# Firm dynamic governance of global innovation by means of flexible networks of connections

Gay, Brigitte
ESCT School of Business, University of Toulouse I

July 2008

# Firm dynamic governance of global innovation by means of flexible networks of connections

par Brigitte GAY

| De Boeck Université | *Journal of Innovation Economics*

2008/2 - N° 2
ISSN | pages 63 à 83

# FIRM DYNAMIC GOVERNANCE OF GLOBAL INNOVATION BY MEANS OF FLEXIBLE NETWORKS OF CONNECTIONS

Brigitte GAY

*University of Toulouse I and ESCT School of Business/France*
*b.gay@esc-toulouse.fr*

## THE CHALLENGE OF NETWORK MANAGEMENT

One of the most important trends in industrial organization of the past quarter century has been the growth of interfirm alliances. These alliances are formed today with considerable ease across organizational and national boundaries. A recent survey found that alliances already account for anywhere from 6 percent to 15 percent of the market value of the typical company and that alliances are expected to account for 16 percent to 25 percent of median company value and more than 40 percent of market value for almost one-quarter of companies by 2010. In current dollars, this means that for the advanced economies as a whole, alliances will represent somewhere between $25 trillion and $40 trillion in value (*Accenture Survey*, 1999). In the biopharmaceutical and in the software sectors, dynamic alliance formation responds to technological shifts. Deloitte Research industry group (2005) wrote that, akin to software networks, alliances in the biotech market will become the foundation of "*innovation ecosystems that companies must build and nurture in order to drive sustained growth for the future*".

Firms are hence embedded into intricate meshes of business relationships. Terms such as "the networked firm" or the "virtual organization" have been increasingly used to describe an organizational form containing a network of firms. For a firm to be situated in complex, unstable, networks formed by inter-firm linkages, is believed to have significant implications for its performance. Strategy is therefore conceptualized as a portfolio of links whereby dynamic positioning into large networks is critical to competitive advantage. A well-positioned company will be able to control or adjust what is happening in an industry or industry sector. How firms impose some control onto the macro network, and how wider networks (all firms in an industry or industry segment) constrain any individual firm, are major issues. It is thus important to consider explicitly the way firms organize all their transactions. Firms seek to position themselves within complex networks, and hence the market, through the continuous configuration of ties.

A major stream in organizational research concerns alliances. Network studies, however, are still scarce in economics though they have recently achieved popularity through the recognition that social and economic networks influence cumulative outcomes (Ahuja, 2000; Baum and Rowley, 2008; Cowan et and Jonard, 2008; Jackson and Wolinsky, 1996; Powell, 1996; Schilling and Phelps, 2007; Walker et al., 1997). Literature on alliances claims that alliances are beneficial because they provide fast access to resources (Gulati, 1998; Teece, 1992), in particular those typical of a more established firm. The alliance is seen from a perspective of a resource-constrained firm and as a condition for prevention of failure during the early days of a company's existence (Stuart, 1998). Direct alliance linkages were found to facilitate knowledge flows between partners (Gomes-Casseres and al., 2006; Mowery and al., 1996). Firms also access external legitimacy when they are able to secure relationships with key actors. Other studies have focused on the antecedents of network formation such as trust and the reduction, for a firm, of risk and opportunism (Uzzi, 1996). Coriat and Dosi (1998) argue that organisational competencies rely upon the complex, difficult to acquire, skills of expert problem solvers and new knowledge creators. Moreover, the importance of distance in knowledge space has been highlighted by a number of authors (Ahuja and Katila, 2001; Mowery, 1998; Noteboom, 2000; Schoenmakers and Duysters, 2006). Knowledge space (distinct or with some degree of overlap between firms) will affect the likelihood of forming an alliance. The distance in knowledge space will also shrink after an alliance. Importantly, many authors (Ahuja, 2000; Deeds and Hill, 1996; Owen-Smith and Powell, 2004; Powell, 1998; Stuart, 2000) have demonstrated the impact of direct and indirect inter-organizational alliances on performance and innovation of firms. Koput and Powell (2003) report higher earnings and survival chances of biotechnology firms with more kinds of activities in alliances with more kinds of partner firms. These studies provide a strong case for the examination of alliances in innovative sectors at multiple levels.

Finally, the biggest growth area in organizational network research is represented by social capital and, more recently, complex network theories developed by physicists and mathematicians, with the analysis of the structure of patterns that emerges from cross-cutting ties. The most fundamental traits of social capital and complex network theories are the shift from atomistic explanations (at individual or link/dyad level) to the explanation of phenomena in terms of linkages among a system of interdependent agents.

Fundamentally, capital is a surplus value and represents an investment with expected returns. To capture the firm's opportunity structure or extent to which it can reach others, or be reached by others in the network, typical social capital studies leverage on two important concepts, centrality (which actors are best connected to others or have more power, influence) and connectivity (whether and how actors are connected to one another through the network).

To convey critical aspects of nodes connectivity, social network analysts have depicted the way an actor is embedded in a relational network as imposing constraints on the actor or else offering the actor opportunities. In particular, the concept of holes in social structure or "structural holes" was developed by Ronald Burt to assess structural autonomy. Social structural advantages derive from the brokerage and control opportunities created by an open social structure. Actors can build relationships with multiple disconnected clusters and use these connections to obtain information and control advantages over others (Burt, 1997). Actors who face fewer constraints, and have more opportunities than others, are thus in advantageous structural positions. Burt developed a measure of constraint as a summary measure of lack of structural holes. The idea of constraint in industry is essential because it highlights the danger that firms having many ties to others could actually lose autonomy rather than gain it, depending on the linkages among the other firms. For Burt, the presence of structural holes in a network is a condition to secure more favourable terms in the opportunities actors choose to pursue. A recent study, using a sample of alliances in the US communications industry, has shown that an actor's connections to separate clusters could lead to improved firm performance, implying that some level of network cohesion could be positive if redundant contacts were avoided (Bae, Gargiulo, 2003). The use of spanning cliques can thus be a deliberate strategy to control different parts of a network (Baum and al., 2003). Burt's theory has particularly important implications for understanding technology-driven industries. There, the innovative activities of high tech, often novel, firms force industries out of their normal boundaries into new sectors and enhance the level of competition in traditional markets.

