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Multiplexity, Growth Mechanisms and Structural Variety in Scientific Collaboration Networks

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ABSTRACT A substantial body of literature has recently been concerned with the structure and dynamics of the collaboration networks that underlie the production and dissemination of scientific knowledge. Despite the growing interest in these networks, relatively little emphasis has been placed on two broad areas of investigation: on the one hand, the interplay of the growth mechanisms underpinning the evolution of collaborative arrangements; on the other, the implications that the structure and multiplexity of these arrangements have on knowledge creation and diffusion. The articles in this Special Issue aim to bridge these gaps in the literature and, by embracing a variety of perspectives, contribute towards a better understanding of how collaboration networks originate, function, and evolve. This Introduction offers a theoretical and methodological framework for the articles here included. It begins by discussing problems of measurement of scientific collaboration, and goes on to examine the role that growth mechanisms, structural variety and multiplexity play in shaping the genesis and functioning of collaboration networks. In reviewing current and emerging research themes, the discussion will also identify promising research directions that will stimulate future work on collaboration networks in science and technology.

KEY WORDS: collaboration networks, co-authorship, co-invention, multiplexity, growth mechanisms, network structure

The transition to a knowledge-based economy has been characterised by a fundamental change in the way scientific and technological research is carried out. Lone scientists and inventors have gradually been superseded by distributed teamwork and, as a result, the locus of innovation has increasingly shifted away from the laboratories of individual firms or academic institutions towards collaboration networks that span various institutions, geographical areas and scientific disciplines. Although this change has been widely

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examined within different streams of the literature, including organisational theory, cognitive and social psychology, sociology, economics, applied mathematics and statistical physics, a number of fundamental areas of investigation still remain to be addressed.

The first area is concerned with the multiplexity of collaborative ties, namely the fact that the same actors may be simultaneously embedded in multiple collaboration networks and thus involved in relationships of a different nature. Despite the ubiquity of multiplex collaboration networks, relatively little is known about the interplay between, and co-evolution of, various concurrent networks connecting the same scientists and inventors. In a similar way, firms collaborating in R&D can be linked to one another both formally, in strategic alliances, and informally, for example through the co-participation of their scientists in the same scientific communities (Schilling & Phelps, 2007). Yet, the two types of networks are usually examined separately, and relatively little effort has been devoted to uncovering how these networks co-evolve and affect each other.

Another area of investigation refers to the mechanisms governing the evolution of collaboration networks. A number of theoretical arguments have been advanced to explain the formation of collaborative ties, and empirical assessment has largely relied upon the statistical analysis of very large-scale electronic databases (Newman, 2001; Wuchty et al., 2007; Jones et al., 2008). Yet, a problem still largely unexplored is concerned with the trade-off between various network growth mechanisms. For instance, a trade-off may exist between mechanisms at different levels of analysis (e.g. the actor or the relationship between actors) or between different mechanisms at the same level of analysis (e.g. the role of institutional and geographic proximity for the creation of a collaborative tie).

A further problem relates to the fact that the structure of collaboration networks tends to be heavily dependent on the nature of the actors involved (scientists or technologists), the industry, the institutional and legal frameworks and the level of analysis (e.g. the individual actor, the organisation or the whole system) (Murray, 2002; Sonnenwald, 2008). For instance, it still needs to be empirically investigated how scientists' institutional affiliations, ability to attract public funding and past experience in collaborating with industry have an impact upon their tendency to engage in collaborative research, and thus can be seen as responsible for shaping the structure of the collaboration network.

This Special Issue aims to contribute to bridging these gaps in the literature, by including articles that collectively shed new light on the antecedents, structure, growth and consequences of collaboration networks in science and technology. The remainder of this Introduction offers a theoretical and methodological context for these articles. Three broad areas of investigation will be briefly discussed: (i) the definition, mapping, and measurement of scientific collaboration and production, (ii) the variety and interplay of growth mechanisms that govern the evolution of scientific collaboration networks and (iii) the implications that the structure of collaboration networks and the multiplexity of collaborative arrangements have in terms of performance-related outcomes, such as knowledge creation and diffusion.

