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Comparing approaches to systems of innovation: the knowledge perspective

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Abstract

This paper identifies and compares three existing systems of innovation approaches, namely, the national system of innovation approach, the technological/sectoral system of innovation approach, and the regional system of innovation approach. By focusing the analysis on knowledge, the research scope, unit of analysis, and analytical frameworks applied by each approach are analyzed and synthesized. The paper reveals that the three approaches claim their major knowledge links, facilitating factors, and boundaries differently. Although three methods have emerged in mapping systems of innovation, these methods provide complementary views, rather than substitutive ones, for constructing a complete configuration of an innovation system. Four methodological problems exist: inconsistent definition of innovation, top-down orientation, independence among innovation systems, and ex-post qualitative analysis. Finally, further methodological issues regarding systems of innovation studies are suggested.

Keywords: Systems of innovation; knowledge perspective

1. Introduction

The world economy is becoming ever more dependent on the production, distribution, and use of knowledge. It has been estimated that more than 50% of gross domestic product (GDP) in the economies of the major OECD countries is now knowledge-based [1]. Since Freeman [2] coined the term ‘national systems of innovation’ in the 1980s, the concept has been widely welcomed by policy makers and academic researchers alike. They have used the concept of systems of innovation as

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a conceptual tool to analyze the current knowledge economy because the approach deals explicitly with knowledge creation, distribution, and utilization as the key component of analysis.

In recent years, there has been a marked increase in research that makes use of the system approach to studying innovation. The various system approaches, whether regional, sector, or national, have been widely used to map and explain interactions between firms and organizations that generate knowledge [3]. However, the diverse and complicated frameworks used in the systems of innovation approach reduce its comprehensibility. Moreover, there is little research that compares approaches by treating knowledge as the central theme. Thus, one aim of this paper is to integrate ongoing systems of innovation studies and to provide a better understanding of the knowledge point of view.

Section 2 examines some recent studies of systems of innovation. Three approaches are identified: (a) national systems of innovation, (b) technological/sectoral systems of innovation, and (c) regional systems of innovation. Our research offers definitions followed by a discussion of elements, units of analysis, and conceptual frameworks that can be applied to each approach. In Section 3, we discuss types of inter-organizational knowledge links, knowledge transfer facilitating factors, and systemic boundaries of each approach. Section 4 surveys three emerging methods for mapping systems of innovation, while Section 5 raises four methodological issues in existing studies of systems of innovation: (a) inconsistent definition of innovation, (b) top-down orientation, (c) independence among systems, and (d) ex post qualitative analysis. Finally, additional paths are suggested for pursuing systems of innovation studies.

2. Conceptual review of approaches to systems of innovation

2.1. Introduction

The systems of innovation approach is useful because it makes it possible to describe, understand, explain, and influence the processes of innovation [4]. It enables us to identify factors that shape and influence innovations. Moreover, Edquist notes that the SI approach is based on a theory of interactive learning [5] as well as an evolutionary theory of technical change [6,7].

We have identified three systems of innovation approaches. They are:

1. the national approach, as suggested by Freeman [2], Lundvall [5], and Nelson [8];
2. the technological/sectoral approaches used by Carlsson and Stankiewicz [9] and Breschi and Malerba [10];
3. the local/regional approaches, as proposed by Cooke et al. [11], Braczyk et al. [12], and De la Mothe and Paquet [13].

The analytical frameworks and systemic boundaries of each approach are discussed in the following sections.

2.2. National systems of innovation approach

The systems of innovation (SI) approach was developed and has evolved since the initial appearance of national systems of innovation (NSI) in studies by Freeman [2,5,8,14,15], Lundvall [5], and Nelson [8]. Freeman defines NSI as 'the network of institutions in the public and private sectors whose activities and interactions imitate, import, modify and diffuse new technologies' (p. 1) [2]. Lundvall draws a distinction between a broad and a narrow definition of NSI. The narrow definition of NSI is 'organizations and institutions involved in searching and exploring—such as R&D departments, technological institutes, and universities' (p. 12) [5]. The broad definition of NSI is 'a system of innovation, ... constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful *knowledge*' (p. 13) [5]. Nelson and Rosenberg regard NSI as 'a set of institutions whose interactions determine the innovative performance' (pp. 2–3) [16].

2.2.1. National systems of innovation as culture- and politics-bounded

Lundvall claims that the concept of an NSI rests on two dimensions: national–cultural and étatist–political [5]. The idea of an abstract nation-state is one point at which the two dimensions coincide, that is, where all individuals belonging to a nation—defined by cultural, technical, and linguistic characteristics—are gathered in one single geographical space and controlled by one central state. In a complicated innovation process, where knowledge exchange is heavily tacit in nature, the parties that originate in the same national environment, i.e., sharing its norms and culturally based system of interpretation, will facilitate interactive learning and innovation.