Another important network feature is centrality. Centrality is a characteristic of individuals. There are three distinct measures of centrality. In particular, degree centrality measures the number of actors a given actor is connected to. In alliance studies, this measure thus refers to the direct number of business relationships. In general, the greater an actor's degree, the more power it has on the network. For example, a greater number of alliances were associated with faster growth in a sample of US biotechnology firms (Powell, 1996). Metrics such as degree centrality and network constraint are hence local and used to measure the social capital of an individual actor or firm.

Node/firm communication throughout the whole network is taken into account by two other metrics, betweenness and closeness centrality. Betweenness centrality (Freeman, 1979; Wasserman and Faust, 1994) is conventionally thought to measure the amount of traffic migrating from each node to every other node that would transit through a given node, and therefore the traffic load that this given node must handle, as well as the influence this node has in the spread of information within the network in the sense of being able to shut it down eventually (Borgatti, 1995). Betweenness centrality hence captures the role of "brokers" or "bridges": those that have most indirect ties and can connect and disconnect large parts. A node's closeness centrality states how close an individual is to the others in the network. In a flow context, closeness is ordinarily interpreted as an index of the expected time until arrival of something flowing through the network (Freeman, 1979; Bavelas, 1950; Sabidussi, 1966). Organizations with high closeness scores are thought to be in a favourable position to obtain new information early.

Combined theoretical and empirical research on complex networks in many fields has also led to two important results:

- Many large networks are scale-free (SF). They follow a power law distribution of connectedness. This uneven distribution indicates that, instead of the nodes or actors of these networks having a random pattern of connections, a few hubs (tail of the distribution) "hold together" numerous small nodes while the great majority of nodes have few connections (head of the distribution), a fact that influences considerably the way the network operates (Albert, Barabasi, 2002).
- Many large networks have the so called *small-world* property. The small-world (SW) behaviour is characterized by the fact that the distance between any two actors or nodes is of a similar order of that of a random network (with short path length between any two nodes and therefore fast circulation of information, technology, products, etc) and, at the same time, as for regular networks, high clustering coefficient or cohesion in nodes neighbourhood. The SW model underlines that changes in diffusion and spreading dynamics are explicitly function of structure (Watts, Strogatz, 1998).

Using visualization techniques as well as network metrics is thus interesting in the sense that they can determine that a network structure is not random, define different types of topologies, their dynamics, and address important questions such as: Do firms live in a small world, in a scale-free network with a "hub and spoke" structure, or a combination of both? Is the structure of an innovation ecosystem stable? Have firms the capacity to manipulate the complex system, and hence the economic environment, in which they are situated? How does the macro network in turn influence their context and may provide benefits or constraints? Can network metrics be used as effective indicators of firms' performance?

In our study, metrics borrowed from both sociologists (social capital theories) and statistical physicists (complex network theories) are proposed to form powerful and complementary tools to help manage effective and temporary forms of business configurations born of the need of rapid change. A two-pronged analysis is therefore conducted, one that maps (visualisation of different snapshots) and examines some properties of the whole network and therefore considers the broader, rather than the local, neighbourhood of firms, and one that looks at some properties of individual firms' embeddedness.

In section 2, we give background data on the study. In section 3, we describe the methodology used. In section 4, we analyze the empirical data on firm and complex network structures and their dynamics. We first measure large scale statistical properties of networks, such as path length, clustering coefficient, and connectivity distribution. We therefore follow a "standard programme of empirical research of a complex network", provided by Dorogovtsev and Mendes (2003). In a second step, consistent with the seminal work of Burt (2000) investigating the business perspective of individual senior managers (with the often cited illustrative case of entrepreneurs Robert and James networks), we present research results on the distinct network capital of the three firms that dominate the biotech sector for the period studied. We consequently measure network constraints to examine the competitive advantage of structural holes for central firms when transactions span opposite sides of holes. To look at the benefits and control of their network position in the macrostructure, we also measure betweenness and closeness centrality scores for the three firms. In section 5, we follow with a discussion of theoretical and empirical work that seeks to understand how innovation, network dynamics and strategy are entwined. Finally, in section 6, we draw our conclusions and perspectives.

Using this analysis, we try to offer managers insights into the best ways to dynamically evaluate and control their local and global environment, as well as their firm's specific position and its strategic relevance.

# BACKGROUND DATA

We chose a major biotech sector of the global pharmaceutical industry for our multilevel analysis for a number of reasons. Emergence of biotechnology has presented a new technology paradigm with respect to drug discovery and development in this industry. It hence provides a natural laboratory for researchers because they can observe how and when existing firms have built their innovation capacities as well as potential links between innovation and firms' embeddedness in social structures, whether institutional, spatial, technological, or other. Also of particular interest in the pharmaceutical industry is the fact that deal making between biotech companies has intensified in recent years. In the 2001-2003 time frame, biotech-biotech alliances accounted for more than 56 percent of new deals. Some 1,023 intrabiotech deals were reported in 2004 compared to only 199 deals in 1997. Biotech companies were involved in 86% of the 2,761 deals signed in 2004 against 64% of the 311 deals signed in 1997 (Cartwright, 2005). The biotech industry is therefore an increasingly mature industry that is no longer wholly reliant on partnerships with big pharmaceutical companies.

Since previous studies in the biotech or health sector have concentrated mostly on alliances formed before 1998 and on biotech-pharma alliances, and considering the above data, our work focuses on more recent underlying topologies which are the result of profound technological and business transformations led by biotechnology in the pharmaceutical industry.

# METHODOLOGY

## Database and software

From a structural perspective, basic network analytic constructs are nodes and ties, where nodes/actors are entities such as humans or firms and ties/links represent relationships among nodes, such as business transactions or web documents connected with directed hyperlinks. Networks are constructed when agents interact. This study thus considers that economic agents/firms are not independent and, while still taking into account their attributes, focuses on their linkages and embeddedness in macrostructures.