The idea of this Special Issue originated in connection with the organisation of ARS'11, the third International Workshop on Social Network Analysis devoted to “Collaboration networks and knowledge diffusion: theory, data and methods”, which was held at the Università degli Studi di Napoli “Federico II”, Naples, on 23–25 June 2011.
Measuring Collaboration in Science and Technology: Methodological Issues

As scientific disciplines specifically devoted to the analysis of scientific production (scientometrics, informetrics, bibliometrics) emerged in the late 1960s, the study of scientific communities, collaboration and knowledge exchange has become intertwined with the development of techniques for the investigation of scientific output and for “science mapping” (Hood & Wilson, 2001). Among these techniques, over the years, a prominent role has been played by the measurement of co-citation, namely the frequency with which two documents are jointly cited by other documents. According to Small (2003), the use of co-citation as the building block for science mapping dovetails with Kuhn’s (1962) idea of research paradigms identified by the clustering of concepts and symbols associated with highly cited papers. Alternative methods for science mapping rely upon the co-occurrence of authors’ names included in the backward citations made by papers to uncover the intellectual root of scientific fields (White & Griffith, 1981), or upon the co-occurrence of words within scientific outputs to identify semantic clusters and research themes (Callon et al., 1983, 1986).

In a similar vein, the concept of “invisible college”, proposed in seventeenth-century England by the members of the Royal Society to emphasise their geographic proximity and regular meetings based on common scientific interests (Zuccala, 2006), was later operationalised by Price (1963, 1986), on the basis of bibliometric indicators, to indicate a group of socially cohesive scientists who are affiliated with geographically distant institutions and yet closely interact and exchange information with one another to monitor the growth of knowledge in their field (Crane, 1972). It is interesting to note that, even though he was a forerunner of the analysis of scientific collaboration based on co-authorship, Price used the concept of invisible college to refer to patterns of informal and indirect forms of intellectual exchange among scientists that are not strictly involved in formal relationships of co-authorship (Zuccala, 2006).

With the growth of the scientific community, the specialisation of individual scientists and scientific fields, and the emergence of collaborative linkages, the scientific literature has shifted emphasis from maps to networks and from “fuzzy” definitions of scientific communities, largely based on narrative and participant observation, to finer-grained definitions of collaboration based on co-authorship and co-patenting relationships (Price, 1963; Merton, 1973). Thus, since the late 1970s, collaboration networks have become the most common tool in the analysis of scientific communities, patterns and processes of collaborative production and joint scientific outputs (Lambiotte & Panzarasa, 2009).

This methodological shift has not been inconsequential. First, studies based primarily on bibliometric data tend to underestimate the role played by any peripheral knowledge flow between scientists (e.g. through mentoring, collegial commentary) that is not formally captured by the co-authorship of a common article or patent (Evans et al., 2011). Second, by assuming that relations are primarily symmetric, the richness of the information on the direction of knowledge flows between individuals cannot be captured (Fagiolo, 2010; Maggioni & Uberti, 2011; Maggioni et al., 2011). Third, the transformation of two-mode (or affiliation) networks into one-mode networks may induce a bias in the computation of a number of network metrics, and thus may hinder the analysis of the growth mechanisms responsible for the evolution of collaboration (Burt, 2005; Opsahl & Panzarasa, 2009). For instance, studies based on projected one-mode networks are focused directly on links...
between scientists and tend to overshadow scientists’ decisions to join papers or patents (as reflected in two-mode links), thus failing to capture the full breadth of the trade-off between incentives and costs of engaging in collaborative endeavours.

Furthermore, the use of bibliometric data across different time periods, different data sources and different institutional arrangements may introduce systematic and unaccounted biases in the analysis. However, despite all these drawbacks, most scholars, who need “paper trails” (Krugman, 1991; Jaffe et al., 1993) to build metrics, still appear to rely on bibliometric data to investigate collaborative behaviour in science and technology.

