) take place and best practices emerge, in specific technologies. Sometimes all stages of innovation cycles (Nooteboom 1999a, 2000; Tushman, Anderson and O'Reilly 1997) may be carried out in them. Or, as innovations diffuse from them through imitation, they may host the actors that pick up problem signs or signals of new opportunities from actors in other regions exploiting existing, yet maturing, technologies (incremental innovation) and engage in exploration, to hit yet another novel combination (radical innovation), which might begin a new cycle of innovation. These regions also maintain competitive and/or collaborative relations with other leading-edge regions, which further propels their innovativeness. This involves close monitoring of what is going on in other key RISs in a particular technology. Many technologies evolve as products incorporating the knowledge contributions of firms and people in several places. Computers and peripherals, for example, are frequently the result of flows back and forth between Silicon Valley in California (prominently) and key Asian locations, such as Penang in Malaysia and Singapore (Gourevitch, Bohn, and McKendrick 2000; McKendrick, Doner, and Haggard 2000).
2. Adapters. While the main emphasis and interest of the scientific community has been in the regions that host actors creating best practices, innovation is not absent from less-than-best-practice regions. These regions do it by providing an environment for steady improvements and incremental innovations, possibly leading gradually to high quality. This takes place in RISs that are able to adopt new innovations from external sources relatively early and gradually improve them. The ability to learn from innovative firms in other places (i.e., imitating) is considered the best route for developing and maintaining innovative capability of this sort (Kim 1997; Mody, Suri, and Tatikonda 1995). Examples of regions include the newly industrializing countries of Southeast Asia, where incremental innovations are becoming common (Kim 1997; Leonard-Barton 1995; Singh 1995). Bangalore in India (Fromhold-Eisebith 1999), parts of Mexico, and the Zhong'guancun area of Beijing, China (Wang 1999), typify this environment. These areas attract a great deal of foreign direct investment, based on their productive workers, but they have not yet attained the perception from the outside as generating a steady flow of more fundamental innovations. Hobday (1994, 1995), Porter et al. (1996), and Roessner et al. (1996) include most of East Asia, including Singapore, as not yet at the stage at which local ability for innovation matches that originating from outside, except in production.
3. Adopters. RISs into which innovations diffuse relatively slowly (latecomers) are regional "imitator systems." They are characterized by actors employing an adopter strategy: they are able to import and use technological solutions (in end products, intermediaries, machinery, or appliances) from external, technologically more advanced sources. Via adopting technologies as users and through learning by imitating, they are able to adopt the production of mature products. Actors in such imitator sys-

tems are not capable of significantly improving those products. Yet, they form parts of innovation systems due to their specialization in more routine parts of production, or even just assembly (McKendrick, Doner, and Haggard 2000).

These different regions may maintain their roles in a rather static manner or they may upgrade their capabilities and gradually improve. This means that it is difficult to make clear distinctions in the real world, as many regions may host actors at varying levels of technological sophistication and, especially in diverse regions, possibly belonging to different technological systems. In a dynamic analysis, this may sometimes be a sign of a relative regional decline, sometimes of a relative upgradation of the overall regional capabilities, and sometimes even a sign of a regional structure that is fit for hosting the various actors involved in the whole innovation cycle (i.e., both those who are specialized in exploration and those who are specialized in exploitation. When progress is made in a region's innovativeness, the basis of its knowledge system changes over time, incorporating and diffusing successively more external technology (Bell and Albu 1999). This is how Kim (1999) described the process by which Korea built technological capability at the national scale. Korea went through three stages: (1) duplicative imitation of mature technology, (2) creative imitation of intermediate technology, and (3) innovation or emerging technology. Each stage required changes in Korea's national system of innovation.

Innovation systems do not operate in isolation but are the dynamic parts of production systems that are geared around getting the right goods for the right markets. Storper and Salais's (1997; Storper 1997, 116-26) typology of "worlds of production" is used in the following to elaborate briefly on the kinds of production systems innovation systems participate in.