The database was assembled by querying specialized internet sites (leading sources for news releases and regulatory filings from companies throughout the world such as Business Wire et PRNewswire, as well as companies' own sites) for alliances made in this biotech sector of the pharmaceutical industry in the years 2000 to 2004, and employing Perl scripts to collect and parse data. Network studies tend to suffer from difficulties in specifying boundaries and thus in providing a coherent picture of network relations. The boundaries of the macro network are set here by the selection of links/alliances that are explicitly made in a major and well-defined area of the industry containing firms operating under VEIC (Venture Economics Industry Classification) primary codes 4111, 4112, and 4121. These companies design and deliver complex biological molecules (antibodies) for the diagnostics and therapeutic markets. The monoclonal antibody market in 2005 was worth over $13bn worldwide, representing a significant growth of 37% (BioPortfolio Limited). The sample contains firms that squarely fall into the chosen VEIC codes because of their core product offering, as well as big pharmaceutical or incumbent biotechnology companies, such as Roche, Amgen, etc, that are unavoidably transacting into this major sector. We find that biotech companies are involved in about 90% of such transactions; 82% of these occur before phase 1 clinical trials. The sample is also concentrated in two sectors (oncology and AIID –Arthritis, Immune and Inflammatory Disorders) and four key markets: USA (59% of the alliances), Canada (6%), Europe (18%), and Japan (9%). The sample is therefore representative of the global biopharmaceutical industry.

We can therefore analyze the discrete network structures and dynamics of firms, paying particular attention to the cohesion features of the different firm-centric networks and their embeddedness within the broader biotech network. Our sample contains 360 firms. The 2000-2003 period is dominated by three firms or hubs, supplying us with the data needed to grasp the industry perspective of individual central actors or firms. Since two of these hubs actually lost their central position in 2004, we can indeed assess if network metrics can be used as tools to predict firms' business position, as already demonstrated by Burt for entrepreneurs (2000). As we are interested in a multi-level analysis including analysis of the evolving macrostructure the three hubs are embedded in, we examined more specifically two discrete periods for a longitudinal analysis, 2000-2001 (period 1) and 2002-2003 (period 2). Centrality and structural hole measures are calculated from one period to another to compute firms' access to capital through time.

We have used TETRALOGIE Network Display Software (IRIT) for the representation of network evolving structures, Cyram Netminer in the calculation of network statistical properties, and the Girvan-Newman (2002) community-finding algorithm. The notion of "community structure" is related to that of clustering, though it differs somewhat. A community consists of a subset of nodes within which the node-node connections are dense, and the edges to nodes in other communities are less dense. The

Girvan-Newman algorithm focuses on links that are least central i.e. most "between" communities. The communities are thus detected by progressively removing edges from the original graph. This algorithm allows us to visualize the decisive structures in the neighbourhood of hub networks in order to show how networks of players are interrelated.

## Network formalism

Centrality measures the importance of a node in the network. The simplest of centrality measures is *degree centrality*, also called *node degree*. The degree $k_i$ of a node $i$ in a network is the number of links connecting it with other nodes. Degree centrality is measured simply by the portion of nodes that are adjacent to each node. The degree distribution (connectivity) function is the probability of the nodes degree.

The neighbourhood of a node $i$ at distance 1 from node is the set of $k_i$ nodes. The clustering coefficient quantifies how close the local neighbourhood of a node is to being part of a clique, a region of the graph (a sub-graph) where every node is connected to every other node. The clustering coefficient is calculated by taking all the neighbours of node $i$, counting the links between them, and then dividing by the maximum number of links that could possibly be drawn between those neighbours (Watts and Strogatz, 1998).

The path length between two nodes $i$ and $j$ is the smallest number of links connecting them.

A network with $n$ nodes and $m$ links is a small-world network if it has a similar path length but a greater clustering of nodes than an equivalent random graph with the same $m$ and $n$. A random or Erdös-Rényi graph is constructed by uniquely assigning each edge to a node pair with uniform probability (Bollobas, 2001).

Betweenness centrality is defined as the share of times that a node $i$ needs a node $k$ (whose centrality is being measured) in order to reach a node $j$ via the shortest path.

A node's closeness is measured by the inverse of the sum of distances from a node to all the other nodes, which is then normalized by multiplying it by ($n$-1).

Formulas as well as extensive discussion about network measures can be found easily in the literature (see for example Degenne and Forsé, 1994). The constraint measure has been described by Burt (2000). Network constraint focuses primarily on the direct ties in ego's immediate circle of contacts. It measures the concentration of relations in a single contact and varies with three dimensions of a network: size or degree, density, and hierarchy [1].

This research is both quantitative and qualitative. We assess (graphical tools) and statistically control for theories in social and complex network analysis but we rely also on field research that has allowed us first hand observation into the specific resources that promote business success in the particular industrial sector examined.

# RESULTS

## Statistical Mechanics of a Fast Paced Biotech Ecosystem

We have first performed basic statistics with the calculation of main properties that describe the SF or the SW model. The first observation is the occurrence in our sample of alliances in a major biotech sector, as for many real-world networks analyzed, of joint SW and SF properties. Table 1 summarizes the values for SW metrics for the whole period. Values expected for random networks of similar number of nodes and links are added in row 2.

*Table 1* – Small-World Features of the Biotechnology Network (period 2000-2003)

| | Clustering coefficient | Shortest Path |
|---|---|---|
| Biotechnology network | *0.27** | *3.5* |
| Theoretical random graph | 0.004 | 6.1 |

**the clustering coefficient of a regular lattice tends towards 0.75*

The biotech sector is highly clustered, like regular lattices and unlike random networks, yet has small average path length, like random graphs. Our sample therefore forms a 'small-world' network. Moreover, average path length value is even smaller than in a random network with constant linking probability, in agreement with modelling studies which consider that for fast innovation diffusion, path lengths should be shorter than those in a random

1. The hierarchy index is the Coleman-Theil inequality index applied to contact-specific constraint scores. This index is the ratio of $\sum_j r_j \ln r_j$ divided by N ln(N), where $N$ is the number of contacts, $r_j$ is the ratio of contact $j$ constraint over average constraint, $c_{ij}/(C/N)$, and $c_{ij}$ is the level of constraint contact $j$ poses for ego (Burt, 1992, pp. 70-71). Hierarchy increases with network size; it is therefore lower for a node which borrows a small network rather than a large one.

