STRATEGIC TECHNOLOGY ALLIANCES AND NETWORKS

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Abstract: This paper briefly reviews the literature on strategic technology alliances (STAs) and networks, allocating the contributions to "micro" (firm) and "meso" perspectives (the network). The focus is on a logical reconstruction of important themes in the literature pertaining to the role of STAs in boosting innovation and in promoting the survival and growth of partners and their environments. Overall the literature points to a quite important role of alliances and networks especially in knowledge intensive industrial activities combining the production and utilization of technological knowledge for competitiveness and growth. Not unexpectedly, important differences are pointed out in terms of incentives and benefits from alliances across different types of firms and industries. Network structure evolves in accordance to the nature of the industry and to the type of technological advancement sought by participating organizations.

Note: This paper draws extensively on work undertaken by the two authors in the context of the research project "Advancing Knowledge-Intensive Entrepreneurship and Innovation for Economic Growth and Social Wellbeing in Europe" (AEGIS), 7th Framework Programme for Research and Technological Development, European Commission, DG Research and Innovation.

1 INTRODUCTION

In 2013 Accenture and General Electric initiated a strategic alliance to develop "technology and analytics applications that help companies across a range of industries take advantage of the massive amounts of industrial strength big data generated through their business operations".[1] The two companies were expanding their existing collaboration in Taleris (Accenture and GE Aviation) which provides airlines and cargo carriers intelligent operations services to predict, prevent and recover from operational disruptions. This agreement aligns the complementary capabilities of a service company and conglomerate with arms in both services and manufacturing to exploit a potentially lucrative application of big data.

Nowadays alliances are hardly the realm of enterprises in developed countries alone. Indus Towers was established in November 2007 as a joint venture between India's Bharti Airtel, Vodafone Essar, and Idea Cellular, with the goal of reducing infrastructure costs for each company. Bhati Airtel and Vodafone Esser, the two largest private telecom-services providers in the country, realized they could cooperate on tower development while remaining competitive in their core businesses of providing telecom services. Together, they decided to jointly establish an independent firm to construct and manage towers throughout the two firms' common operating regions. Idea Cellular, the third largest telecom operator, was also offered a smaller share in the new firm. With a portfolio of over 110,000 towers, Indus Towers quickly became the largest telecom tower company in the world.[2] Over the past two-three decades, Brazil's Petrobrás has evolved successfully into a global leader in deep sea drilling techniques by using strategic alliances to help it absorb external knowledge to generate unique solutions as well as develop its own formidable internal research capabilities.[3]

The aforementioned examples are just three of a large number of strategic technology alliances being formed every day. Strategic technology alliances play indeed a prominent role

[1] *Accenture Newsroom: Accenture and GE Form Global Strategic Alliance to Develop Advanced Applications that Leverage Industrial Strength Big Data to Drive Efficiency and Productivity*. (2013, June 18). Website: http://newsroom.accenture.com/news/accenture-and-ge-form-global-strategic-alliance-to-develop-advanced-applications-that-leverage-industrial-strength-big-data-to-drive-efficiency-and-productivity.htm Accessed April 25, 2014.

[2] Gulati, et al. (2010)

[3] Furtado and Gomes de Freitas (2000)

in contemporary business environments. Innovation is increasingly complex, building on several technological fields. This includes technology producers, namely high tech manufacturing sectors such as pharmaceuticals, especially following the introduction of molecular biology in the mid-1970s, and microelectronics, where innovation hinges on competencies in fields as different as solid physics, construction of semiconductor manufacturing and testing equipment, and programming logic. It also includes technology users, namely knowledge intensive services such as finance and management consulting; and it includes more traditional technology user sectors such as construction and agriculture. Firms cannot master all the relevant information and knowledge required to innovate and, therefore, they look for partners with complementary capabilities to assist in an increased rate of introduction of new products and processes, to monitor new opportunities and enter new markets, and to sustain long-lasting competitive advantage.

At the same time, in the scholarly realm, a vast literature on networks has emerged on several related fields such as economics, management, sociology and organization theory. In particular, an important area of research has focused on networks arising from strategic technological alliances (Ozman, 2009; Malerba and Vonortas, 2009). Nowadays, the idea that innovation must be understood looking also at the webs of the various relationships occurring among firms is widely, if not unanimously, accepted (Powell and Grodal, 2004).

This paper reviews (selectively) the existing empirical literature on this theme, trying to locate important contributions within a single conceptual model. The model links in a co-evolutionary perspective the "micro" dimension of organizations (in particular firms) and the "meso" dimension of networks as a step towards the impact of strategic technology alliances on growth and development (i.e. the "macro" dimension).

The rest of the paper is structured as follows. In Section 2, a definition of strategic technology alliances is put forward together with some basic evidence. In Section 3, we advance our conceptual framework which relies on a bidirectional causal link between strategic alliances and networks. In Section 4, we take the point of view of organizations and ask two questions: i) what are the characteristics of networking activity of different types of organizations? ii) how networking activity impacts on their innovative and economic performance? In Section 5, we take the point of view of networks and ask what is the role of different organizations in affecting the growth and dynamics of networks and how it influences the rate and direction of technological progress in industries. Based on this review Section 6 suggests possible directions for future empirical research. Finally, Section 7 concludes.

2. DEFINITION, SOURCES OF DATA, STYLIZED FACTS

2.1 Definition

The term strategic alliance was introduced in the 1980s to describe the multitude of forms of agreements between firms, universities and other research organisations that analysts had already begun to observe. Strategic alliances essentially refer to agreements whereby two or more partners share the commitment to reach a common goal by pooling their resources together and co-ordinating their activities (Teece, 1992; Hagedoorn, 2002).