In the "industrial world," generic and standardized products are produced for a market with undifferentiated demand. This can be done endlessly once the required skills have been learned. Actors belonging to industrial worlds are likely to be found in adopter RISs. Only through external shocks (drop in demand) may regions of this type start looking around for more sophisticated technologies to adopt themselves. As parts of innovation systems, they are able to adapt to new standards or requirements demanded by those more actively involved in innovating. Industrial worlds tend to be in lower labor cost regions or countries and mature industrial regions.

In the "market world," products are in many ways standardized (they consist of parts made according to standardized specifications), but they are produced for dedicated customers. Market worlds tend to be specialized production regions with large numbers of firms in an industry. Market worlds are likely to be in operation in adapter regions. Producers may be of the adapter type because they may engage in incremental innovation while adjusting their production to the needs of customers.

The "interpersonal world" produces for dedicated customers with specialized needs. For this purpose, specialized capabilities are needed as well. This world is found in technological and industrial districts, and it is the central locus of leading-edge innovation. This world is obviously a genuine innovator RIS. This is the kind of system in which it is usually assumed that proximity among actors is required due to the need for frequent interpersonal communication and shared understandings to support it.

The "world of intellectual resources" uses scientific methods for developing new generic products for specialized purposes. The intellectual worlds are designed to specialize in the phase of particular innovation cycles that explore new knowledge, and they may comprise those parts of the interpersonal world that are geared toward innovation (e.g., R&D projects). As part of innovation processes, relations in this world are, indeed, maintained with actors in an interpersonal world. Storper (1997, 124-25) seemed to assume that interaction in innovation takes place in the districts, or RISs, of the interpersonal world. Productive activities may also take place over long distance as external transactions may happen over long distances in predictable, formal, contractual governance regimes (Storper 1997, 124-25). This world may be the progressive core of a genuine innovator system, and it often works in close connection with the interpersonal world in the same or a closely connected location.

These worlds may be connected to each other through concrete production relations. They may also become connected via forming key nodes of cycles of innovation over time: what is first discovered in the intellectual and interpersonal worlds is transferred to other places after or during a period of consolidation by actors in them (FDI, licensing, etc.) or imitated by actors in the industrial or market worlds. Sometimes these worlds may operate in the same place, as suggested above, and sometimes they are separated by space so that each type of activity is located in regions (RISs) where they find the best fit with other actors in the local environment. A spatial division of labor reflects the relative advantages of local environments for activities before and after the emergence of a dominant design (Utterback and Afuah 2000) or as technological clusters as opposed to operational clusters (McKendrick, Doner, and Haggard 2000). Younger technologies are characterized by a wider, more open-minded perspective, based on many links to sources of knowledge. By the time production begins, the number of partners and suppliers is reduced to reflect the standardization of production.

The above considerations on the sectoral specialization versus diversity of regions and the relative maturity versus advancement of their technologies are brought together in Table 1, which outlines a typology of RISs involved in different types of SISs. Regions that host genuine innovators may be diversified or specialized, but with specialization may come an inability to connect to other industries or shift to new technological regimes as times change (i.e., to sustain innovativeness in the region). Adapter regions may acquire a high level of competence, enhanced by diversity, which enables greater technological sophistication. Adopter regions exhibit innovativeness only in production, and many are unable to exhibit any innovativeness because of specialization in assembly with few local suppliers.

TABLE 1. A Typology of Regional Innovation Systems

Characterization of Region	*Sectoral Diversity*	*Sectoral Specialization*
Genuine innovators (best practice places)	"Stars" (e.g., Silicon Valley, Cambridge, U.K.)	"Shooting stars" (e.g., Detroit, U.S., eighteenth-century Glasgow)
Adapters (relatively high levels of diverse competences)	"Living room lamps" (e.g., Hsinchu, Taiwan)	"Spotlights" (e.g., Bangalore, India)
Adopters (production-oriented competences)	"Chandeliers" (e.g., Bangkok, Thailand)	"Candles" (e.g., Dongguan, China)

As these ideas are at an experimental stage, the names of the various types of RISs are obviously playful. Among other things, we do not aim to approximate real scales (from stars to candles). The real-world examples we provide are also only suggestive as no in-depth analyses of the places are carried out.