**Growth Mechanisms of Collaboration Networks**

Research has long suggested a variety of mechanisms underpinning the structure and evolution of social interaction among individuals (Lazarsfeld & Merton, 1954; Kossinets & Watts, 2006). These mechanisms, or a suitable combination of them, can also be advocated to explain the creation, maintenance and severance of collaborative ties in scientific production (Price, 1965; Merton, 1968; Laband & Tollison, 2000; Wuchty et al., 2007; Jones et al., 2008; Sonnenwald, 2008). Scientists draw on their social networks to find inspiration and ideas for new research projects and to identify and select collaborators based on a wide range of personal factors. For instance, similarity in vision and working style, trust, respect, personal compatibility, positive feelings for each other and enjoyment of each other’s company have been reported to affect the evolution of collaborative relationships (Hara et al., 2003; Creamer, 2004).

These determining factors are often subsumed under more general principles of network growth that explain the evolution of collaborative ties in terms of the scientists’ attributes, their institutional affiliation and geographic location, and the structure of relations in which they are embedded (Jones et al., 2008). For instance, the principle of reinforcement is concerned with the tendency of scientists to forge new ties with others with whom they have already collaborated (Guimerà et al., 2005). As such, reinforcement also reflects the positive impact that repetitive ties have on the development of trust, mutual feelings and the sharing of common interests, objectives and working styles. In turn, the association between similarity of personal attributes, on the one hand, and inter-personal attraction and tie creation, on the other hand, is emphasised by the principle of homophily that explains why collaborations are more likely to occur between similar scientists than dissimilar scientists (McPherson et al., 2001; Jones et al., 2008).

An alternative, and to some degree complementary, way of examining the evolution of collaborative ties is from the standpoint of strategic network formation (Jackson & Wolinsky, 1996; Goyal, 2007; Jackson, 2010). From this perspective, and like with models based on similarity and personal compatibility, a scientist’s choice still plays a central role in the network dynamics. However, strategic models of network formation more explicitly emphasise the costs and benefits associated with a scientist’s choice of collaborators (Jackson & Wolinsky, 1996). In this sense, similarity and personal compatibility can be seen as driving network evolution insofar as they have a positive association with scientific performance.

There are settings, however, in which scientists might choose collaborators with whom they do not share personal attributes because in so doing they believe they can enhance their performance. In such cases, the costs of incompatibility are lower than the benefits...
arising from collaborating with dissimilar others. For instance, heterophilous collaborations among scientists from different disciplinary areas can be seen as a means for engaging in inter-disciplinary work, which in turn may foster visibility, facilitate the creation of new knowledge and skills and enhance the overall quality of the collaborative endeavour (Shi et al., 2009). In particular, it has been suggested that occupying brokering positions between otherwise disconnected collaborators from different disciplines provides a scientist with the opportunity to maintain specialisation and at the same time increases research performance through access to distinct sources of new knowledge (Whitfield, 2008). In these cases, the benefits typically associated with similarity of scientific background are traded off against the expectation of a higher performance that stems from interaction with dissimilar others.

Performance, Multiplexity and Forms of Scientific Collaboration

A further area of research that has attracted much attention in recent times deals with the topological features of collaboration networks in science and technology and their connection with performance. The seminal contributions of Newman (2000) and Watts and Strogatz (1998) on small-world networks and Albert and Barabási (2002) on the power-law distribution of nodal degrees have sparked an enormous interest in the community of innovation scholars. Empirical studies on various collaboration networks, including scientific co-authorship (Newman, 2001; Goyal et al., 2006), patent co-invention (Fleming et al., 2007), R&D alliances (Schilling & Phelps, 2007) and publicly sponsored research projects (Breschi & Cusmano, 2004), have confirmed the emergence of small-world properties in such networks and the highly skewed distribution in the number of partners across actors. From a more theoretical perspective, Cowan and Jonard (2003, 2004) have proposed a simulation model, showing that small-world networks outperform other network architectures in terms of efficiency in knowledge diffusion, though not necessarily in terms of equality of diffusion across actors.

While most studies have been focused on a single relation at a time, a few attempts have been made more recently to examine the multiplicity of relationships in which scientists are embedded (Murray, 2002; Breschi & Catalini, 2010). The interest in multiplex networks arises from the fact that, due to the increasing involvement of academic researchers in the commercialisation of scientific output, many scientists are nowadays facing different and often contrasting logics and norms of behaviour; on the one hand, the logic of science, with its emphasis on norms of openness and communalism; on the other hand, the logic of technology, with its stress on norms of private appropriation and exclusion (Dasgupta & David, 1994).