Freeman [15], in his historical review of NSI studies, suggests that there have been major differences among countries in how they have organized and sustained the development and diffusion of technological innovation within their national economies. In other words, nations differ not only in the quantity of innovations introduced but also in the methods by which these innovations are adopted and in their sectoral composition [17]. Following the same line of argument, in his empirical studies of 15 countries [8], Nelson found considerable diversity among each nation's institutional arrangements supporting technical innovation.

2.2.2. Analytical framework

Freeman uses the concept of NSI to describe and interpret Japan's performance following World War II [2]. In describing the Japanese national innovation system, he concentrated on the following four elements:

1. *The role of the Ministry of International Trade and Industry (MITI)*: The guiding hand of MITI shaped the long-term pattern of structural change in the Japanese economy. MITI's influence was exerted based largely on judgments about the future direction of technical change (technological forecasting) and the relative importance of various technologies.

2. *The role of company R&D in importing technologies*: The method used to assimilate and improve on imported technology was mainly some form of reverse engineering, e.g., in automobiles and machine tools.
3. *The role of education and training and related social innovations*: There was a sizeable increase in the number of young people acquiring secondary and higher levels of education, especially in science and engineering, combined with an increase in the quality of industrial training, both of which were carried out mainly or entirely at the enterprise level through the mechanism of lifetime employment.
4. *The conglomerate structure of industry*: The important feature of inter-company organization within *keiretsus* (vertically integrated groups of firms), which facilitated horizontal information flows and minimized transaction costs (pp. 331–41) [14].

Lundvall takes a thematic approach that focuses on processes of learning and user-producer interactions, drawing case studies mainly from Scandinavian countries [5]. However, the user-producer linkages he cites are not restricted only to physical commodity flows, but can be expanded to learning and knowledge flows of the firm's value-added activities. Lundvall claims that the user–producer linkages can be found at the interface between university and industry, and between industry and some of the final users of industry, such as workers, consumers, and the public. Lundvall suggests that national idiosyncrasies may be reflected in: (a) the internal organization of firms, (b) inter-firm relationships, (c) the role of public sector, (d) the institutional setup of the financial sector, and (e) R&D intensity and organization.

Nelson tends to take a country approach to studying the national system of innovation in the fifteen developed and developing countries [8]. However, the concept of NSI seems not to be consistently used by authors from each country [4]. Instead, their studies tend to focus on: (a) the allocation of R&D activity, (b) the sources of its funding, (c) the characteristics of firms, (d) important industries, (e) the roles of universities, and (f) government policy in the country. Nelson and Rosenberg justify their approach by noting that 'the orientation of this project ... [is to] try to understand, rather than to theorize first and then attempt to prove or calibrate the theory' (p. 4) [16].

McKelvey provides a comprehensive comparison of authors working in the NSI approach [18]. She argues that they have different interpretations of how NSI works in terms of mechanisms for inducing innovation and the focus of technological change. Socio-institutional adaptation [2], supplier-customer interactive learning [5], and firm competence and routines [8] play major roles in achieving the effective use of new technology and innovation in the national domain. Freeman focuses on long waves of technical change. Lundvall stresses the importance of both continuous innovation and long waves. Nelson argues that the process of technical change is an evolutionary process involved in selection and mutation.

2.3. Technological/sectoral systems of innovation approach

2.3.1. Technological interdependence

Unlike other SI approaches, in technological systems of innovation (TSI) or sectoral systems of innovation (SSI) analysis, the knowledge links between firms and organizations result mainly from technological interdependence. Both SSI and TSI stress the economic dynamics of technology development [19] and the importance of inter-industry technology flows [9,10,20,21].

Carlsson and Stankiewicz [9] define technological systems as 'networks of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of creating, diffusing and utilizing technology focus on knowledge, information and competence flow' (p. 111). They suggest that the main elements of TSI are:

1. *Economic competence*: the sum of the total of a firm's abilities to generate and take advantage of business opportunities.
2. *Clusters and networks*: a successful innovation seems to require the interaction among agents with different competences. Moreover, the nature of innovation is uncertain and complex, therefore networks provide other alternatives for governing innovation.
3. *Institutional infrastructure*: a set of institutional arrangements directly or indirectly support, stimulate, and regulate the process of innovation and the diffusion of technology.
4. *Development blocks*: the development block is dynamic in nature and incorporates the characteristic of disequilibrium. It creates tension within the technological system that varies in strength and composition over time and generates development potential for the system (pp. 100–9) [9].