- "Stars" are the suns for their surrounding planets: With the leading-edge innovations that they keep pushing to the market, they generate the energy that keeps other places going, either via imitation or enhanced innovativeness in other stars. They are kept strong by the multiple links among diverse industries as, for example, in Silicon Valley where the venture capitalists that keep the electronics industry alive also finance start-up biotechnology companies. Actors in their key industries also monitor developments and maintain close links with other centers of excellence on the world scale.
- "Shooting stars" live as long as they are able to live on the strength of an innovation or a set of interrelated innovations, such as those related to technological and organizational innovations in automobile production in Detroit from 1910 to 1960 and in shipbuilding in Liverpool during the eighteenth century.
- "Living room lamp" regions host actors with relatively high levels of competences in a number of different sectors, each of which maintain close links with nonlocal sources of innovation. They may also be locally connected so as to collaborate in improving local production conditions; local cross-sectoral connections may also give rise to occasional technological improvements. It is possible that these regions become "rising stars" and later give rise to genuine innovations. Korea, but perhaps particularly the Seoul region, also fits this description.
- "Spotlights" get the stimuli to engage in mainly incremental innovation through their strong external connections. Through the high competences, they are able to respond to relatively advanced R&D-related improvements, for example, delegated by headquarters staff or in collaboration with main contractors, such as Nike's developed partners in Taiwan and Korea (Donaghu and Barff 1990).
- "Chandeliers" are regions where many sectors are colocated but where those sectors are not strongly linked to each other. Rather, they maintain relatively stronger links to their respective external customers, main contractors, and other sources of knowledge. Thus, chandeliers consist of several islands of locally isolated industrial activ-

ity. Their colocation may be supported, for example, by strong government support and consequently improved production environment (involving infrastructure, finance, education, etc.).

- “Candles” stay alive as long as their relatively simple production-oriented competences are utilized and supported by externally based customers, main contractors, or corporate structures. They may become efficient masters in certain production lines. Occasional incremental innovations in production activities may occur, but this is most likely to happen via imitation or knowledge transfer within corporate networks than through the initiative of local actors.

Local and Distant Connections

It has been postulated in the literature on RISs and localized learning that the creation of noncosmopolitan (Storper 1997) or unique (Maskell 1999) knowledge through learning takes place more easily within proximate relations (e.g., Maskell and Malmberg 1999a, 1999b; Asheim and Cooke 1999). Yet, as the importance of links to nonregional networks is also a recurrent finding in recent research on industrial districts and technology districts (Amin and Thrift 1992; Tödtling and Kaufmann 1999; Maillat 1995; Mueller and Loveridge 1995; Storper 1993), it seems increasingly clear that the connections of regional actors to extraregional actors stand as momentous in technological progression. Connections to other networks in other regions provide access to a diversity of ideas and bases for comparison with local practices that are not internally generated (Amin and Thrift 1992, 1993; Camagni 1995; Maillat 1995; Tödtling 1995). An interesting example is seen in the immigrant communities from around the world that converge in and benefit Silicon Valley, partly by maintaining their previous connections (Saxenian 1999). External connections help actors within a regional system to stay in tune with what happens in the market, what happens among other producers (both competitors and collaborators), customers, scientists, regulators, support agencies, and other sources of technological knowledge and help them form fruitful relations with these agents.

It may be the case that the content of learning in nonlocal networks differs from the kind of learning that occurs in local relations (Oinas 2000). Overall, however, we do not seem to understand the nature and relative significance of proximate and distant connections in innovative activity very well to date. It is often assumed that only codifiable and hence non-culture-dependent, cosmopolitan-scientific, or professional languages can be communicated over longer distances (Storper 1997, 114). Noncosmopolitan knowledge is usually believed to involve a considerable tacit component that makes it glued to concrete local relationships. Yet, as Storper (1997) pointed out, “Noncosmopolitan knowledge is not necessarily associated with proximity or localization. The two are theoretically distinct: noncosmopolitan knowledge can be ‘localized’ in a restricted technological, organizational, or professional ‘space’, that is, in certain interpretative networks that transcend local geographical space" (p. 71). Due to the complexity of this issue, there is no pretence of exhausting it here. Let us point out that even if innovation systems were considered as localized (e.g., Asheim and Cooke 1999), it would not mean that they operate in total isolation. Being localized, then, must mean that either most relationships or key relationships in production systems or worlds of production take place in proximate relationships. What the SIS framework suggests, in addition, is that there is the possibility that neither most nor the key relationships are necessarily proximate.

