Embedding network analysis in spatial studies of innovation

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Published online: 29 July 2008
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Regional scientists, economic geographers and other spatially oriented analysts concerned with the consequences of spatially distributed sources and uses of innovation have been identified by [Fagerberg and Verspagen \(2006\)](#) as one of five core disciplinary groups that populates fully one-third of an international network now focusing on innovation. In addition to membership drawn heavily from its principal spatial disciplines, this group includes 48% of self-declared sociologists and 42% of management scholars in its subnetwork. The topic of innovation continues to be highly relevant to our disciplines and is therefore worthy of stocktaking.

Knowledge and innovation networks are not novel topics in regional science journals. Indeed, contributors to an earlier special issue of the *Annals of Regional Science* pointed to the significance of emerging knowledge and scientific networks by noting the importance of gravity formulations in characterizing scientific networking behavior ([Beckmann 1993](#)) and the rising importance of scientific collaboration ([Andersson and Persson 1993](#)) to the growth of knowledge. These insights were based principally on early evidence of coauthorships from the Science Citation Index, which has meantime become a commercial source of bibliometric data used by researchers in many fields, particularly the growing field of scientometrics.

Interest in innovation networks among regional scientists gained considerable momentum and redirection from theoretical support for the role of knowledge and education in economic growth ([Lucas 1988](#)) and from a body of influential empirical work that demonstrated the spatial dimension and consequences of knowledge spillovers and innovation flows. What is novel in recent years is the breadth and variety of administrative data made available concerning the *location* of knowledge economy

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agents, particularly author citations, copatenting, patent citations, research consortia memberships, corporate alliances, university expansions, and so on. The empirical possibilities for network-based regional studies of innovation have expanded enormously and with it the vital paper trails necessary to trace network links.

1 Proximate innovation networks

Regional scientists have benefitted from key theoretical advances that better specify the role of knowledge and innovation in national and regional economies. While Schumpeter, Lundvall and Porter are seen in results reported by [Fagerberg and Verspagen \(2006, p 12\)](#) as constituting the overall foundation of innovation research by spatial scientists, others see the intersection of endogenous growth theory and the new economic geography as more relevant, including a number of seminal studies that demonstrate how newly exploited data are capable of linking technological advances among knowledge economy agents to regional structures, productivity, and growth (as reviewed by [Feldman 1999](#); [Breschi and Lissoni 2001](#); [Döring and Schnellenback 2006](#)). Much of the initial research inferred the likely presence of geographic spillovers, which offered intriguing new evidence that *local* networks were indeed active in business clusters, Marshallian districts, and regional economies, although the actual mechanisms remained unclear, which became one objective of further network-based investigations ([Autant-Bernard and Mairesse 2007](#), pp 341–350).

A methodological bias also tilted researchers—particularly regional scientists and economic geographers—quite logically toward geographically detected local spillovers, supported in part by an easy familiarity with traditional gravity models and GIS-enabled adjacency matrices, which permit ever-smaller local geographies as units of analysis and stimulated the development of tests and correctives for their spatial autocorrelation.¹ At the same time, the data most frequently used is count-based; so, inferential methods have moved steadily beyond OLS and related techniques to favor Poisson, negative binomial, and zero-inflated negative binomial approaches.

2 Distant innovation networks

Far less had been accomplished by regional scientists in formulating the distant, indirectly connected networks that originate as contact-chains among geographically dispersed agents. However, knowledge economy concepts were also very much alive in other disciplines, most notably economic sociology and management studies, where an agent's network position relative to others could be shown to affect the amount and quality of information available. *Small World* approximations of contact patterns were popular representations of more serious potentials available in graph theory and network analysis to model emerging network concepts and theories. Network logics were quickly applied to innovative industry leaders and firms springing up in Silicon Valley

¹ See Geoda website: <http://www.geoda.uiuc.edu/>.

and connected to others further afield, which added the missing analytic dimension of knowledge flows between distant agents.²

Working in parallel, network methodologies were also being developed in analytical sociology, which resulted in several powerful software packages that are downloadable at no or low cost and are capable of handling the very large administrative data sets so frequently analyzed.³ Considerable effort has been spent developing various tests and metrics that help describe, diagnose, and characterize these large networks, several of which will be referenced by articles in this issue. Sociologists and others have also developed a repertoire of primary data collection methods that are used to assemble smaller, purpose-built data sets for network analysis, some of which will be reported later in this issue.

Rich as these data sets are for the studies of innovation reported here; their network architectures remain simple schematic channels within which communication flows of unspecified importance may or may not move in either direction.⁴ However, network analytic software is capable of analyzing far more complex interaction systems, where directed flows between nodes and flows weighted by value metrics can be analyzed. Quite apart from innovation studies, network analytic capacities may convince some to reconsider the canon of traditional regional science topics that are characterized by interactive network qualities, such as daily travel, migration, I/O matrices, and flows of all kinds that pass through a wide range of spatially specified nodes (e.g., real properties, airports, web-pages).