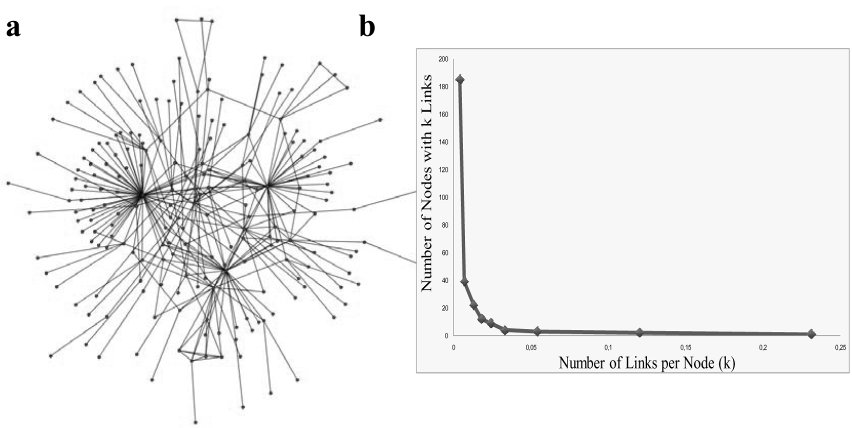
network (Cowan, Jonard, 2004). This value actually fits the theoretical path length value expected from a scale-free network of the same size dominated by a few, highly-connected, hubs (theoretical value = 3.78). Figure 1 shows that the biotech network organizes itself in a scale-free state, confirming that some firms dominate the connectivity and therefore the whole system.

These results do not occur by accident. The network is "wired" here around central firms with extremely short path lengths that introduce minimum distance between firms; network structure therefore influences the speed and extent of diffusion between central actors in the system and all other firms. If the biotech network is wired for fast communication, then the question arises not only of which firms dominate the network but also of how long central firms can actually control the network: in a technology-intensive sector, such as the one studied here, rapid diffusion through short path lengths indeed implies that firms can only build on their existing assets in decreasing proportion through time unless they make a radical innovation in one of their knowledge categories.

*Figure 1* – Illustration of the biotech sector scale-free network architecture for period 2000-2003

**a.** Scale-free main component of firms' business transactions. The network is characterized by hubs, or nodes/firms with a large number of connections to other elements.

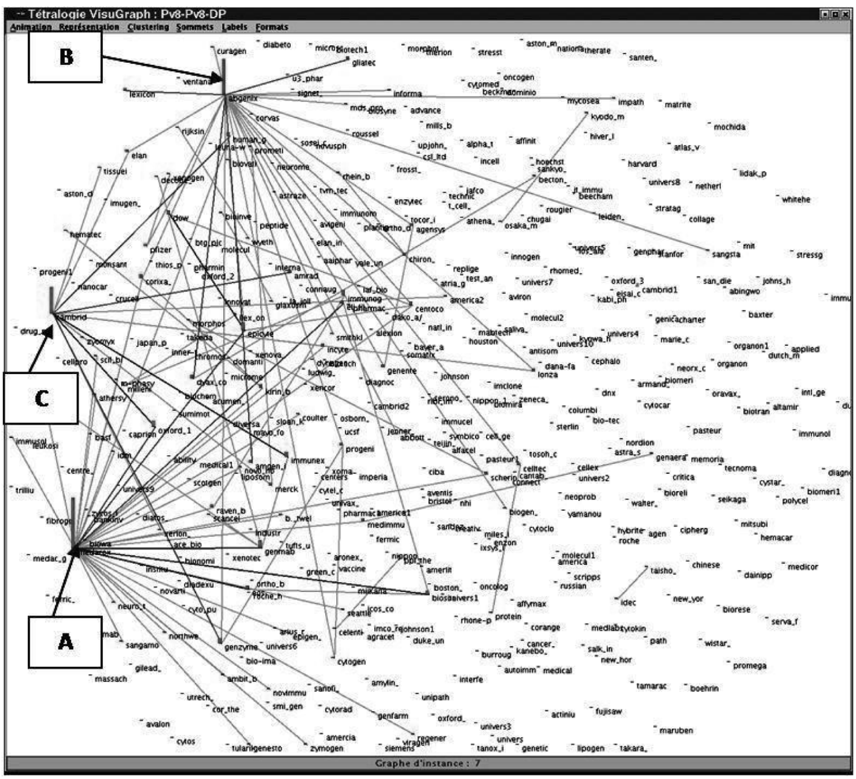
**b**. Degree distribution of firms' transactions. The tail of the distribution follows an approximate power law. The raw data have been binned.




Indeed, though the network displays SW and SF properties, its structure changes over time. Two network maps of our sample corresponding to two discrete periods describe firms' positions and their evolution (Figures 2 and 3). Three firms occupy key network positions over time. A detailed analysis of their transactions in our database showed that they have mostly (about 80% of their transactions) partnered out breakthrough technologies, or specific products derived from these technologies.

Therefore, as shown on the graph in Figure 2, though they connect to most other firms in the network and clearly dominate the structure, they are at the same time diffusing out innovative proprietary assets and will rapidly lose control unless they build on new assets. It is certainly interesting to note that, while these 3 hubs make more alliances than the 206 firms that form the macro network for the two periods examined, these alliance scores nevertheless decrease in the second period and competitors clearly emerge (Figure 3).