In local and regional innovative systems, two sets of effects operate simultaneously (Camagni 1995; cf. Malmberg and Maskell 1997): proximity effects, such as reductions in costs because of quicker circulation of information, face-to-face contacts, and lower costs of collecting information or sharing knowledge, and socialization effects, related to collective learning, cooperation, and socialization of risks. These two processes are collective but not necessarily (explicitly) cooperative (meaning concrete, goal-oriented interaction whether in the form of supplier-customer relationship, joint R&D, or informal collaboration); they spread beyond bilateral interfirm relationships. In nonlocal relations, the proximity effect is missing and leaves only socialization effects and the possible forms that they may take over space.

Shared rationalities, or common frameworks of action (Storper 1997, 45), must be seen central in the socialization effect. Such frameworks of action, which are specific to the different worlds of production, are formed by conventions (Storper and Salais 1997, 15-17), which bring about coordination among actors (Storper 1997, 42-43). They "include taken-for-granted mutually coherent expectations, routines, and practices, which are sometimes manifested as formal institutions and rules but often not" (Storper 1997, 38). This implies that conventions are also key carriers of collectively shared tacit knowledge related to the functioning of the relevant innovation system. Following Blanc and Sierra (1999), the more precise content of Camagni's socialization effect can be interpreted to have four aspects: (1) organizational proximity (including formal relationships with suppliers), (2) relational proximity (which includes noneconomic relationships), (3) institutional proximity (especially of local informal institutions), and (4) temporal proximity (a shared vision of the future). Geographical proximity does not guarantee the other proximities, but those can partially substitute for geographical proximity (for a related discussion in terms of competence relatedness, see Oinas 1999; Oinas and van Gils 2001). There are complex trade-offs between the various proximities. When the potential involved in each type of proximity is actualized, it is manifested in shared context-specific conventions, coordinating both local and nonlocal relations.

The issues related to the question of how and to what degree conventional relations based on the various proximities are maintained over space remains largely unanswered to date. Exactly how knowledge grows and is shared in an agglomeration is beginning to be teased out in detailed studies (Henry, Pinch, and Russell

1996; Pinch and Henry 1999; Porter 1998). More work needs to be done on nonlocal relations and especially on the distant transferability or exchangeability of knowledge that involves a considerable share of tacitness.

Types of Connectors

The actors that create and maintain the relations that are emphasized in the SIS approach are centrally individuals (entrepreneurs, managers, employees, individuals in governmental or semigovernmental bodies, researchers, etc.) with their interpersonal networks (face-to-face, virtual, or a combination of these) and firms (multilocational/multinational) and their networks of various sorts: (advanced) customers, universities, research institutions, support organizations (such as chambers of commerce, knowledge centers, government bodies, and consultants). The reasons for the success of some places and the lack of success of others appear to be two interrelated things: first, interfirm differences in the degree to which active, extroverted behavior takes place and, second, the technical culture created within intensively connected communities of professionals, much of which is summed up by the characteristics of technologically successful regions (Malecki 1997; Sweeney 1991, 1999). This section discusses the nature of the actors creating those connections (cf. Oinas and Malecki 1999; Bunnell and Coe 2001). Innovation involving both local and distant relations often center on networks of these actors.