Alliances denote some degree of strategic and operational co-ordination and may involve equity investments. Alliances can occur vertically across the value chain, from the provision of raw materials and other factors of production, through research, design, production and assembly of parts, components and systems, to product/service distribution and servicing. They can also occur horizontally between partners at the same level of the value chain. An alliance can have both horizontal and vertical elements. Alliances can involve cooperation among firms and other organizations, notably universities (Mowery and Sampat, 2005). Partners may be based in one country. They may also be dispersed in several countries, thus establishing an international alliance.

A subset of alliances can be characterised as innovation-based, focusing primarily on the generation, exchange, adaptation and exploitation of technical advances. These are called herein ***strategic technology alliances (STAs)*****.** This paper focuses on formal STAs. We do not consider forms of informal cooperation, occurring, for instance, through information exchange among engineers or scientists (Von Hippel, 1987).

Our definition is broad, encompassing several ways in which collaboration can occur: various legal arrangements, different degrees of resources commitment, different levels and directions of technological flows, different coordination mechanisms, and different time horizons may characterize strategic technological alliances. Examples include:

- research and development (R&D) joint ventures, where two or more organizations constitute a new legal entity in order to perform R&D activities. For instance, Total and Amyris announced in 2011 the formation of a joint venture to develop, produce and commercialize a range of renewable fuels and products;

- joint R&D agreements, where organizations share resources to undertake joint R&D projects. For instance, BASF and Monsanto Company announced in 2007 a long-term R&D and commercialization collaboration in plant biotechnology that focused on the development of high yielding crops and crops that are more tolerant to adverse environmental conditions;

- licensing and cross-licensing agreements. For instance, in 2014 Google and Samsung signed a global patent cross-license agreement covering a broad range of technologies and business areas. The agreement covers existing patents and those filed over the next ten years;[4]
- research contracts, where one partner undertakes research for another organization. For instance, Bend Research, a biotech company specialized in developing ways that make it possible for drugs to enter the body and go to the places they are meant to treat, had exclusive research contracts with Pfizer from 1994 to 2008.

2.2 Data Sources

The reliability of alliances data has been a frequent concern in the literature (Shilling, 2009). In broad terms, datasets used in the empirical analyses on strategic technology alliances can be grouped into three classes. *Literature-based datasets* are built by consulting specialized journals, financial newspapers and other general sources of information of public announcements of collaborative agreements. Two notable examples in this category are the Cooperative Agreements and Technology Indicators (CATI) dataset, collected by John Hagedoorn and colleagues at the Maastricht Economic Research Institute on Innovation and Technology (MERIT), and the Securities Data Company (SDC) Platinum Joint Ventures and Strategic Alliances dataset collected by Thompson Reuters. Both datasets collect data for several sectors worldwide. CATI has a focus on R&D-related agreements and excludes from the analysis publicly funded agreements, while SDC covers both R&D and non-R&D related alliances involving different types of organizations, such as firms, universities, and research centers. Industry specific datasets have been assembled as well. For biotech, the Recombinant Capital (RECAP) database collects data coming from sources such as press releases, Securities and Exchange Commission (SEC) filings and company presentations describing alliances between organizations of any type; while the Bioscan database tracks over time the activities of a specific set of firms designated as biotechnology-related. For Information and Communication Technology (ICT) sectors the Advanced Research Project on Agreement (ARPA) database has been developed at Politecnico di Milano (Colombo and Garrone, 1996).

A second type of dataset is produced by *surveys*. In this case, data are collected through questionnaires in which firms report the extent of their collaborative activities, the motives behind them, and the types of collaborators (i.e. competitors, customers, suppliers or

[4] See http://global.samsungtomorrow.com/?p=33461. Accessed June 24, 2014.

universities). Veugelers and Cassiman, (2002) and Tether (2002), for instance, used data from the Community Innovation Surveys (CIS), collected by the member states of the European Union, for the analysis of innovative inputs and outputs by European firms. Recently, Kim and Vonortas (2014) used data from the European AEGIS Survey to understand the factors underlying the willingness of small knowledge-intensive firms to participate in collaborative agreements.[5]

A third class of data refers to *government-sponsored cooperative agreements* or originates from antitrust laws. Data on projects promoted by the European Union (in particular within the context of European Framework Programs) has been collected for some time and analyzed (see for instance Breschi and Cusmano, 2004). For the US, data have been collected by the Cooperative Research (CORE) and the National Cooperative Research Act - Research Joint Ventures (NCRA-RJV) databases using information from the Federal Register at the US Department of Justice (Link et al., 2005; Vonortas, 1997). Under the National Cooperative Research Act, voluntary filings of R&D partnerships give firms benefits in case of anti-trust interventions. Finally, for Japan, Branstetter and Sakakibara (2002) have analyzed R&D consortia with a degree of government subsidization and intervention.

While the consistency in coverage of STAs across databases is limited, Schilling (2009) shows that different sources (in particular MERIT-CATI, SDC, CORE, RECAP and Bioscan) exhibit similar (although definitely not identical) trends in terms of sectoral composition and activity over time. High tech industries such as information technologies and biotechnology constitute the bulk of STAs activities, especially in the most recent decades. STAs became prominent around the second half of the 80s.[6]

2.3 Motivations behind strategic alliances

The theoretical and empirical literature has, over the years, tried to identify the most prevalent motives for the establishment of strategic alliances (Link and Zmud, 1984, Hagedoorn, 1993; Hagedoorn et al., 2000; Caloghirou et al., 2003; Colombo et al., 2006; Kim and Vonortas,

[5]The survey was carried out during 2010-2011 in the context of the launched in an attempt to identify motives, characteristics and patterns in the creation and growth of young firms which are based on the intensive use of knowledge and operate in both knowledge-intensive and low tech sectors. It was carried out during Fall 2010 and Spring 2011 (Research project "Advancing Knowledge-Intensive Entrepreneurship and Innovation for Economic Growth and Social Wellbeing in Europe" (AEGIS), 7th Framework Programme for Research and Technological Development, European Commission).