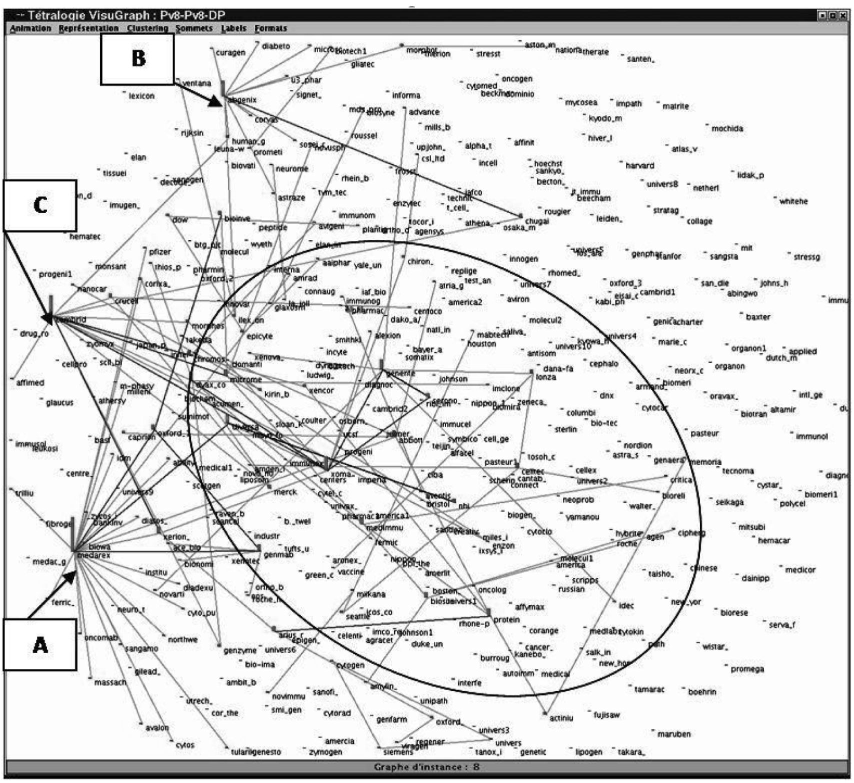
*Figure 2* – Alliances in the biotech sector for period 1




This industry segment is dominated by three "hubs", firms A, B, and C. To help visualization, nodes are replaced on the graph by bars, the size of which being proportional, for each node, to its alliance score or degree.

A closer examination of our database shows the diffusion by hubs of cutting-edge innovations needed to engineer fully human monoclonal antibody molecules and the shift of the industry in the second period towards competing technologies leading to the production of fragment antibodies and their derivatives. These snapshots of a major biotech sector illuminate the competitive advantage of hubs in a biotech network, but beyond this the competitive pressure exerted constantly by the whole dynamic system. The network forms at the same time a "hub and spoke" and a "small world" structure into which firms' situation changes constantly. The short distances between firms in these unstable systems permit at the same time domination but also the decline of hubs in line with the spread of innovation and technological shifts.

*Figure 3* – Alliances in the biotech sector for period 2




The graph shows that degree diminishes for firms A, B, and C compared to Figure 2. Concurrently, the graph shows the emergence of new competing firms (delimited by a ring on the graph). The position of nodes is kept constant in Figures 2 and 3 to help track changes in alliance activity.

It is thus crucial to look at how firms can actually leverage network positions for competitive advantage. We therefore turned to metrics derived from socio-economic studies to examine the three hubs and whether we could derive management prescriptions from this analysis.

## Examining Evolving Firm Position and Networking Capability in the Biotech Sector

How do these three hubs stack up in terms of power (centrality) and autonomy (lack of constraint) as time goes by? Can they control the ecosystem they are enmeshed in, if so for how long? How does sustained contractual activity between all firms in the macro-structure affect these firms' individual capital? We have used four network metrics based on a comprehensive review of network research in sociology. Tables 2 and 3 summarize the values for these metrics for the three hubs and two periods.

*Table 2* – Network Metrics of Top Three Firms for Period 1

| **Period 1** | **Centrality** | | | **Constraint** |
|---|---|---|---|---|
| **Firm** | *Dc (rank)* | *Bc (rank)* | *Cc (rank)* | |
| *A* | 0.3 (1) | 0.37 (1) | 0.36 (1) | 0.034 |
| *B* | 0.2 (2) | 0.26 (2) | 0.32 (2) | 0.051 |
| *C* | 0.15 (3) | 0.18 (3) | 0.3 (3) | 0.07 |

*Table 3* – Network Metrics of Top Three Firms for Period 2

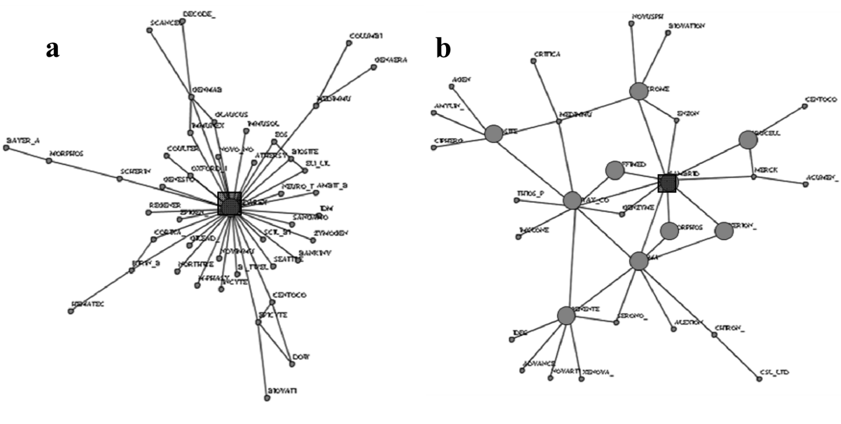
| **Period 2** | **Centrality** | | | **Constraint** |
|---|---|---|---|---|
| **Firm** | *Dc (rank)* | *Bc (rank)* | *Cc (rank)* | |
| *A* | 0.17 (1) | 0.2 (1) | 0.21 (5) | 0.051 |
| *B* | 0.07 (3) | 0.09 (5) | 0.15 (55) | 0.097 |
| *C* | 0.09 (2) | 0.17 (2) | 0.23 (1) | 0.141 |

As already observed in Figures 2 and 3, the three firms consistently dominate the network with high value for degree of linkage (*Dc*) or direct number of transactions. The network degree centrality mean value is about 0.015 for the two periods. The hubs have also the highest rank in the first period in terms of betweenness (*Bc*) and closeness centrality (*Cc*), which highlights their effective control of the biotech sector. The low value of the constraint index in the first period is also an indicator of their structural autonomy.

In the second period however, though still high, their degree centrality decreases about two-fold and their constraint index increases, reflecting a loss of control and autonomy. Moreover, measurement of the closeness centrality index reveals that firm B is disconnecting from the industry sector in the second period (its rank goes from 2 to 55). Also the constraint index for firm C in the $2^{nd}$ period is higher than expected since firm C has about the same value for degree of linkage as firm B but a higher constraint index with higher hierarchy (hierarchy is 0.065 for firm B and 0.113 for firm C). The density or local redundancy of its network also increases from 0.006 to 0.09 from one period to the other and has the highest value compared to other hubs at all times. Hierarchy and density indicate network closure in the neighbourhood of firm C.