Breschi and Malerba define SSI as 'the specific clusters of the firms, technologies, and industries involved in the generation and diffusion of new technologies and in the knowledge flows that take place amongst them' (p. 131) [10]. The inter-industry relation is an important one in SSI or TSI analysis. It consists of one or more distinguishable elements of industry that are closely interrelated [21]. The interdependence among industries is derived mainly from increasing returns in the generation of knowledge accumulation and interdependence among technologies and industries [3].

Regarding the interrelation among industries, Pavitt suggests there is a strong interdependent relationship among the industry taxonomies he studied [20]. This means that innovation in one industry can provide inputs into production processes in other industries. Pavitt further finds that the relationship is strong between 'specialized equipment suppliers' and 'science-based firms,' and between 'scale-intensive firms' and 'specialized equipment suppliers.' Well-designed infrastructure and well-organized networks are not enough to build development blocks. More importantly, competent users and suppliers, and entrepreneurs who develop the capability to identify, expand, and exploit business opportunities are crucial in order to transform an industrial network into a development block [22].

2.3.2. Sectoral specificity

The SSI approach contributes the crucial idea that regarding all technological or sectoral systems as homogeneous is dangerous. In addition, the approach believes that the SSI approach must be based on a clear understanding of the nature of technology (e.g., tacit or codified) and the relation between science and technology [23].

Archibugi et al. claim that sectors and technologies matter and have their own dynamic [24]. Moreover, the differences of technical change among manufacturing sectors vary in terms of sources of technology, involvement of user needs, and means of appropriate benefit [20].

Pavitt provides an industrial taxonomy in the manufacturing sector. He identifies four main industries, namely: (a) *supplier-dominated firms,* such as agriculture and housing; (b) *scale-intensive firms,* such as bulk material and assembly; (c) *specialized suppliers firms,* such as machinery and instruments; and (d) *science-based firms,* such as electronic firms and chemical firms.

Breschi and Malerba also explore the concept of 'technological regime': technological opportunities, appropriability, science base, and knowledge accumulation to analyze sector specificity [10].

SSI studies found that some industries are characterized by several firms located in specific geographical areas in which they cooperate in innovation processes but compete with other regions within and across countries. In other industries, a few large firms compete at the global level but cooperate extensively at the local level with some specialized producers. The SSI approach suggests that different industries may have different competitive, interactive, and organizational boundaries that extend beyond national borders. SSI considers not only country-specific factors but also integrates the impact of globalization of technology. In other words, the SSI approach examines the inter-industry, interdependent relationship not only at local and national levels but also in wider global systems.

2.4. Regional/local system of innovation approach

2.4.1. Region as a nexus of non-traded interdependence

Emerging in the late 1990s, studies of regional or local systems of innovation (RSI) surged at the same time as research in fields such as industrial economics, regional economics, and economic geography. The terms used to explicitly or implicitly explain RSI vary among these fields, but the concept of RSI can be traced back to Marshall's industrial district [25], Perrous' economic spaces [26], Dahmén's development blocks [27], Camagni's innovative milieu [28], and to regional innovation systems [11,13].

The rise of RSI is a response to the perceived importance of the local supply of managerial and technical skills, accumulated tacit knowledge, and knowledge spillover. Although Saxenian does not specifically use the RSI notion, she uses the concept of RSI implicitly to illuminate how the dynamics of production networks or inter-firm partnerships have helped to account for prosperous regional economies, such as the case of Silicon Valley, California [29]. In her study, inter-firm networks are shown how to spread the costs and risks of developing new technologies and how to foster reciprocal innovation among involved firms. Through inter-firm partnerships, technology transfer is remarkable in the forms of informal information exchange, human resource development and mobility, and networking within the region. A new institutional innovation, represented by the inter-firm network, has produced a successful and dynamic relationship with technological innovation.

Drawing on research by the GREMI group (Groupe de Recherche European sur les Milieux Innovateurs), Camagni [28] defines an innovative milieu as

> the set, or the complex network of mainly informal social relationships on a limited geographical area, often determining a specific external image and a specific internal representation and sense of belonging, which enhance the local innovative capability through synergetic and collective learning process (p. 3).

There are two important elements in the definition: (a) the importance of informal relationships in linking the innovative network; and (b) the collective learning process that enhances local innovation capability.