[6] Similarly, Link and Scott (2005) show an increase in university-industry relationship for the US since the 1980s.

2014). While differences among sectors exist (Zirulia, 2009), the main motives are the following:

1. Access product and financial markets, and attain legal political advantages in host countries in case of international agreements;
2. Share costs and risk of large investments such as R&D;
3. Access complementary resources and skills of partners, such as finance, complementary technologies, and benefit from research synergies;
4. Accelerate return on investments through more rapid diffusion of assets;
5. Deploy resources efficiently to create economies of scale, specialisation and/or rationalisation;
6. Increase strategic flexibility through the creation and optimal exploitation of new investment options;
7. Co-opt competition and gain market power;
8. Increase revenues for public research organizations, and universities in particular.

3 TOWARDS A CONCEPTUAL MODEL OF ALLIANCES AND NETWORKS

The conceptual model we develop in this section, which will drive our literature review, places the network at its core. During the last couple of decades, the economics and management literatures have gradually modified the notion of networks from "informal" to "formal". In early studies the term "network" was used to indicate a more or less informal governance mechanism of transactions between firms and within hierarchies (Williamson, 1991). As the number of alliances ballooned in the late 1980s and 1990s the emphasis turned onto issues of opportunism and trust in economic relations as impacted by the set of relationships of an organization (Gulati; 1998; Nooteboom, 2001). Nowadays, thanks to strong influence of an emerging literature across social sciences (Newman, 2010; Malerba and Vonortas, 2009), networks are seen as set of formal relations to be formally represented and analysed by graph theory and social network analysis.

A *network*, then, is a graph in the proper meaning of graph theory – a set of *nodes* and a set of *relations*, or links, connecting pairs of nodes (Bollobas, 1998). STA network nodes are mostly firms, and less frequently other types of organizations such as universities or research centres. Each node is characterized by certain attributes such as size, profitability, age, innovativeness, and technological specialization. The typical attributes of pairs of nodes are measures of similarity or dissimilarity in such dimensions. We will often distinguish among three types of nodes: i) large, incumbent firms; ii) new, typically small firms; and iii) public research organizations. The distinction matters because the three types of nodes usually play different roles in networks. By analogy, we can also talk of attributes of networks. In the case of STA networks, attributes can refer to structure and performance, including the rate and direction of technological progress.

STA networks are not static objects. Rather, they have *emergent properties* which evolve over time following the incentives of organizations to form and sever links (Jackson, 2010). Incentives vary over time depending on the current structure of networks in relation to their objectives and because nodes' attributes change over time. In other words, nodes (in particular their attributes) and networks (their structure and performance) co-evolve (Gilsing, 2005; Ahuja et al., 2012).

We will refer to nodes and their attributes as the *micro* level of analysis, while the network and its structure constitutes the *meso* level. The impact of strategic alliances on growth and development (the *macro* dimension) is likely to be mediated by the networks. Networks, as constituent elements of sectoral systems of innovation (Malerba, 2002), should be part of the explanation of economic growth, economic development and catching-up (Nelson and Malerba, 2012).

The theoretical perspective sketched out in the previous paragraphs has an empirical counterpart which is the study of:

i) (The *micro* level) Antecedents and consequences of the networking behaviour of nodes. More concretely, what are the main motives for different types of nodes to enter strategic technology alliances? What attributes (at the node and dyad level) affect the number and type of relations in which nodes are involved? In turn, what attributes (at the node and dyad level) are affected by the relations?

ii) (The *meso* level) The role of nodes in network structure, evolution, and performance. More concretely, what is the role played by different types of nodes (such as incumbents, start-ups, public research organizations) in the network? How do they affect network performance such as the rate of technological progress, the division of innovative labour and the direction of technical change?

A graphical representation of previous considerations is provided in Figure 1 below:

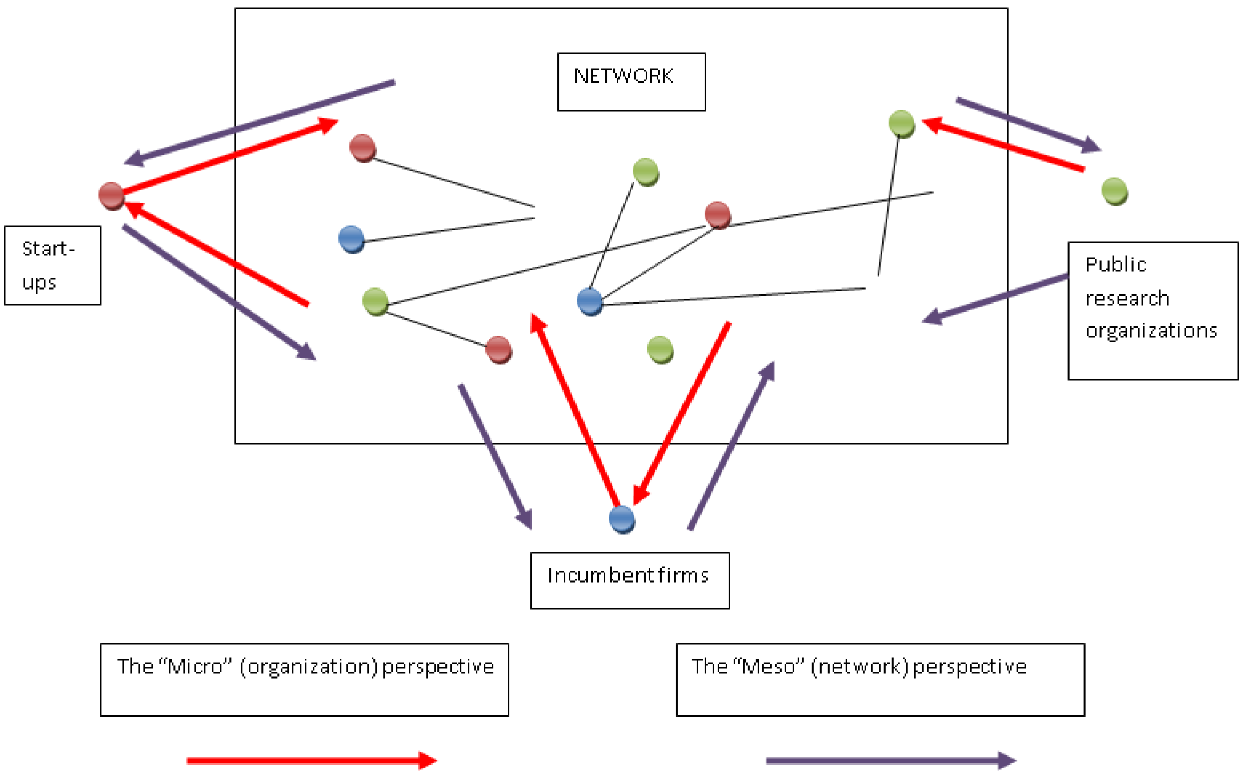

Figure 1: A conceptual framework for strategic technological alliances and networks

In the following two sections we take in turn the micro perspective by investigating the nature of networking activity of different types of nodes (Section 4) and the meso perspective pointing at the role of different types of nodes in affecting network structure and evolution and the rate and direction of technological progress (Section 5).

4. STRATEGIC ALLIANCES AND NETWORKS: THE "MICRO" PERSPECTIVE

4.1 The antecedents of networking activity

A descriptive account of network activity rests on the *motives* for firms and other organizations to enter strategic technology alliances and on their characteristics which make more likely the participation to such partnerships. The factors that affect the likelihood that firms participate in networks can be firm-specific, dyad-specific, or industry-specific.

Considering firm-specific factors first, the literature has determined three variables positively affecting the participation to alliance networks: i) size; ii) R&D orientation and innovativeness; iii) previous experience in collaboration.

A positive relation between size and propensity to form strategic alliances, or between size and the number of alliances, is probably one of the most recurrent results in the literature, robust across time, sectors and countries. It is found in Link and Bauer (1987), Kleinknecht and Reijen (1992), Hagedoorn and Schakenraad (1994), Colombo (1995), Colombo and Garrone (1996), Siebert (1996), Vonortas (1997), Ahuja (2000), Fritch and Lukas (2001), Bayona et al. (2001), Tether (2002), Veugelers and Cassiman (2002), Hernan et al. (2003), Becker and Dietz (2004). The positive effect of firm size shows also for university-industry relations (Stuart et al. 2007; Fontana et al., 2006). There are several possible explanations for this result. Large firms usually engage in a wide range of economic activities, increasing the opportunities for fruitful cooperation. They can spread the gain from innovation over a larger base of economic activity, increasing their incentives towards cooperative agreements, as a form of R&D investment (Cohen and Klepper, 1996). Some forms of cooperative agreements (for instance R&D joint ventures) entail high physical and legal set-up costs for which small firms lack financial resources. Finally, large firms can have significant bargaining power in contracting with their partners.

It is interesting to notice that, when the analysis focuses on new firms only, the results of the effect of size are somewhat different and mixed. Shan (1990), for instance, find a negative relationship between size and network participation in biotech; Shan et al. (1994) do not find a significant relationship; Colombo et al. (2006) find an inverted U shape for a sample of Italian new technology-based firms. Some authors (Colombo et al, 2006) have tried to explain this result as the net effect of two forces: a positive effect of size, related to the "spreading" of managerial and transaction cost; and a negative effect of size, as long as size is correlated with the control of significant commercial assets that make alliances less needed.

The positive relation between R&D intensity and technological capabilities, on the one side, and network participation, on the other, is a common result as well (Tether, 2002; Fritch and Lukas, 2001; Bayona et al; 2001; Link and Bauer, 1987; Sakakibara, 2002; Stuart, 1998). Exploratory internal R&D also increases the probability that firms collaborate with universities (Bercovitz and Feldman, 2007). This suggests that internal and cooperative R&D should be seen as complementary rather that substitute which, in turn, points at the role of absorptive capacity (Cohen and Levinthal, 1989): in order to evaluate and fully absorb the outcomes of strategic alliances firms need to have pre-existing capabilities in the corresponding scientific or technological fields (Zhao and Anand, 2009). Conversely, firms lacking technological capabilities are not in the position to reap the benefits from cooperation (Rothaermel and Hess, 2007). Stuart (1998) confirms this view by showing that firms in more crowded technology areas are more likely to form agreements, claiming that such firms have many potential partners as well as the relevant absorptive capacity. For start-ups, another explanation may hold. In many cases their attractiveness as partners is related to specific technological competences and knowledge to which large incumbents want to have access. Frequently this knowledge is embodied and signalled by patents: holding valuable patents allows start-up firms to be active in networks and to attract prominent incumbents (Rothaermel, 2002; Stuart et al. 1999). In the case of new firms, patents play the fundamental role of reducing informal asymmetries and adverse selection.