Firms and Their Networks

Kelley and Brooks (1992) distinguished between firms with primarily active and social external linkages and those with passive and asocial linkages (see also Amendola and Bruno 1990; Estimé, Drilhon, and Julien 1993). Indeed, the role of active, extroverted firms needs to be acknowledged in their role of making connections (Malecki and Poehling 1999; Patchell, Hayter, and Rees 1999). It is via the multilocational networks of facilities, alliances, and other linkages that such extroverted corporations and small and medium-sized enterprises alike are able to make SISs cut through possibly several RISs. These extroverted, active firms utilize written sources for acquiring information, interact with sales representatives, participate in trade shows, contact with vendors, and create close relationships with special-order customers for sharing of technical information (Malecki and Poehling 1999).

Via extroverted behavior, even small firms compensate for their size limitation in the adoption of new technology (Julien 1995; Rothwell 1992). Oerlemans, Meeus, and Boekema (1998) found that access to external resources increases innovation in small firms over those using only internal resources. Firms used four distinct types of external information: public knowledge infrastructure, private knowledge infrastructure, production column, and intermediaries. The most significant is the production column, comprised of buyers, suppliers, and other firms, reinforcing the view that links with customers, or producer-user connections, are the most beneficial. However, networks alone are not as effective as the combination of internal technical ability and effort with external networks (MacPherson 1997). The most likely firms to be active in seeking out external information are those with in-house R&D activity (Tsipouri 1991; Keeble et al. 1998; MacPherson 1992), which increases their absorptive capacity (Cohen and Levinthal 1989).

The wider networks of active, extroverted firms tend to encompass both more connections within the region and outside it. Extroverted firms are also more likely to aim at competition in international markets (MacPherson 1995). Externally oriented firms are able to overcome the constraints related to a peripheral location (Alderman 1999; Vaessen and Wever 1993). Vaessen and Keeble (1995) found that growth-oriented firms do more R&D and have more external programs for worker training regardless of their regional environment. Localized technological knowledge is highest where both the receptivity to nonlocal information and regional network connectivity provide access to and absorption of external information, combining it with internal competence (Antonelli 1999; MacPherson 1997). The combination of a critical mass and diversity of firms together with a set of fast-growing firms at technological frontiers appears to be the key to success at the level of a region (Chesbrough 1999).

In sum, the capability to innovate successfully at the firm level appears to be strongly conditioned by the ability to accumulate specific knowledge internally and to access sources of knowledge via external relations. The ideal case may exist when the firm's external networks can learn from strong local knowledge infrastructures, as well as maintain links to global networks of best practice in technologies, products, and services. Jacobs and de Man (1996) suggested that firms' strategies toward local and nonlocal clusters have different effects on which activities should be located in which locations. Local clusters allow greater cooperation and intensive user-producer interaction. Nonlocal clusters open possibilities to work with other clients and suppliers, and to tap—if not to become fully integrated—into different knowledge networks.

Multilocationality/multinationality is a form of extroversion. There is a growing tendency for companies to seek extraregional connections by using several home bases, including R&D and sophisticated production. External knowledge is most easily obtained by MNCs, with corporate facilities in various locations exploiting the relative advantages of their locations (Ferdows 1997), which may be seen as types of RISs. But such external knowledge must be internalized. To integrate knowledge residing in distant locations, firms must become locals in those places (Blanc and Sierra 1999; Cohendet et al. 1999; Gassmann and von Zedtwitz 1999; Reger 1999). This is evident in the five competencies that Amin and Cohendet (1999) suggested are now critical for globalized firms: (1) integrate the firm internally, (2) exploit advantages of proximity at many locations, (3) integrate fragmented pieces of localized learning, (4) invest continually in access to knowledge, and (5) focus on a small number of core competencies. This suggests three aspects to the information-age organization's structure: decentralization, information practices that promote both an awareness of external information and information-sharing within the organization, and a network structure for the outsourcing of noncore activities (Mendelson and Pillai 1999). For smaller firms, it is more difficult to be all things at once, but an effort to make external connections seems to be a minimal requirement.

Technology-based firms are particularly inclined to diversify their technology sources (Granstrand 1998) even though dispersed corporate networks do not necessarily have the result of diversifying firms' technological capabilities (Zander 1999). There is actually only scarce empirical evidence of projects that integrate knowledge across related technologies within MNCs internationally, yet, to some degree, it does happen (Zander 1998, 19).