Regional scientists may find good reasons to adopt a network orientation that accompanies and enriches their spatial orientation, perhaps, for example, by supplementing concepts of increasing agglomerative or spatial returns to scale with comparable “Matthew Effect”⁵ returns to network prominence. If so, we might reasonably expect a flowering of new ideas and wholly new perspectives concerning theoretical deepening and more subtle policy inferences, including the serious revision of partially or poorly understood concepts left as unfinished business.

3 Synthesis in progress

As the two streams began to merge, network analysts—mainly sociologists in the United States and management scholars in Europe—steadily added spatial features to their models and—as can be seen in several articles in this issue—spatial analysts have begun to incorporate network logics in studies of innovative proximity. The potential here is probably quite large, since the cumulative, long-term effects of interacting network and spatial behavior are yet to be explored.

² For reviews of recent research, see Coulon (2005) and Hoang and Antoncic (2003).

³ The International Network for Social Network Analysis (<http://www.insna.org/>) provides excellent links and sources of software, publications, handbooks, conferences, etc., concerning network analysis.

⁴ Citation data are inherently directed, but this attribute waits to be fully exploited in future studies.

⁵ We may consider this effect to imply that disproportionate benefits accrue to better known network nodes than lesser nodes of otherwise equivalent “value,” a concept named and evaluated at length by Merton (1968, 1988).

As [Hoekman et al. \(2008\)](#) demonstrate below, Europe's dominant spatial centers consist of an elite set of collaborating regions that constitute Europe's knowledge core. This convergence might logically arise in a slowly evolving system of stable network nodes through which "knowledge-spillover agents" filter gradually in the course of typical career trajectories ([Bergman and Schubert 2005](#), pp 171–173). Perhaps network-imprinted capacities eventually become overlaid on spatial nodes through processes not presently understood, lingering on after incumbents depart ([Agrawal et al. 2003](#)). The interaction between evolving spatial and networked systems remains a topic open for exploration, as does the equally interesting situation where a radical rupture of existing knowledge networks suddenly stimulates the expansion of their geographic reach and range (so-called "scale-free networks"). The infamous partitioning and purging of existing knowledge nodes immediately prior to and during WWII led to the Diaspora of European scientists, which eventually proved capable of transforming the basic architecture of US scientific and innovative networks and places, but the understanding of this historic transformation actually remains more narrative than analytic, more mission-team than network focused, and more personality-cultic than spatially oriented.⁶ It is hoped that these kinds of questions⁷ and this emerging confluence of methods and approaches to innovation research that inspire the present issue may also inspire others to consider further work on interactive aspects of spatial and network analysis.

The papers included in this special issue cover a range of network and spatial issues associated with innovation in regions and nations, mainly European.⁸ Analytic approaches to studying innovation include an intriguing range of alternative network metrics, spatial proximities, and modeling procedures to examine knowledge externalities⁹ at several geographic scales. The articles pose a rich set of research questions and demonstrate novel analytic research designs that help advance our understanding of regional innovation.

The lead article by [Mancinelli and Mazzanti \(2008\)](#) analyzes microlevel evidence of productivity gains in small and medium firms due to innovative R&D and networking (local vs. external), and whether these are complementary or substitutive strategies. The research is based upon primary data collected from 243 firms active in key sectors of Emilia Romagna. It supports the expected finding that R&D is indeed a driver of productivity gains in firms, while networking to gain innovative scale economies may be a consequent complement of R&D, but not a substitute. Thus, networking is most likely among firms that already conduct R&D with the innovative intent to seek collaborative scale opportunities, rather than representing an alternative mechanism

⁶ "Matthew Effects" arising from relocated Nobel and other highly regarded scientists proliferated rapidly in a networked outpouring of influential new PhDs, perhaps fueling as well the spatial diffusion initiated by the internally disruptive redeployment of US military research and production away from the east toward what would become "silicon valley" and other US points west. For a regionally oriented view, see [Markusen et al. \(1991\)](#).

⁷ Thanks to Börje Johansson for suggesting such questions, which merit further inquiry.

⁸ Unlike Europe, the near-absence of papers by US authors in this issue is probably accounted for by the early, enthusiastic, and virtually exclusive pursuit of innovation network analyses by US sociologists and management scientists, rather than by regional scientists and geographers.

⁹ For a useful taxonomy of proximity and network-based externality effects, see [Johansson \(2005\)](#).

for the average SME to engage externally in networked innovative potentials and opportunities.