Figure 4 displays the relevance of the network metrics used; if we compare network structure in the neighbourhood of firm A in period 1 (lowest constraint index as seen in Tables II and III) and firm C in period 2 (highest constraint index), we see easily that firm A controls its network while, for firm C, degree centrality is distributed at the periphery of the network. We have for firm C, notwithstanding good indicators of firm position within the whole system, a loss of structural autonomy.

*Figure 4* – Local network position and connection structure of firm A (a) and firm C (b).




Community structure is extracted using the Girvan and Newman algorithm. Firm A and C nodes are represented as squares, competitors of firm C as large dots.

Firm A network shows low density and many structural holes with disconnected clusters. A detailed analysis of its transactions within the non-overlapping cliques reveals the investment of firm A in different technological fields (e.g. plantibody and phage display) as well as the use of co-partnering with small innovative bio-techs in some of these fields. Conversely, most of firm C's contacts are interconnected and redundant by cohesion. Firm C is highly constrained because other central contacts, chiefly competitors, as revealed by the database, are involved in patent disputes with firm C and have relations with firm C other contacts. These many potential leaders get the same information as is available to firm C and this cannot be avoided in the negotiations firm C has with each other contact. Consequently, both firms B and C have 'defects' in their networks. In agreement with this analysis, firms B and C have since been acquired (end 2005 for firm B and in June 2006 for firm C).

This analysis has a practical implication for firms and the value of their networks. To maintain its autonomy in a technology-intensive network, a firm must ensure that it stays central while preventing constraint from binding its strategic action.

## IMPLICATIONS FOR STRATEGIC MANAGEMENT PRACTICE

Network approaches have appeared as new tools for use in industrial economics and strategic management (Bala et al., 2006; Hamdouch, 2008; White et al., 2005). As in these recent studies, we stress the importance for managers of closely tracking the dynamic topologies at macro level (sector and industry) as well as in firms' neighbourhood. We have shown that alliance dynamics respond to technological shifts. How firms are situated within different technological cycles that may overlap is therefore an important question. In particular, obsolescence of technologies occurs quickly and competing technologies are very often disruptive.

Multilevel network mapping provides the context for the analysis of the ability of firms to position themselves in unbalanced sectors of the economy and control their business environment. The mapping exercise imposes that three levels are considered simultaneously and dynamically: the focal firm, firm-centric networks of alliances, and the macro network the firm is enmeshed in.

The continuous use of visualization techniques and network metrics could help pro-active alliance management of firms under rapidly changing conditions as well as fast adjustment and counter moves to respond to the constraints imposed by thousands of other players in an industry. Moreover, the use of global and local network metrics permits tracking not only of competitors but also the qualitative evaluation of evolving positions of firm partners (old, current, or to-be) in all industrial sectors of interest. Are they well positioned, strategically, technically, sector- or industry-wise, etc? In a global environment where relying dynamically on alliances is a major strategic issue, the tracking of partners becomes an essential aspect of strategy.

## Evaluate the network through local and global key metrics

A recent paper (Bala et al., 2006) has provided evidence that network metrics (clustering coefficient, path length, degree centrality) could be strong predictors of firm growth in the software industry. Our study corroborates these findings in that they demonstrate that network positions do matter as well as the relevance of using key network metrics that describe firms' positions and network structures at firm- and macro-levels. These studies hence make a strong case for the strategic configuration of networks.

Centrality metrics (degree, betweenness, and closeness) are needed to assess the position of the firm locally and globally. The use of the constraint index as a key metric, compared to the measure of the clustering coefficient, gives managers the ability to distinguish between cohesive structures that may be redundant and networks with structural holes. A structural hole means that distinct information flows are present in the firm ego network, a major criterion especially in technology-intensive and highly competitive sectors. We have found that legal agreements within our database were essentially dyadic. In our analysis of hubs, redundant structures in a firm's neighbourhood tended to reveal relentless competition. However, separate clusters of firms were representative of partnering among a few firms while the hub nonetheless also had many unconnected partners, thus increasing the number of structural holes in its neighbourhood. An example has been given in Figure 4.

## Strategy and Network Dynamics

In line with other works (Ahuja, 2000; Powell et al. 2005), our study confirms the crucial role of degree centrality in shaping network structure and firm position in the network. Impressively, firm degree centrality can have important consequences in engineering the wider network. Analysis such as summarized in Table I indicates that the biotech network is then even more efficient in moving innovations, products, and other resources through the system than in a "small-world" because it in fact forms a small-world with skewed distribution. These empirical results fit recent theoretical models that demonstrate that innovation alliance networks can have combined small-world and scale-free features (Cowan and Jonard, 2008). In our study, diffusion occurs rapidly along very short paths and is brokered by hubs with key core competencies that dominate the network while the diffusion occurs.

The system dynamics and its very short paths present benefits as well as disadvantages. While short paths allow control of the system by hubs, they also allow rapid take-over by firms with breakthrough innovations (as can be intuited from Figure 3, the alliance network in this biotech sector has changed since and is continuously evolving; data not shown).

Gulati (1998) proposed that ego networks create inimitable and non-substitutable value, difficult for competitors to imitate and substitute. We have actually seen that a great majority of nodes had few connections and that hubs ego networks were undeniably idiosyncratic, in terms of partners and structure, but also dynamically formed. The structural pattern of a firm's alliances may in fact have potential or drawbacks, as demonstrated here through the analysis of different firms evolving ego networks.

Firms are consequently not endowed with a fixed set of core assets with everlasting value, nor therefore with a fixed set of relationships. Firms should hence develop, sell, and/or acquire different resources depending on their existing resource stocks and their life cycle position (Gulati, Gargiulo, 1999; Colwell, 2003). As in contemporary theory (resource-based view), they are different in what they possess and do (Barney, 1991; Grant, 1996) but, as others suggest (Kogut, 2000; Schumpeter, 1912) and as demonstrated in our empirical study, the dynamics of knowledge diffusion and imitation will reduce variety among firms unless new innovation is created. Central firms thus have some degree of control over their market environment which, unless they seek new innovations, is eroded as specialized innovation is absorbed by others and new market innovation is brought in, mostly by new entrants inside or outside the industry (Levinthal et al., 1993).