Finally, the finding that firms with more experience in managing collaborative ties are more likely to enter further collaborative agreements is also quite robust (Gulati, 1995; Powell et al., 1996; Ahuja, 2000; Sakakibara. 2002; Hernan et al., 2003; Sampson, 2005; Vonortas and Okamura, 2009). Three main explanations have been proposed. The first relates to the notion of "cooperative capability" (Gulati, 1998). With experience, firms learn how to manage their collaborative ties, to develop interfirm knowledge sharing routines and appropriate, to govern contractual arrangements characterized by moral hazard and incompleteness, and to initiate the necessary changes in the partnership as it evolves over time. Experience, then increases the returns from strategic technological alliances, and consequently their formation rates. A second explanation points at the role of previous partners as sources of information about new opportunities for alliances and new partners (Gulati and Gargiulo, 1999). The third explanation is of particular relevance to new firms and it is related to a reputation effect. Stuart et al. (1999) show that biotechnology start-ups aim entering alliances with prominent partners because this is likely to provide significant advantages in terms of both performance and of subsequent ties. Connecting to a prestigious incumbent does not only provide access to superior quality resources but also entails strong reputational benefits.

Regarding dyad-specific factors, Okamura and Vonortas (2009) find that firms are more likely to collaborate the closer they are in terms of technological and market profiles, the higher the expected knowledge spillovers among them and the more familiar they are with each other through past interaction. The effect of technological proximity can be interpreted in light of the role of absorptive capacity. In order to learn, firms need pre-existing knowledge in the partner's field of expertise, and cognitive proximity is required for effective communication to occur. Similar results are obtained by Stuart (1998). However, excessive similarity may harm cooperation, limiting the opportunity for complementarities to be exploited. Along these lines, Mowery et al. (1998) find evidence of an inverted U relationship between partners' technological overlap and the probability of alliance formation. Evidence of a non-linear effect is provided in Okamura and Vonortas (2009). Through repeated interactions (developing familiarity) firms can build trust, lowering transaction costs and limiting the risk of opportunistic behavior (Gulati, 1995), although prior alliances with the same partners may also create disincentives through the anticipation of reduced additional benefits from the new R&D alliance (Hoang and Rothaermel, 2005) or potential lock-in (Molina-Morales and Martinez-Fernandez, 2009). Finally, there is evidence that the relative importance of dyadic factors may vary in different types of agreements (Garcez and Sbragia, 2013).

Environmental conditions also affect the intensity of strategic technological alliances. Link and Bauer (1987), Sakakibara (2002), Hernan et al. (2003) find that R&D cooperation is more likely to occur in concentrated industries. Recently, Yu et al. (2013) showed that the global competitive intensity between two rival multinationals in the automobile industry positively affects the likelihood that they will ally in any host country.[7] A number of possible explanations exist. In oligopolistic markets it is easier to find appropriate partners or to reach agreement towards cooperation. In addition, market power associated with such structures allows firms to appropriate the return from the alliance. Once again, it is worth mentioning that mixed results are found for start-ups. While Colombo et al. (2006) find that alliances are less frequent in more competitive sectors, negative relation between concentration and the rate of formation of strategic alliances is found by Eisenhardt and Shooven (1996) based on a sample of 102 US new firms in the semiconductor sector. In particular, these authors find that the number of competitors in the segment in which the firm operate positively affects the rate of alliances formation. They relate this result to the gains of accessing external resources when market conditions are difficult.

4.2 The impact of networking on performance

Firms enter technological agreements because they expect to increase their own performance. There are two relevant issues in this respect: first, the distribution of returns from cooperative ventures, because STAs are known for their intrinsic uncertainty and the likelihood of “partnership mal-functioning” (Lokshin et al. 2011); second, a reasonable quantitative assessment of such effects and the factors that positively or negatively affect their magnitude.

Assessing the success or the failure of a strategic alliance is not straightforward. Often the true goal of cooperation is not known, but even when it is known side effects can be important. When the termination date of an agreement is not fixed ex ante, its dissolution can be consistent with both failure (i.e. the objective of cooperation has not been reached and

[7] STAs may also impact competition as shown by Tong and Reuer (2010).

cannot be reasonably reached in the future) and with success (i.e. the goal has been reached) (Kogut, 1988). One way to solve this problem is to use partnership performance as *perceived* by individual partners. Using questionnaire data on European firms, Caloghirou et al. (2003) show that partnership success depends significantly on the closeness of the cooperative research to the in-house R&D effort of the firm, on the firm's effort to learn from the partnership and its partners, and on the absence of problems of knowledge appropriation between partners.

It is less problematic to assess the relationship between the various dimensions of a firm networking strategy and its overall economic performance. The most common empirical finding in the literature is the positive association between firm participation in networks, measured by number of agreements or number of partners, and firm economic and innovative performance, measured by sales, growth, patents or survival (see for instance Cusmano, 2005; Branstetter and Sakakibara, 2002; Siebert, 1996; Hagedoorn and Schakenraad, 1994; Mitchell and Singh, 1996). Nevertheless, some studies find that STAs' impact can be characterized by diminishing returns, finally turning out to be negative (Rothaermel and Alexandre, 2009) or that network centrality may be less important in a network of geographically proximate firms (Whittington et al., 2009).