Individuals and Their Networks

The role of individual entrepreneurial initiative is obviously central in creating and transferring innovations, whether based on imitation and adaptation of technological solutions elsewhere (e.g., Fujimoto 1998, 23), differentiation (Nooteboom 2000), or novel combinations (e.g., palm-size devices and other hybrids of mobile telephones and portable computers). Competent and mobile individuals are equally an important group of connectors (e.g., Eliasson 1998). For instance, in a comparison of twelve U.S. semiconductor regions, Almeida and Kogut (1999) found the high level of intraregional mobility of engineers in Northern California unique.

Individuals seldom innovate alone, however. Interpersonal networks are increasingly seen as a powerful force in learning and maintaining (technological) capabilities. Their role can also be highlighted in making connections within technological systems. Recent research describes innovation networks as technological communities (Powell, Koput, and Smith-Doerr 1996; Rycroft and Kash 1999), or communities of practice (e.g., Aldrich 1998; Brown and Duguid 1994; Lave and Wenger 1991; Wenger and Snyder 2000). Through intensive relations, members of technological communities share common ways of thinking about work-related issues (the collaborative project, perceiving the problems to be solved, getting about solving problems, etc.), which enables the sharing of tacit knowledge. Moreover, they often share similarities in their educational backgrounds and features of lifestyle (in many cases including a highly international orientation accompanied by frequent traveling), which facilitates the process of learning to communicate meanings in a long-standing collaborative situation. While such technological communities may be locally or regionally based, they need not be. The literature on communities of practice usually refers to collective practice-based learning within business organizations. Amin and Cohendet (2000) observed that such communities of practice may also operate across space in multilocational firms. In addition, there is no reason to think that communities of practice would be limited to organizations only: tightly knit networks also consist of communities of professionals who may have an intimate understanding of each others work, whether or not they are (physically) located in the same (local) community (Oinas 2001). These communities also function effectively as connectors between firms and locations but often within technological systems.

Conclusions and Challenges for Future Research

The notion of SIS has been used to refer to the organization of technological systems in space as well as their evolution in time. The SIS approach shares the view of the emerging meso-level analyses of technological evolution in that it regards as central both the concrete interactions through which innovations emerge and diffuse and the broader societal (techno-economico-cultural) context (cf. Green et al. 1999). It is distinct, however, in the sense that we emphasize centrally the spatial dimensions so as to pay attention to the evolution of technological trajectories in space. SISs are also seen as distinct from NISs because they do not necessarily reside within national boundaries. In regard to RISs, the SIS approach depicts that the capabilities and results of several RISs might be included in one SIS, simultaneously and/or over time. Accordingly, what we call the SIS refers to those (parts of) region-specific innovation systems that are relevant for the development of particular technological systems, involving the various interconnections of subsystems over space. In other words, "spatial innovation systems consist of overlapping and interlinked national, regional and sectoral systems of innovation which all are manifested in different configurations in space" (Oinas and Malecki 1999, 10). Thus, the SIS approach aims to highlight the "complex and evolving integration at different levels of local, national and global forces" (Archibugi and Michie 1997, 122). It seems that this complexity is increasingly recognized but that we are still at the stage where many basic concepts need to be searched and developed for pinning it down (e.g., Howells and Roberts 2000) and for finding patterns in that complexity. It is the aim of the SIS approach to provide some building blocks for analyzing the complex processes around innovation.

It is especially the connections between regional systems that remain relatively little understood. We know that local as well as nonlocal sources of innovative activity are decisive for innovations to occur and evolve, but we are just beginning to understand "the details related to the cofunctioning of proximity versus distance effects in various sorts of innovation" (Oinas and Malecki 1999, 25; cf. Blanc and Sierra 1999; Bunnell and Coe 2001; Gertler 1995; Hudson 1999; Oinas 1999, 2000; Oinas and Virkkala 1997).

This article was aimed at proposing a broad framework for analyzing SISs. In so doing, we have not penetrated into the details of actual technological systems and their evolution in time and space. We conclude by outlining several interrelated challenges that remain to be tackled in continued work on identifying and analyzing SISs.