The double-sided relations between technical progress and economic growth have already been underlined. As some put it, there cannot be growth without technical progress (Metcalfe, 2002; Usher, 1980). Metcalfe used the concept of "restless capitalism" as opposed to capitalism in equilibrium because, as he wrote, "the growth of knowledge cannot be formulated meaningfully as a constellation of equilibrating forces" because knowledge maintains "a potential for change that is ever present'. Therefore, in a dynamic ecosystem with continuous building of new linkages, the aptitude of firms to position themselves in unbalanced sectors of the economy where actors deal with fast change, and to capture new innovation, can only be envisaged if the firm is perceived as an open system which takes into account the renewal and dynamics of innovation (Bouvier-Patron, 2001) and as a result, the instability of industry structure.

## CONCLUSION AND LIMITATIONS OF THE STUDY

Lately, network research has underlined the need for multi-level theorizing and empirical analysis of network strategy, as well as the need to consider network dynamics. Multiple level linkages, at firm-, cluster-, and macro-network, are unstable as well as recursive in the sense that changes at one level necessarily induce changes at the others. Network results have thus strong strategic implications. Managers must consider firm embeddedness, and therefore capital, in complex, ever-changing, alliance networks. Structured alliance management ought to be very dynamic, as sustained firm performance is the ultimate goal. We have shown that centrality and constraint metrics measure network and therefore strategic "equilibrium": in the fight between constraint and power, but which is the winner, and for how long? In our study, to survive, dominant business configurations are built upon central positioning with little constraint. These configurations hinge on innovation.

To our knowledge, no other study has attempted to look specifically at hubs, the structure of their alliance networks, the macrostructure or biotech sector firms are embedded in, and the interdependency and co-evolution of these multiple levels. However, our study has limitations. We have examined a single sector of the pharmaceutical industry for a limited albeit recent period. We need now to study this sector from 2005 to 2008 to acquire more knowledge of its life cycle and how its network properties and different hubs will evolve. In particular, as suggested by Cowan and Jonard (2008), the balance between hub-like and small-world, more cohesive, structures may differ depending on the maturity of the industry. Understanding the relations between industry life cycle and multilevel network structures is essential. In addition, geographical clustering may affect innovation flows. Firms that have worldwide connections will also be more difficult to constrain. Finally, we need to use data on more major high tech sectors within the pharmaceutical industry as well as in other industries to evaluate whether our findings can be generalized. Each of these limitations represents an exciting area for future research.

## REFERENCES

AHUJA, G. (2000), "Collaboration Networks, Structural Holes, and Innovation: A. Longitudinal Study", *Administrative Science Quarterly*, n° 45, pp. 425-455.

AHUJA, G., KATILA, R. (2001), "Technological acquisitions and the innovation performance of acquiring firms: A longitudinal study", *Strategic Management Journal*, n° 22, pp. 197-220.

ALBERT, R., BARABASI, A.-L. (2002), "Statistical Mechanics of Complex Networks", *Reviews of Modern. Physics*, n° 74, pp. 47-97.

BAE, J., GARGIULO, M. (2003), "Local action and efficient alliance strategies in the telecommunications Industry", *Working Paper*, INSEAD, France.

BALA, I., LEE, C.-H., VENKATRAMAN, N. (2006), "Managing small world ecosystems: Some lessons from the software sector", *California Management Review*, 48 (3), pp. 28-47.

BARNEY, J. (1991), "Firm resources and sustained competitive advantages", *Journal of management*, n° 17, pp. 99-120.

Baum, J. A. C., SHIPILOV, A. V., ROWLEY, T. J. (2003), "Where do small worlds come from?", *Industrial and Corporate Change*, n° 12, pp. 697-725.

BAUM, J. A. C. and ROWLEY, T. J. (2008), "Evolving webs in network economies", Baum, Joel A.C. and Tim J. Rowley (eds.), *Advances in Strategic Management* (JAI/Emerald)

BAVELAS, A. (1950), "Communication patterns in task oriented groups," *Journal of the Acoustical Society of America*, n° 22, pp. 271-282.

BOLLOBAS, M. (2001), *Random Graphs*, 2nd Edition, Cambridge University Press, Cambridge.

BORGATTI, S. P. (1995), "Centrality and AIDS", *Connections*, 18 (1), pp. 112-114.

BOUVIER-PATRON, P. (2001), "Analysis of change within and between firms embedded in their environment in the context of increasing interactions: understanding complexity of organizations", *European Journal of Economic and Social Systems*, 15 (1), pp. 1-38.

BURT, R. S. (1997), *Structural holes: The social structure of competition*, Harvard University Press.Davis and Greeve, Cambridge, MA.

BURT, R. S. (2000), *The Network Structure of Social Capital.* R.I. Sutton and B.M. Staw (eds.), Research in Organizational Behavior, JAI Press, Greenwich, CT.

CARTWRIGHT, H. (2005), "Deal making in the biotech sector", white paper, *BioPartnering Today*.

COLWELL, K. A. (2003), "The structure of alliance networks in nascent organizational fields: The case of nanotechnology", *Doctoral dissertation*, University of Oregon, Eugene.

CORIAT, B., DOSI, G. (1998), "Learning how to govern and learning how to solve problems: On the co-evolution of competences, conflicts and organizational routines", in *The Dynamic Firm: The Role of Technology, Strategy, Organization and Regions*, Alfred D. Chandler, J. R. (ed.), Peter Hagström and Orjan Sölvell.

COWAN, R., JONARD, N. (2004), "Network structure and the diffusion of knowledge", *Journal of Economic Dynamics and Control*, 28 (8), pp. 1557-1575.

COWAN, R. and JONARD, N. (2008), "If the alliance fits ...: Innovation and network dynamics" forthcoming in J. A. C. Baum and T.J. Rowley (eds), *Network Strategy: Advances in Strategic Management*, 25, JAI/Elsevier, Oxford UK.

DEGENNE, A., FORSÉ, M. (1994), *Les Réseaux sociaux*, Armand Colin, Paris.