The positive association between network participation and performance holds for new firms too (Shan et al., 1994). Interestingly, for start-ups the identity of partners and the nature of network activity seem to be particularly important. Stuart (2000), in a sample of semiconductor firms, shows that partner innovativeness has a greater impact on firm patenting rate and sales growth than the simple count of technical agreements. Partner sales matter for growth especially if firms are small or young (this is explained with reference to the "status enhancing" effect of these alliances). Baum et al. (2000) consider a sample of 142 start-ups in biotechnology and show a positive effect of the number of alliances with pharmaceutical firms, the variety in the type of partners (pharmaceutical firms, university, biotech firms, etc) and the number of alliances with rivals with a narrower product scope on firm performance. Similar results can be found in Gulati and Higgins (2003).

There is also evidence that the structure of the alliance network in which a firm is embedded has an impact on innovative output. Based on a longitudinal study of the patent performance of more than 1000 firms in 11-industry level alliance networks, Schilling and Phelps (2007) find that firms located in "dense" areas of the network and that are at short distance to a wide range of firms have a greater innovative output than firms located in areas without those characteristics. This result is related to the small world model of Watts and Strogatz (1998) and more generally to the structural properties of innovative networks, discussed in Section 5.1.

5. STRATEGIC ALLIANCES AND NETWORKS: THE "MESO" PERSPECTIVE

In this section, we take a "meso" perspective, and review literature addressing the following two questions:

1. The structure and evolution of networks, with a particular interest in the role played by different types of organizations;
2. The network contribution to technological progress, again distinguishing among different types of organizations.

5.1 Structure and evolution of networks

In recent years, important contributions on graph theory such as the "small world" model of Watts and Strogatz (1998) and the "scale free" model of Barabasi and Albert (1999) have promoted network structure and evolution as a primary object of interest. The structure of the overall STA network resulting from different organizations' (uncoordinated) choices matters for two reasons. First, network structure is anticipated to have an impact on the level of efficiency of the industry (Cowan and Jonard, 2003, 2004). In other words, the structure of the network of alliances is an important factor in explaining cross-sectional variation in the rate of technological progress. When knowledge is widely distributed among firms, networks become the locus of innovation (Powell et al., 1996) providing access to resources and to knowledge that are otherwise unattainable for the individual firms. Second, firms' position in the network, and their "status" (Podolny and Page, 1998) can affect their propensity to enter into new alliances as well as their economic and innovative performance (Vonortas, 2009).

The "small world" model by Watts and Strogatz (1998) shows that it is possible to have a network which is simultaneously sparse and characterised by high clustering and low average distance. A network is sparse when the number of existing links is small compared to the maximum conceivable number. Clustering, instead, refers to the likelihood of close triads, i.e. the probability that my friends are friends with each other. In other terms, networks are characterized by high clustering if they are composed by a number of cohesive sub-groups in which nodes are primarily connected with most other members of the subgroup. Finally, the average distance is low when, on average, the number of steps to go from any node to another through a path of connected nodes is small. What Watts and Strogatz show is that in a network characterized by such cliques few "shortcuts" among otherwise disconnected areas dramatically reduce the average distance among actors.

Subsequent theoretical models (e.g. Cowan and Jonard, 2003, 2004) have shown that small world networks (networks exhibiting both high cliquishness and low average distance) are the most efficient in the process of knowledge creation and diffusion. This result relies on the positive role that clustering and low distance can play on the innovation process.

There are two main reasons for cliques to play a positive role in STA networks. Both reasons are related to the contribution of cliques to building "social capital", defined as the sum of resources that accrue to a firm by virtue of possessing a durable network of relationships. The first reason can be labelled as "cognitive". Firms collaborating repeatedly can develop a common language for cooperation, common practices and behavioural routines, mutual understanding of partners' operation, and so forth, which promote the creation of new knowledge and its transmission among the firms in the clique (Oliver, 2001; Uzzi, 1996). The second reason can be labelled as "reputational" and can be divided into two motivations. Ex post (once the alliance has been formed), the participation to a clique can favour cooperation in a context of contractual incompleteness by providing information about a partner's "deviation" from agreed principles, thus increasing the cost of opportunistic behaviour. Ex ante (before the alliance is formed), distributed information about actors' competences and trustworthiness can reduce the degree of information asymmetry, again favouring the formation of links (Coleman, 1988; Rowley et al., 2000).

The existence of cohesive sub-groups has been shown in several sectors. In an early contribution, Nohria and Garcia-Pont (1991) considered 35 leading firms in the automobile industry and the 133 alliances they formed during the 1980s. They detected six "strategic" blocks. It turned out that strategic blocks were composed by firms with complementary capabilities and were such that firms in each block had access to a similar set of capabilities. Similarly, the analysis of Gomes-Casseres (1996) shows that competition in the personal digital assistant market has been shaped by alliance groups (constellations) of firms combining different sectors including computer hardware and software, telecommunications and consumer electronics.

This view of social capital as "closure" (Coleman, 1988), which stresses the benefits of clustering in networks, is often contrasted with the "structural holes" argument (Burt, 1992). Burt considers players (individuals or organizations) in a competitive arena (for instance, a market) characterized by a social context (social network among the players). The theory suggests that the players' position in the network should help explaining their performance in the competition. In particular, a player's performance should be positively correlated with the extent to which the player manages non-redundant contacts in its network. Contacts are defined as redundant if they are connected by a strong relationship (cohesion criterion) or when they have, in turn, the same contacts (redundancy by structural equivalence). Whenever two contacts are non redundant a structural hole is assumed to exist between them. Players that occupy structural holes can enjoy higher rates of return on their investments. Non redundant contacts are more likely to give them timely access to diverse sources of information as well as to allow control over such information in order to secure more favourable terms in the opportunities they choose to pursue.