The tensions created by such contradicting demands may have negative consequences in terms of efficiency and welfare. For example, it has been shown that the most valuable scientific output does not necessarily translate into commercially successful innovations (Gittelman & Kogut, 2003; Gittelman, 2007). Moreover, the enforcement of property rights on scientific output may restrict access to new knowledge and, thus, impair the cumulative advancement of science (Murray & Stern, 2007). Finally, the lure of tangible economic benefits may lead to contrasts within teams regarding the attribution of authorship and inventorship rights (Ducor, 2000; Lissoni & Montobbio, 2008).

Notwithstanding these potentially negative effects, a related stream of research has stressed that the existence of actors at the intersection of collaboration networks in science
and technology plays a crucial role in mediating those conflicting logics and in ensuring a smooth transfer of knowledge from the realm of science to that of technology. Building upon Cockburn and Henderson’s (1998) insight, Murray (2002) provides one of the first attempts to examine the co-evolution of the co-publishing and co-inventing networks, revealing that the extent of overlap between them is small, but that a few key scientists play a crucial role in connecting the two worlds, by engaging in a variety of activities, such as mentoring, advising, consulting, licensing and new firm foundations (Lissoni, 2010). Further contributions also show that teams hosting scientists engaged simultaneously in patenting and publishing outperform other teams in terms of technological impact (Bonaccorsi & Thoma, 2007), and that such scientists tend to be over-represented among the most central actors in both networks (Breschi & Catalini, 2010).

The Contributions in the Special Issue

The five articles that appear in this Special Issue revolve around the following main themes: (i) the growth mechanisms behind the process of formation of collaborative ties; (ii) the existence of a rich variety of shapes and structures in collaboration networks, according to specific scientific and technological fields, institutional and legal frameworks and levels of analysis; (iii) the multiplexity of ties in concurrent networks; (iv) the effects of network structures on performance.

The articles place a special emphasis on the role that scientists’ choices and incentives play in the creation of collaborative ties. The underlying assumption is that scientists have some degree of discretion over which collaborations they wish to forge and how much effort, time and resources they invest in each of their collaborators. Even when gains and costs are not explicitly evaluated and compared across potential collaborations, scientists create and maintain collaborative ties with each other when these ties are (expected to be) mutually beneficial for the connected scientists, and sever existing ones when they are not. In this sense, the network structures and growth mechanisms can also be seen as reflecting the strategies used by scientists to increase the impact of their work and by institutions to devise appropriate hiring policies in an effort to enhance their visibility.

The articles integrate each other as they address similar research problems, but from different, yet complementary angles. For instance, new insights into network dynamics, growth mechanisms and network structure are offered by Broekel and Hartog, who study the combination of multiple ordering principles at various levels of analysis in an inter-organisational network, by D’Amore, Iorio, Labory and Stawinoga, who examine the combined impact of institutional and geographic proximity upon the creation of inter-organisational ties, and by De Stefano and Zaccarin, who focus on the distinctive role that preferential attachment, triadic closure and spatial proximity play in co-authorship and co-invention networks. The relation between network structure and actors’ attributes is investigated by Lissoni, Llerena and Sanditov, who show how the small-world signature of the collaboration network is rooted in the inventors’ institutional background.

Multiplexity is another recurrent area of investigation in this Special Issue. For instance, the article by De Stefano and Zaccarin uncovers the distinctive structures and dynamics characterising co-invention (technology-based relation) and co-authorship (science-based relation) networks, while the article by D’Amore, Iorio, Labory and Stawinoga and the article by Beaudry and Kanarian place emphasis on the trade-off between the conflicting incentive...
systems of basic versus applied research, and of industry versus academic institutions, respectively.

Altogether, the articles included in this Special Issue contribute towards a better understanding of scientific collaboration networks, not only by embracing a wide variety of approaches, but also by developing a rich and theoretically grounded framework for studying how these networks originate, function and evolve. In so doing, they help lay a new foundation for, and inspire, future work on how to study collaborative production in science and technology. In what follows, the contributions made by each of the five articles will be briefly discussed in turn.