Cooke et al. do not provide a clear definition for RSI. Instead, they use three key institutional forms: financial capacity, institutional learning, and productive culture, which facilitate systemic innovation at the regional level [11]. From the related definitions of RSI discussed above, the untraded interdependence of a region is best illustrated in Marshall's notion that the mysteries of knowledge are 'in the air,' Saxenian's 'blurred firms,' Camagni's 'informal relations,' and Cooke et al.'s 'productive culture.' RSI is intimately tied to tacit knowledge exchange. The boundaries of RSI depend on the range that untraded interdependence can reach. Consequently, the size and boundaries of RSI are vague.

The RSI approach stresses that a successful regional innovation system needs to develop a collective identity. The regional identity acts as a crucial vehicle for activating social capital and enhancing regional innovation capability. This is difficult to achieve at a distance and is why regional clusters or agglomerations are such a valuable feature of innovation-based competitive advantage.

2.4.2. The importance of proximity

Regional systems of innovation also highlight the fact that geographical and cultural proximity to advanced users and a network of institutionalized relationships are important sources of innovation. Regions evolve along different trajectories through combinations of political, cultural, and economic forces [11].

Network systems reflect distinctive national and regional institutions and histories and local social and productive interdependencies among various patterns of regional development [29]. Saxenian compares two distinct industrial systems, one in Silicon Valley, California and the other along Route 128 in Boston, attempting to explain why the former outperformed the latter in the 1990s. In Silicon Valley, the industrial structure was dominated by many small firms. In contrast, a few large firms dominated Route 128. Her research found that the innovative capability of regions can be influenced by industrial structure, inter-firm communication, and the organizational behavior of firms.

Cooke and his colleagues provide some crucial cultural features for successful RSI. They are: (a) a culture of cooperation; (b) an associative culture; (c) the ability and experience to carry out institutional change; (d) coordination and public/private consensus; (e) a productive culture with sub-elements of labor relationships, cooperation at work, company responsibility for society, and productive specialization; (f) existing interface mechanisms located in the scientific, technological, productive, and financial fields [11].

The frameworks of these three SI approaches should not be regarded as mutually exclusive. Indeed, establishing the interrelationships among these frameworks offers new insights into more integrated SI approaches [30]. A summary of the analytical frameworks is given in Table 1.

3. Comparing approaches: the knowledge perspective

Studies of systems of innovation raise an interesting question regarding the uneven distribution of innovation in regions, nations, and sectors. In the real world, it is often the case that innovative sectors are concentrated only in a few regions and nations. Other sectors are becoming increasingly globally distributed.

There are several reasons for establishing different systemic boundaries in systems of innovation:

- the nature and production of knowledge (e.g., the degree of tacitness)
- inter-organizational knowledge links (e.g., establishing effective collective learning)
- factors that facilitate knowledge transfer (e.g., common languages and shared culture).

3.1. Nature and production of knowledge

Knowledge is different from information. Information relates to data, while knowledge involves a wider process that involves cognitive structures that assimilate information and put it into a broader context, thereby allowing actions to be undertaken on that basis. Information exists *independently* of the receiver and transmitter. Knowledge is information that has been translated so that humans understand it. Knowledge cannot be said to ‘flow’ but can be said to be ‘shared’ or ‘transferred’ [31]. Understanding the distinction between knowledge and information is the first step toward realizing the uneven distribution of innovation.

Technological knowledge involves various degrees of specificity, tacitness, complexity, and interdependence. The more specific, tacit, complex, and interdependent the knowledge is, the harder it is to share and transfer. Polanyi indicates that tacit knowledge is illustrated by the fact that one knows more than he/she says [32]. He

Table 1
Summary of analytical frameworks in systems of innovation approaches

Author	Type of SI	Study context	Units of analysis	Analytical framework
Freeman [2]	NSI	Japan	Social-economic adaptation	MITI; company R&D for importing technology; education and training institutions; *keiretsu*
Lundvall [5]	NSI	Scandinavian countries, mainly Denmark	User–producer interactive learning	Role of public sector, education, R&D institutions, standard and training institutions; production system; marketing system; Financial sector
Nelson [8]	NSI	15 developing and developed countries	Co-evolution between technology and organizationFirm-based competence and routines	Allocation of R&D activity; sources of its funding; characteristics of the firms; important industries; roles of university; government policy
Carlsson [22]	TS	Swedish technological system	Technological knowledge networks	Institutional infrastructure; clustering resource; economic competence, development block
Breschi & Malerba [10]	SSI	Various sectors in OECD countries	Inter-sector knowledge interaction	Technological regimes; dynamics of innovation; knowledge and spatial boundary
Saxenian [29]	RSI	IT sectors in Silicon Valley & Rt. 128	Blurred firms in a region	Informal information exchange; human resource; inter-firm networks
Cooke et al. [11]	RSI	Innovative regions in Europe	Localized social and productive interdependence	Financial capacity; institutional learning, productive culture

also stresses that tacit and explicit knowledge are not divided, and that explicit or codified knowledge requires tacit knowledge for its interpretation. Therefore, interpreting tacit knowledge itself also generates new tacit knowledge [33].