In the case of STAs, the network is mostly seen as a conduit of information about technology (for instance about more or less promising technological directions). In this perspective, nodes in a clique have by definition redundant links, and according to this view, a non efficient structure of the ego-network. Burt's argument has clearly a normative flavour. Organizations should fill structural holes, because this allows them a higher rate of return.

With a particular focus on start-ups, Walker et al. (1997) consider how the rate of alliance formation depends on the structure of the networks in which firms are embedded, for a sample of biotech firms in the period 1984-1988. They find that firms endowed with "social capital" (located in dense areas of the network) form more links than firms active in less dense areas (full of structural holes). At the same time, it is shown that new links tend to increase the level of social capital.

The literature has also emphasized that different network structures can be preferred on the basis of the type of knowledge that is transmitted through the network and the type of learning activity. For instance, Rowley et al. (2000) have argued for high-density and strong ties in the case of exploitation activities and for low-density and weak ties in the case of knowledge exploration activities. Nooteboom and Gilsing (2004) argue that loose and non-redundant ties may be best for knowledge identification whereas strong ties are needed for the transfer of complex and highly tacit knowledge. The idea that different network structures can be optimal in different contexts points at the role of networks in different stages of industry evolution. In industries at early stages of evolution, where exploration activities are more important, non-redundant links may favour the generation of variety. On the contrary, closely knit networks with strong ties may be more appropriate in mature industries, where exploitation of knowledge becomes more relevant (Vonortas, 2009). Importantly, however, the relationship between networks and industries is not limited to that: the two can co-evolve. In an analysis of the pharmaceutical industry, Orsenigo et al. (2001) analyzed the structural evolution of the network of collaborative agreements after the biotechnology revolution. The main conclusion is that the specific nature of the technology and the related learning processes in the sector affect the organization forms of R&D through networks, the patterns of division of labour and industrial dynamics, including the entry of new biotech firms, and that those factors influence each other.

It is natural to ask whether networks of strategic alliances are small worlds. The answer from existing studies is generally “yes”. Verspagen and Duysters (2004) find a “small world” network for the alliances of the two sectors they analyze: chemicals and food (639 firms in their sample) and electronics and ICT (837 firms). Cowan and Jonard (2004) find a small world in the network of firms participating in the Basic Research in Industrial Technology (BRITE)/European Research in Advanced Materials (EURAM)programme and the network of research institutes from the Targeted Socio-Economic Research (TSER) programme. Breschi and Cusmano (2004) find high clustering and low average distance for the network of firms, universities and research institute participating to the 3rd and 4th European Framework programs.

A related aspect of interest concerns the *formation* of small worlds. A paper of relevance in this field, although not related to technology, is by Baum et al. (2003). Their theory is that a small world structure emerges from a cliquish network, through clique-spanning ties. The authors try to understand the identity of the actors that activate such ties and propose three alternatives explanations: 1) chance: the addition of new links increases the probability that some of them will be outside the cliques; 2): insurgent partnering, activated by peripheral actors in the network that aim at improving their status; and 3) control partnering, activated by actors that attempt to preserve their privileged position. They consider the network of Canadian investment banks, emerging from underwriting syndicates over the period is 1952-1990. They find support for all three explanations, especially for the chance and insurgent partnering motives. This kind of exercise would be worthy to be replicated on interfirm STAs, in particular to understand if new technology-based firms can play a role as clique-spanning ties activator and how this can impact on their performance.

The dynamics of networks is also at the core of the theory of scale-free networks (Barabasi and Albert, 1999). The starting point of this line of research lies in the attempt to explain a stylized fact on networks that the small world model cannot explain: the observation that nodes can be ranked in terms of the number of links they maintain and, most importantly that few of them have many links whereas most have very few links. More formally, the distribution of links typically follows a power law distribution. Such structures are defined as scale-free networks because the average degree of nodes (their scale) is not representative of the number of links that each node has. Barabasi and Albert (1999) show that this structure can emerge in a growing network if a preferential attachment mechanism is at work: the probability of a new connection at time *t+1* positively depends on the number of connections a node has at time *t*.

Evidence suggests that innovation networks have a power law distribution of links, and this is driven by a preferential attachment mechanism (Breschi and Cusmano, 2004). The scale-free model places particular emphasis on the role of new start-ups because it explicitly considers a growing network with new nodes "coming in" over time. In analysing the evolution of networks and industries, Riccaboni and Pammolli (2002) apply the model to networks in life sciences and ICT. They show that large, incumbent firms take the role of "hubs" (i.e. highly connected firms), to which new firms attach, agreeing with the discussion in Section 4. Vonortas and Okamura (2013) show the same phenomenon extensively in the case of the European Framework Programmes while Vonortas (2013) discusses it across the network literature.

5.2 Network contribution to technological progress

When looking at the contribution of overall networking activity on the rate and direction of technological change, a modern theme in the (mainly theoretical) literature is associated with the view of technological alliances as *real options*. That is to say, STAs can be considered as resource economising instruments that assist participants to hedge their bets. In turbulent technological environments characterised by significant levels of uncertainty firms engage in exploratory activities in order to cope with environmental discontinuities. If, in addition to uncertainty, one considers that R&D investments are at least partially irreversible, a real option approach becomes plausible (Kogut, 1991, Bajeux-Besnainou et al., 2010). It is only a small step then to imagine the network operating as a *search engine* for alliance participants (Hemphill and Vonortas, 2003). Empirically, the view of alliances as options has a significant interpretative power with respect to large firms-small firms alliances. A notable example is the pharma-biotech sector, where for large pharmaceutical firms the agreements with biotech start-ups, with their superior knowledge in the new paradigm, has also had such an exploratory nature (Vassollo et al., 2004). From the network perspective, then, the association with start-ups is part of a technological diversification strategy of large firms.