Kaufmann and Schwartz (2008) provide further evidence about networking strategies of Israeli SMEs in the innovation-intensive biotechnology sector. Since networking is seen widely as an important strategy for innovative SMEs to learn about and possibly appropriate new knowledge or to gain collaborative scale advantages, this paper investigates whether deliberate strategies to cultivate interfirm relationships actually pay-off in gaining advantageous network positions. Drawing upon a survey of 35 young biotechnology firms, they demonstrate the importance of pursuing exposure and activation routines when interacting early in the life-cycle with other firms and organizations.

Moving the level of analysis up to the immediate locality in which firms and other organizations are engaged in networks, Bergman and Maier (2008) investigate how well-positioned 121 local Austrian districts are within networks formed by constituent units (firms, universities, etc.) seeking research partners. Such positioning is modeled as a consequence of local assets and qualities of local districts and their neighboring districts. Using alternative measures of network centrality attained by districts in both ICT and all sector networks, their results indicate the importance of participation in collaborative research in prior European Framework Program networks by firms and universities located in or near local districts, and the surprising insignificance of conventionally measured R&D or university stocks of local personnel.

In an article that investigates innovation at the same geographic scale, Wilhemsson (2008) draws upon evidence of 2,000 interfirm patent holders in 100 Swedish labor markets. His study seeks to determine whether the infrequent collaborative networks observed represent efforts by firms in 16 core technologies to compensate for local deficits of proximity and agglomerative externalities. He finds evidence that inventor networks do arise less frequently in larger metropolitan areas, thereby supporting the substitution hypothesis. However, employment density in labor markets increases both the chances of collaboration and the distances spanned by collaborating firms.

Complementing the evidence of joint patent holders for a single country, Paci and Usai (2008) trace patent citations that link 175 NUTS 0, 1, and 2 level regions in 17 European countries. They are principally interested in the effects of geographic distance on citation links, which were found to decrease with distance. Citation flows were also higher between contiguous regions, regions with similar technological trajectories, and other regions in the same country. Observations of patent citations over two periods revealed that the distance between regions gained importance, while contiguity and national borders lost importance.

Although fewer countries are observed, the contrasting network flows between five large European countries studied by Maggioni and Uberti (2008) provide an international study of multiple network architectures by eliminating the intracountry links, which Paci and Usai (2008) found to be losing influence. Maggioni and Uberti model evidence of *international* knowledge flows represented by Internet hyperlinks, EPO copatent applications, Erasmus student mobility, and European research networks at NUTS 2 level regions. The role of distance was detected using gravity models and overall flows appeared to favor a club of several “super-regions”—detected by means of a core-periphery analysis—through which pass most international knowledge flows.

At the same time, topological analysis found evidence of a “small world” structure for almost all networks, thus preserving a rough balance of effectiveness and equity in network structures.

The possibility raised by [Maggioni and Uberti \(2008\)](#) that collaborative knowledge flows may now track distinct core-periphery trajectories is explicitly investigated by [Hoekman et al. \(2008\)](#). They study the evidence of *international* copatenting and copublication across the 1316 NUTS 3 regions of 29 European countries to detect whether collaboration is dominated by either national capitol regions or regions associated with innovative and scientific excellence. Distance is again found to diminish collaborative possibilities, while evidence also supports the idea that an elite set of collaborating regions may indeed constitute Europe’s knowledge core.

The vital importance of selecting the best evidence to frame and conduct network-based studies is clear, and the choice a researcher must often make is whether to collect primary data about agents and their involvement in innovation networks or to exploit available administrative records of documented innovation events (citations, publications, patents, research consortia) that reveal linkages and networks between such agents. To explore analytic issues of concern to researchers who are tempted to apply network analysis, [Ter Wal and Boschma \(2008\)](#) examine methodological considerations to be taken on board when collecting primary data or transforming patent data.

4 Final notes

Network thinking and approaches of the types included in this special issue may stimulate heightened interdisciplinary efforts to collaborate on innovation approaches and topics of shared concern, although [Fagerberg and Verspagen \(2006, p 20\)](#) see “...a possibility that the existing social organization of the field will not be strong enough to allow for a common base of knowledge to continue to develop, and that the field (innovation studies) instead will fragment into several different intellectual communities with little common interaction...” Despite their concerns, it may well be that convergent network analytics of the types reported in this issue could help knit together a key group of innovation scholars, but even if fragmentation of innovation scholars deepens, which is by no means obvious, it seems clear that network analysis has already found a place in the regional scientists’ toolkit and that further developments along methodological lines can be expected as new and extended applications are attempted.

Acknowledgments Comments by Corrine Autant, Björe Johansson, Gunther Maier, and Roger Stough are gratefully acknowledged.

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