Knowledge accumulation and utilization occur as the result of search activities and other learning efforts and routines. A firm's R&D contributes not only to the creation of knowledge inside the firm but also to the absorption of knowledge from outside the firm [34]. Not all types of knowledge have the same impact on firms. The impact can depend on the nature of innovation, e.g., whether it is incremental or radical, and on the technological paradigm. Radical technological change may be competence-destroying or competence-enhancing [35]. Knowledge needs to be managed well, otherwise it can form competence rigidity [36].

Gibbons et al. suggest that the world's production of knowledge is emerging into a new mode— Mode 2—alongside the traditional disciplinary structure of science and technology denoted as Mode 1 [37]. Mode 2 is a *distributed* knowledge production system. The authors argue that the process of knowledge production:

1. operates increasingly within an application context where problems are transdisciplinary in nature.
2. is carried on increasingly in non-hierarchical, heterogeneously organized forms that are essentially transient; and
3. involves many actors (firms, universities, research laboratories, think tanks, and consultants) throughout the process.

Nonaka and Takeuchi [38] propose that knowledge can be created through four interactive processes between tacit knowledge and codified knowledge. These four interactive processes are: (a) *socialization* (tacit knowledge to tacit knowledge); (b) *externalization* (tacit knowledge to codified knowledge); (c) *combination* (codified knowledge to codified knowledge); and (d) *internalization* (codified knowledge to tacit knowledge). They argue that these four knowledge-generation models are ubiquitous at the individual, group, organization, and inter-organization levels [38].

Faulkner and Senker highlight the importance of tacit knowledge in inter-organizational cooperation [33]. They find that tacit knowledge is articulated mainly through personal networks, which firms are keen to capture in emerging technologies such as computation, biotechnology, and new materials.

Yamin suggests that cooperation may be more appropriate for transferring tacit knowledge that cannot be specified in contract [39].

Specialization in innovation is enhanced by informal interactions that are a tacit knowledge-extensive exchange. A continuous search for new information, which occurs not only within single industries but also among them, is a vital condition for continuous innovation. Drawing on sources of innovation from other industries is crucial when technology fusion [40] and technological convergence [41] emerge, such as in opto-electronics, mechatronics, and information and communication technologies. Christensen cites the case of computer hard-disk technology to illustrate the new 'destructive technology' that can emerge from outside the existing industry when the current market leader has failed to reach its potential [42].

The effectiveness of information channels is dynamic in nature and varies according to the technologies, the purpose(s) of interaction, and the stage of communication. Firms involved in various technologies search for different informal relationships in order to transfer preliminary research results to their new inputs [33]. The degree of knowledge creation through informal relationships can be low at the beginning of an interaction, and then grow quickly along with the growth of mutual understanding, to become saturated in the long run when possible sources of innovation have been fully explored [36]. Specialization in innovation is not, however, a once-for-all activity but a continuous creative construction/destruction process.

Firm-level factors of specialization in innovation highlight the fact that synergies can occur in industry specializations when innovative firms establish networks with their users and suppliers, in other words, when a development pole [26] or development block [22,27] has been formed. Such factors convey a message that scale and scope of economies in innovation tend to be easily explored and exploited when a development pole exists. A virtuous cycle exists between the formation of new innovative firms and the economic dominance of their development poles. However, the sustainability of firm-level specialization in innovation is decided based on whether a firm can exploit its technology in each technological trajectory and/or upgrade its current technology into a new technology trajectory.

3.2. Knowledge links, transfers, and systemic boundaries

3.2.1. Knowledge links

Knowledge creation and accumulation are not decided just by the firm itself but are influenced by other firms and knowledge-creating institutions [5,43]. Systems of innovation can also be viewed as 'collective learning' among systemic actors, and knowledge links are mechanisms that facilitate this collective learning. The NSI approach stresses major knowledge links through inter-organizational knowledge creation that takes place among firms, universities, and governments—so-called triple-helix interactions [44]. Systemic links between technological systems and SSI rest on the science-technology relation and technological complementarities or synergistic inter-technology/inter-sector dependence [45]. The systemic links of RSI are built on untraded tacit knowledge sharing and social network embeddedness. Knowledge links in RSI tend to be informal, implicit, relational, and cultural among actors.