DEEDS, D. L., HILL, C. W. (1996), "Strategic alliances and the rate of new product development: an empirical study of entrepreneurial biotechnology firms", *Journal of Business Venturing*, 11 (1), pp. 41-55.

DOROGOVTSEV, S. N., MENDES, J. F. F. (2003), *Evolution of Networks: From Biological Nets to the Internet and WWW*, Oxford University Press, Oxford UK.

FREEMAN, L. C. (1979), "Centrality in networks: I. Conceptual Clarification," *Social Networks*, n° 1, pp. 215-239.

GIRVAN, M., NEWMAN, M. E. J. (2002), "Community structure in social and biological networks", *Proc. Nat. Acad. Sci.*, n° 99, pp. 7821-7826.

GOMES-CASSERES, B., HAGEDOORN, J., JAFFE, A. (2006), "Do alliances promote. Knowledge flows?", *Journal of Financial Economics*, n° 80, pp. 5-33.

GRANT, R. M. (1996), "Towards a knowledge-based theory of the firm," *Strategic Management Journal*, n° 17, pp. 109-122.

GULATI, R. (1998), "Alliances and networks", *Strategic Management Journal*, 19, pp. 293-317.

GULATI, R., GARGIULO, M. (1999), "Where do inter-organizational networks come from?", *American Journal of Sociology*, n° 104, pp. 473-506.

HAMDOUCH, A. (2008), "Conceptualizing innovation clusters and networks", *Forum The Spirit of Innovation III: Innovation Networks*, Tacoma-Seattle, 14-16 May 2008, 27 p.

JACKSON, M. O., WOLINSKY, A. (1996), "A strategic model of social and economic networks", *Journal of Economic Theory*, 71 (1), pp. 44 -74.

KALMBACH, C. J. R., ROUSSEL, R. (1999), "Dispelling the myths of alliances", *Accenture Outlook Special Edition.*

KOGUT, B. (2000), "The Network as Knowledge: Generative Rules and the Emergence of Structure", *Strategic Management Journal*, n° 21, pp. 405-425.

KOPUT, K., POWELL, W. W. (2003), "Organizational growth and alliance capability: science and strategy in a knowledge-intensive industry", *Working paper*, College of Business and Public Administration. University of Arizona.

LEVINTHAL, D., MARCH, A., JAMES, G. (1993), "The Myopia of Learning", *Strategic Management Journal*, n° 14, pp. 95-112.

METCALFE, J. S. (2002), "Knowledge of growth and the growth of knowledge," *Journal of Evolutionary Economics*, n° 12, pp. 3-15.

MOWERY, D. C., OXLEY, J. E., SILVERMAN, B. S. (1996), "Strategic alliances and inter-firm knowledge transfer", *Strategic Management Journal*, n° 17, pp. 77-91.

MOWERY, D. C., OXLEY, J. E., SILVERMAN, B. S. (1998), "Technological overlap and inter-firm cooperation: Implications for the resource-based view of the firm", *Research Policy*, n° 27, pp. 507-523.

NOOTEBOOM, B. (2000), *Learning and Innovation in Organizations and Economics*, Oxford University Press.

OWEN-SMITH, J., POWELL, W. W. (2004), "Knowledge networks as channels and conduits: The effects of. spill-overs in the boston biotechnology community", *Organization Science*, 15 (1), pp. 5-21.

POWELL, W. W. (1996), "Inter-organizational collaboration in the biotechnology industry", *Journal of Institutional theoretical Economics*, n° 152, pp. 197-215.

POWELL, W. W. (1998), "Learning from collaboration: Knowledge and networks in the biotechnology and pharmaceutical industries", *California Management Review*, n° 40, pp. 228-240.

POWELL, W. W., WHITE, D. R., KOPUT, K. W., OWEN-SMITH. J. (2005), "Network dynamics and field evolution: The growth of inter-organizational collaboration in the life sciences", *American Journal of Sociology*, n° 110, pp. 1132-1205.

SABIDUSSI, G. (1966), "The centrality index of a graph", *Psychometrika*, 31 (4), pp. 581-603.

SCHILLING, M., PHELPS, C. (2007), "Interfirm collaboration networks and knowledge creation: The impact of large scale network structure on firm innovation", *Management Science*, n° 53, pp. 1113-1126.

SCHOENMAKERS, W., DUYSTERS, G. (2006), "Learning in strategic technology alliances", *Technology analysis and strategic management*, n° 18, pp. 245-264.

SCHUMPETER, J. A. (1912/1934), *Theorie der wirtschaftlichen Entwicklung*, Duncker and Humblot, Leipzig. English translation published in 1934 as *The Theory of Economic Development*, Harvard University Press, Cambridge, MA.

STUART, T. E. (1998), "Producer network positions and propensities to collaborate: An investigation of strategic alliance formations in a high-technology industry", *Administrative Science Quarterly*, 43 (3), pp. 668-698.

STUART, T. E. (2000), "Inter-organizational alliances and the performance of firms: A study of growth and innovation rates in a high-technology industry", *Strategic Management Journal* n° 21, pp. 791-811.

TEECE, D. J. (1992), "Competition, cooperation, and innovation: Organizational arrangements for regimes of rapid technological progress", *Journal of Economic Behavior and Organization*, Elsevier, 18 (1), pp. 1-25.

USHER, D. (1980), *The Measurement of Economic Growth*, Blackwell, Oxford.

UZZI, B. (1996), "The Sources and Consequences of Embeddedness for the Economic Performance of Organizations", *American Sociological Review,* n° 61, pp. 674-698.

WALKER, G., KOGUT, B., SHAN W. (1997) "Social Capital, Structural Holes and the Formation of an Industry Network", *Organization Science*, n° 8, pp. 108-125.

WASSERMAN, S., FAUST, K. (1994), *Social Network Analysis*, Cambridge University Press, Cambridge.

WATTS, D. J., STROGATZ, S. H. (1998), "Collective dynamics of 'small-world' networks", *Nature*, n° 393, pp. 440-442.

WHITE, D. R., OWEN-SMITH, J., MOODY, J., POWELL, W. W. (2005), "Networks, fields and organizations: Micro-dynamics, scale and cohesive embeddings", *Computational and Mathematical Organization Theory*, n° 10, pp. 95-117.