1. An important issue is understanding dynamics: seeing the need for technological systems to evolve as firms and that their interactive patterns change, that is, as products, strategies, resource bases, and information bases change (Ebers and Grandori 1997; Galli and Teubal 1997). The evolutionary trajectories of firms must be matched rather closely by the evolution of their networks and the broader institutional environments. Yet, it is very difficult, for example, for regional support organizations to keep up with general trends as well as the varied and specific needs for firms for support (Braczyk and Heidenreich 1998; Cooke 1998).
2. We do not know very much about how successful firms build their local and extralocal networks of contacts. As Cantwell and Piscitello (2000) noted, "We need to know more . . .about changes in the exact geographical composition of technological activity in each industry" (p. 45). Does it matter whether local relations or linkages to other regions are the first to be built, as long as the firm can survive until the appropriate network is assembled? Does a region's success depend on a specific degree of globalness in its firms' networks? Or are the local relations really relatively most important? We have some hints about these matters. For example, the necessary progression by a firm from a technological focus to a market focus (Roberts 1990) typically coincides with a shift in linkages from local to national and international markets (Autio 1994; Christensen 1991; Christensen and Lindmark 1993). However, it is not yet clear which kinds of processes or activities of innovation are dependent on proximity (i.e., constrained by the need to establish close personal relations at close distance in specific institutional and conventional set-ups) and which are those that can be carried out over long distances. To start finding out, we assume that the appropriate units of analysis are the interactions related to specific technologies and models of products, which are typically organized within product families (Sanderson and Uzumeri 1995).
3. What remains to be further explored in the specific interactions within innovation systems are their "soft" sides. The degree to which the embeddedness of the relevant actors in their possibly different local institutional environments—involving their specific cultural conventions—affects their external relations is a key question. Local practitioners may remain tied to traditional factors as the basis for local development, and this may impede their ability to interact effectively with external actors. Alternatively, their embeddedness in local social relations involving strong interactions within professional communities with specific business cultures may provide the basis for finding useful complementarities with externally emerging technology, knowledge, and business cultures (cf. Malecki 2000; Wong 1998). Central is the question of the transferability of tacit knowledge as part of the operation of various communities of practice over space (Oinas 2001). There is very little empirical evidence that we can draw on concerning the travel of tacit knowledge over space, yet we should be reminded that the distinction between codified and tacit knowledge is not fixed in a "spiral of knowledge" (Krogh, Ichijo, and Nonaka 2000; Nonaka and Konno 1998). Complex and changing combinations of codified and tacit knowledge are likely to be found in innovative interactions in different spheres of activity in technological systems.
4. There is indeed a need to gain deeper understanding of the types of networks firms and individuals and firms create for different strategic purposes. While implementation networks (and the regional environments that support them) are highly important for firms to succeed in their existing competitive contexts, learning networks are more relevant for the competitive success of firms in the long run (Oinas and Packalén 1998). Minimally, differentiating between types of network relations will be helpful in understanding the types of connections actors create between RISs within SISs and the kinds of knowledge exchanges that are involved in them.

5. There is a need to incorporate conceptual insight into comprehensive empirical studies. Yet, technological systems are not identifiable with simple means. They involve knowledge systems, innovative capability, knowledge transfer, and so on—largely intangible objects that are difficult to define and investigate (Smith 1995, 86). The collective nature of technological development often has no formal manifestation but involves informal, invisible practices. This renders research difficult; data are not readily available. " 'Problem-solving' networks are what really define (technological) systems, not buyer-supplier links. Such relationships can only be identified and analyzed through primary data collection (via interviews, plant visits, etc.), which also needs to be oriented toward analyzing infrastructure and institutional arrangements" (Braunerhjelm and Carlsson 1999, 290). We are beginning to see the results of research along these lines in a few sectors, such as aircraft (Eriksson 1995; Frenken 2000) and hard disk drives (Gourevich, Bohn, and McKendrick 2000), but we do not know if these are special cases or the tip of a generally applicable iceberg.

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