3.2.2. Knowledge transfers

A science-technology relationship can identify new technological opportunities that may derive from scientific discoveries and inventions. In fact, a firm's technology development may even involve a different degree of science base. For example, some technologies or sectors involve a high degree of scientific research (e.g., biotechnology and microelectronic technology), while other technologies, such as shoemaking, may not. Inter-sector knowledge transfers can be identified by value networks among suppliers, buyers, competitors, firms in related sectors, and

Table 2
Comparing systems of innovation approaches: the knowledge perspective

Approach	Major knowledge links	Knowledge transfer facilitating factors	Systemic boundaries
NSI	Triple-helix interactions	Common language, social, cultural codes of communication	Nation-bounded
TS/SSI	Inter-technological links	Technological complementarities and synergies Science and technology relation	Sector- or technology-bounded, not necessarily nation-bounded
RSI	Tacit knowledge sharing Social networks	Geographical proximity Co-location learning Tacit knowledge spillover	Region-bounded

other complementary firms. Transfers can also be traced via innovation input–output analysis between technologies and sectors [46].

3.2.3. Systemic boundaries

The NSI approach takes nations as its natural boundaries. National culture, languages, and governments play key roles in influencing innovation in various sectors and technologies in a nation. In contrast, the SSI and TSI approaches claim that the system is built on technological interdependence. SSI and TSI analyses are sector and technology specific. TSI and SSI are not necessarily constrained by national boundaries but can cross them. The RSI approach takes a specific region as given. The approach investigates how an untraded productive culture, an inter-firm network, and regional institutions influence the innovative performance of sector or industry clusters in a region. Table 2 summarizes the differences among the various approaches to systems of innovation.

4. Methods for mapping systems of innovation

4.1. Systemic links as collective innovation

A system consists of elements and interrelations among the elements. Thus, analyzing individual elements alone cannot construct the whole picture of a system. More importantly, the interactions among elements should also be considered. If innovation is treated as an interactive learning process, then the interactions among actors paves the way for studying innovation using a systemic lens [5]. Put another way, in order to understand systems of innovation, we must consider not only the major actors but also the interactions among the actors in the system.

In the 1990s, there as a pronounced shift of firms' behavior away from a strict reliance on internal R&D to greater emphasis on various forms of externally based collaborative R&D [47], and a firm's ability to manage this interdependence became a key source of competitiveness [48]. Interactions among firms and knowledge-generating organizations actually create new economic resources that would otherwise not exist or whose existence would be delayed [49]. Interaction contributes not only formal codified knowledge but also tacit knowledge and skills [33].

Mody suggests that learning is a key motive for cooperation [50]. As he notes 'an alliance is a flexible organizational mode that allows firms to bring complementary strengths together in order to experiment with new technological and organizational ideas' (p. 151). Ciborra notes that cooperation is an institutional arrangement that allows firms to more effectively implement strategies for organizational learning and innovation [51]. Moreover, he defines an alliance as a device to access or develop different cognitive frames, routines, work arrangements, and cultures so that the firm is able to overcome organizational inertia. The most successful partners are those who possess 'receptivity to learning,' that is a superior ability to foster horizontal and vertical communications and to transfer learning from individual projects back to the organization [52].

Williamson [53,54] focuses exclusively on transaction cost as the unit of analysis, where the mechanisms of market and hierarchy of governance are recommended. However, these two mechanisms seem inadequate to capture the structural effects that require an analysis of the network context within which innovation is introduced [55]. There were a variety of reasons why the logical home for R&D was located inside the corporation, including the need for closer integration with production, a desire to minimize transaction costs and opportunism, the nature of tacit knowledge, and technology interdependence. However, interaction has two aspects: one, to jointly produce knowledge among partners, the other to cooperate and/or compete for knowledge exploitation [56]. Therefore, interaction can have a mixed flavor of both cooperation and competition.

4.2. Relations between firms: networks, communities, and clusters

No firm, large or small, can innovate or survive without a network [57]. Recent studies have proposed three methods for identifying the interdependent relation between firms and other actors in systems of innovation.

4.2.1. Networks

The first method is the network approach [57,58,59]. Håkansson sees firms at the center of networking behavior, identifying three types of behavior: (a) vertical links with customers and suppliers; (b) horizontal links with competitors and other firms providing complementary assets; and (c) knowledge-generating links with universities, R&D institutions, etc [59].