The article by Lissoni, Llerena and Sanditov uses data on EPO patent applications in order to study the structural properties of networks of inventors in France in different technologies. The article focuses on the different institutional background of inventors, and finds that the higher the presence of inventors from universities and public research organisations (mainly CNRS), the more likely the networks are to exhibit small-world properties (i.e. they show a relatively high clustering coefficient and a relatively low average path length when compared to similar random structures). This is explained in terms of the large average size of teams and high mobility displayed by these two types of inventors who are therefore able to establish relations between otherwise disconnected cliques.

The article by De Stefano and Zaccarin explores the simultaneous embeddedness of scientists in the networks of co-invention and co-publication, by focusing on a sample of authors—inventors located in the area of Trieste, characterised by a high concentration of international research organisations. Through the application of exponential random multigraph models, the authors uncover the most likely mechanisms leading to the observed multiplexity of ties among actors. Their findings show that co-invention and co-authorship ties tend to co-occur to a significantly larger than expected extent. In other words, the existence of one type of tie significantly increases the likelihood that also the other type of tie exists. However, unlike what was observed in univariate networks, their findings suggest that preferential attachment mechanisms do not play any significant role in the evolution of the multiplex network. Rather, tie formation takes place among peers in the multiplex relational structure. Quite importantly, the article also shows the existence of rather complex triangulation structures. In particular, it reports evidence of a strong tendency for actors sharing multiple co-authors to get involved in co-inventing ties. Finally, results show that academic scientists are likely to be involved in multiplex ties, and that spatial co-location matters only for co-authorship, but not for co-invention and multiplex ties.

The article by Beaudry and Kananian investigates the factors influencing an academic's propensity to patent and the quality of patenting in two specific scientific fields: nanotechnology and biotechnology. The authors find that a university researcher is more likely to be listed as an inventor of a patented innovation, regardless of the assignee, if she receives private funding, has a high level of integration in the scientific network (measured by cliquishness and betweenness centrality) and has shown a prior capacity to successfully collaborate with industry. The authors also show the existence of a nonlinear concave relation between public funding and the number of patent claims. Finally, their results indicate that diversity is an important resource in scientific interaction and that “business” matters, i.e. scientists closely involved in research that leads to patents owned by private partners produce more and better patents than other academic inventors.
The article by Broekel and Hartog is concerned with inter-organisational networks and aims at uncovering the network mechanisms underpinning their structure. Previous work has placed emphasis on various mechanisms at the node, dyadic or global network levels, but very rarely has looked at a combination of mechanisms that lie at all these three levels simultaneously. To remedy this shortcoming, the authors draw on exponential random graph models and conduct a cross-sectional study on the growth mechanisms responsible for the structure of the network underlying the transfer of technological knowledge in the Dutch aviation industry in 2008. Findings provide support in favour of an integrated approach to the genesis of network structure to uncover mechanisms at all three levels. At the node level, results suggest that non-profit and large organisations are more likely to forge ties to other organisations than profit and small organisations. At the dyadic level, the authors show that organisations tend to favour collaborations with other organisations that are in geographic proximity and with which they share a similar institutional background. However, no support is found for social and cognitive proximity. At the global network level, the study provides evidence in favour of triadic closure, thus indicating that partners of the same organisation are likely to become partners themselves.

The article by D’Amore, Iorio, Labory and Stasinoga aims to investigate the trade-off between spatial and institutional distances in scientific collaboration networks. To this end, the authors draw on a unique data set on co-authorship of scientific publications in the Italian biotech sector during the period 2003–2005. Findings show that there is an inverse relationship between institutional and spatial distances: the institutional proximity between any two collaborating organisations increases as the geographic distance separating them becomes larger, and vice versa. Biotech firms appear to balance the two distances according to the nature of the knowledge exchanged. The authors show that basic research is performed in relatively stable, institutionally heterogeneous and spatially localised networks. By contrast, in applied research, organisations tend to collaborate with others with which they share a similar institutional profile, so as to protect the secrecy of innovation, but that are separated by relatively long geographic distances, so as to access the necessary financial and material resources.

References