In contrast, DeBresson and Amesse focus on innovative firms as the center of networking behavior and propose four types of networks used by innovators: (a) the supplier–user network; (b) the network of pioneers and adopters within the same industry; (c) international strategic alliance; and (d) professional inter-organizational network [58].

4.2.2. Innovation communities

The third method is the 'innovation community' approach. Basing on the perspective of organizational ecology, Lynn et al. view organizations as the center of the analysis and propose a framework for an innovative community that refers to organizations directly involved in the commercialization of a new technology. Innovation community members might include new small firms, university departments, research institutions, established firms, venture capital organizations, regulatory bodies, industrial associations, scientific bodies, and suppliers [60].

Furthermore, the authors also identified three levels of governing structures that influence the way an innovation community works: superstructure, substructure, and technological structure.

4.2.3. Clusters

The second method for tracing interdependent relations in systems of innovation is the 'knowledge-based cluster' approach. This sees a specific technology as the center of analysis. Holmen and Jacobsson propose a method for identifying actors in a knowledge-based cluster by using a specific 'patent class,' which is a set of related patents, such as patent co-classifications and patent citations [61]. They claim that the knowledge-based cluster approach can catch more complete actors in a specific knowledge-based cluster, especially firms in horizontal links. This approach can also be applied to the similar co-publication analysis.

These three methods for mapping systems of innovation are not mutually exclusive. The network approach tends to map formal interactions involved in both technological and market activities. However, the network approach deals with few informal interactions. The community approach provides insights within which to frame informal and institutional interaction in systems of innovation. However, it does little in terms of technological interdependence. The knowledge-based cluster approach captures interdependence among technologies, but the research argues that not all systemic links can be identified using patents and publication analysis in the cluster approach (see Table 3).

Despite the variety of methods for mapping systems of innovation, network/community/cluster approaches do serve as a search and evaluation procedure for the different possible combinations. However, network/community/cluster approa-

Table 3
Methods for mapping systems of innovation

Methods	Units of link	Advantages	Weaknesses
Networking/snowball approach	Agent-base (firms/organization)	Inter-organizational formal activity mapping	Not considering informal knowledge links
Community/membership approach	Membership-base	Mapping technological interdependence Structure governance	Not all firms have formal knowledge links with each community member
Clustering approach	Patent/publication-base	Codified knowledge mapping	No considering tacit knowledge mapping

ches are dynamic and evolve over time. The entry barrier for new partners and the lock-in of existing partners are pervasive symptoms in network/community/cluster operations. Even network actors are unwilling to transfer their core competence to others if it means exposing their intangible assets to network partners without getting any benefit in return.

5. New challenges to systems of innovation studies

Setting priorities is the most important and urgent issue to be addressed in SI analysis [62]. In particular, the SI approach may produce a range of suggested adjustments for firms and policy makers. While the production of joint knowledge involving the firm and an external actor is becoming increasingly crucial for inducing innovation, SI studies do not provide firms with clear guidelines for systemic interaction. The approach does not indicate which types of actors (firms and organizations) the firm should cooperate with or where these potential partners are located.

Furthermore, the current debates on systems of innovation are still unresolved. These debates relate mainly to four challenges: (a) the definition of innovation; (b) the prevailing top-down orientation; (c) the dynamics of systemic boundaries; and (d) the emphasis on ex-post explanation rather than ex-ante predication.

5.1. Challenge 1: inconsistent definition of innovation

Each SI study has its own definition of innovation. Lundvall makes a distinction between a narrow and broad definition of a system of innovation. In his narrow definition, innovation tends to be defined by reference to actors and organizations, such as R&D departments, technological institutes, and universities [5]. In his broader definition, a system of innovation would include every part, structure, and institutional setup affecting learning as well as searching and exploring.

Nelson has his own definition adopted in his earlier study [16], which claims that innovation is not limited to the behavior of firms at the forefront of world technology or to institutions doing the most advanced scientific research, but depends more broadly on the factors influencing national technological capabilities [63]. In Nelson's view, the study of innovation should therefore include its generation and diffusion.

Edquist adopts a wide and ambiguous definition of innovation [4]. Carlsson and Stankiewicz adopt a narrow definition that is centered on technological innovation [9]. They also consider the emergence and development of new organizational setups as one form of innovation. Lundvall's definition of innovation also includes institutional innovations [5].

Finally, Freeman adds the crucial role played by social and educational innovation in facilitating the diffusion of new technologies in the Japanese national system of innovation [2].

5.2. Challenge 2: a need for bottom-up orientation

Various systems of innovation programs have had more impact on national and industrial-level policy formulation than firms' technology strategy and management [24]. This is attributed to their prevailing top-down orientation. Few studies, except Autio [64] and Saviotti and Nooteboom [65], try to link the firm's strategy to the systemic context of an innovation process that is complex and interactive in character. The focus of SI studies on the firm's strategy and management still requires that more research be done.

5.3. Challenge 3: establishing interdependence among systems of innovation

There is the question of whether and in what way—in a world where technology and business are increasingly international—the concept of NSI still makes sense. Moreover, with the increasing internationalization of technology, efforts on the part of nations and firms to keep secret understandings won in R&D will be increasingly futile [63]. Both the diminishing importance of policies, histories, and cultures [66], and the global market of symbolic analysts [67] limit the NSI approach.

With the integration of regional economies via such organizations as the EU, some researchers claim that a supra-national (European) system of innovation is emerging between national and global domains [68,69]. Further, the increasingly inward technology transfer [70] and the globalization of technology production [71] have blurred the distinction between domestic firms and foreign ones.

Freeman mentions that the concept of national differences in innovative capabilities determining national performance has recently been challenged on the grounds that MNEs are changing the face of the world economy in the direction of globalization [15]. He suggests that competitive advantage is created and sustained through a highly localized process. Differences in national economic structures, values, cultures, institutions, and histories contribute profoundly to competitive success.

The intensification of global competition has made the role of the home nation more important, not less. Particularly from the standpoint of developing countries, national policies for catching up in technology remain of fundamental importance [21]. Moreover, Kogut [72] suggests that the position of a nation still matters in enhancing a country's competitiveness due to the differences between countries in how finance is organized; how workers are hired, paid, and promoted; and how technology is developed. In their book, *Technology, Globalisation and Economic Performance*, Archibugi and Michie conclude that nations matter, perhaps even more than ever, in a global world [30].

It is clear that SIs do not operate in isolation from each other. A pertinent analysis of the SI approach needs to integrate three systemic dimensions: geographical, technological, and institutional. An analysis of regional/national SIs focuses more attention on its support from geographical and institutional actors, and treats each sectoral/technological system as identical. The sectoral/

technological system of innovation approach appreciates the difference among sectors and technologies and analyses interdependent structure among related industry clusters. However, an emerging effort of this SSI approach brings innovation support from other regional/national actors into sectors/technologies, which extends consideration of system of innovation beyond the sectoral boundary [22].

Finally, most technological infrastructure is naturally locally or nationally bounded because of its characteristic as public goods and/or semi-public goods. In general, the targeted actors of infrastructure provision are not limited by the technological and functional context. However, the high quality of infrastructure is a necessary platform for the firm's innovativeness but not sufficient to form a strong economic block. A good innovation system seems to present a mixed picture of sustainable interactions within its innovative subsystems, and healthy interactions between its subsystems and its environment (global innovation system).

5.4. *Challenge 4: quantitative models for ex ante prediction*

By adopting an evolutionary perspective, SI studies have contributed to understanding the existing dynamics of the innovation process. However, the evolutionary approaches have provided little, if any, predictive insights into how SIs will evolve in the future [24]. Therefore, ex ante quantitative models are urgently needed. Some ex ante quantitative models that simulate SIs have emerged such as system dynamics models, complexity theory, and history-friendly models.

6. Conclusion

The success of firms, regions, sectors, and nations has become increasingly dependent on how firms and organizations effectively generate and use knowledge in a world that is becoming more and more global. Various SI studies have provided useful frameworks for explaining how the interactions between firms and other organizations facilitate knowledge creation, distribution, and utilization within specific spatial (i.e., regional, national, supra-national, global), technological, and sectoral systems.

By explicitly treating knowledge as the center of analysis, we compared key researchers, conceptual frameworks, and units of analysis in three existing SI approaches, namely, the national systems of innovation approach, the regional systems of innovation approach, and the technological/sectoral systems of innovation approach. We found that major knowledge links, knowledge transfer facilitating factors, and systemic boundaries vary across these approaches. Although three methods for mapping systems of innovation have emerged, these methods provide a complementary view rather than a substitutive one on which to construct a complete configuration of the innovation system.

Four methodological problems prevail, including inconsistent definition of innovation, top-down orientation, independence among innovation systems, and ex-post qualitative analysis.

Finally, we suggest that further SI studies could: (a) focus on the co-evolution between institutional innovation and technological innovation, (b) build up systems of innovation by using firms as the central actors, (c) identify the inter-dependent relationships between different SI approaches, and (d) take more ex ante quantitative models to simulate the dynamic systems of innovation.

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