A related theme is associated to the "collective" direction of technological change in industry. From society's point of view, a certain degree of technological experimentation should be maintained – or using evolutionary terminology, variety generation mechanisms must be present. Firms need to explore different routes in environments characterized by substantive uncertainty. If firms in a network explore collectively the same areas of the technological space, risks of technological "lock-in" are possible. Indeed, some authors have argued that the advantages of the network form of organization over more integrated forms (hierarchies) include the preservation of technological variety (Kogut, 2000). The existence of different cliques can play an important role in this respect. Even if lock-in exists at the level of single sub-groups of firms, it can be counterbalanced by different groups exploring various technological directions. Similarly, variety and access to novel information can be guaranteed by short-cuts or clique-spanning ties in a “small world” network. Such variety generation mechanisms can, of course, operate in parallel to variety produced by start-ups participating in the networks.

The distinction between incumbents and start-ups matters particularly in the face of technological discontinuities. A traditional distinction here is between competence-enhancing discontinuities, favouring incumbent firms versus new entrants, and competence-destroying discontinuities, favouring new entrants versus incumbents (Tushman and Anderson, 1986). This distinction has been adapted to networks by Madhavan et al. (1998) who define structure reinforcing events as those discontinuities which favour incumbents in the network, leading to an increase in their centrality, and structure loosening events as those discontinuities which favour more peripheral agents, reducing the degree of centralization in the network. Similarly, Rosenkpof and Tushman (1998) discuss the link between network intensity and the stages of technological life cycles. They show that in the flight simulation industry the rate of creation of new technical agreements is high at the discontinuities, while cliques emerge in mature phases.

6 DIRECTIONS FOR FUTURE RESEARCH

The conceptual model developed in Section 3 guided the organization of the survey of the *existing* theoretical and empirical research on STAs and networks we presented in Sections 4 and 5. Based on the same model, we suggest in this Section what we believe are two fruitful directions for future empirical research.

A first theme refers to the role of STAs in the management of risk and uncertainty. While technological risk-sharing is often mentioned as an important motivation behind alliances (see Section 2.3), empirical assessment of this claim, beyond examples and case studies, is rare.[8] Relatedly, empirical research lags behind theoretical investigations that have started to explore the role of STAs as real options (Section 3.2). At the node level, large scale analyses

[8] For a recent treatment focusing on micro and small European firms see Kim and Vonortas (2014).

on how firms manage their portfolio of alliances, possibly based on publicly available information such as patent data, appear promising. Furthermore, it can be noted that at the firm level technological risk interacts with the risk of opportunistic behaviour as partnerships evolve (see Section 4.1). Such analyses would be particularly important in the discussion of the impact of networking on performance (Section 4.2) especially with regards to the strategic and managerial implications of alliances met in the literature. The empirical analysis of STAs and risk management would have consequences at the meso level as well. In fact, the discussion on the role of networks in the "collective" direction of technological change in industry put forth in Section 5.2 deserves much more empirical investigation than it has received until now. The comparison of different networks (different technologies or the same technologies in the different countries) in their relationship with risk management, and the impact that their structural properties have on such relationships, are important issues with clear consequences on the industrial and technology policy debate.

The second theme refers to the evolution and dynamics of networks. Other authors have already identified this as a fundamental gap in our current knowledge on networks. In the introduction to a special issue on *Organization Science*, Ahuja et al. (2012) claim that "although scholarly understanding of the factors that influence the formation of relationships between entities exists, understanding the origins and evolution of alternative types of network structures remains a research issue demanding attention" (p. 434). In the case of STA networks, this lack of understanding takes specific forms. For instance, the origin and evolution of inter-firm networks are likely to be tightly coupled with other simultaneously occurring dynamic processes, as captured by the well consolidated concepts of industry or technology life cycles. We need to know how these may impact on the determinants of tie formation (Section 4.1) and the type of ties that are formed; and we need to know how these exogenous factors matter vis-à-vis endogenous mechanisms of network dynamics such as preferential attachment. Probably, technological specificities will lead to the identification of different mechanism in differed contexts, so that taxonomical exercises will be valuable as well. In a related vein, significant opportunities remain for studying the role of network structures in mediating between technological discontinuities and their consequences on industry evolution (Section 5.2). Clique internal structure and the capabilities which firms have access to may influence how they react to environmental shocks. Moreover, the role of technological discontinuities in networks points, once again, at the role of stages of industry evolution. Since the birth of new industries is typically simultaneous with (competence-destroying) technological discontinuities, the entry of new firms is likely to be favoured by their role in the network. At the same time, when industries mature, or technological discontinuities are competence-enhancing, a core of interconnected incumbents may emerge, erecting barriers to entry and survival against firms outside the network (Zirulia, 2009). Over time, then, not only the optimal network structures may change but also the role and opportunities in networks for start-ups and incumbents.

7 CONCLUDING REMARKS

In this paper we briefly reviewed the literature on strategic technology alliances and networks, allocating the contributions to "micro" (firm) and "meso" perspectives (the network). Our focus was on a logical reconstruction of important themes in the literature, rather than the production of a complete compendium of publications, in order to point out what we reasonably know already and what we would like to know next. The latter resulted into suggestions of possibilities for future investigations.

While the intent of the paper was not to provide policy implications, some readily arise from the aforementioned categorization. From the micro perspective, policies aiming at firm growth and prosperity should accommodate, at least, and frequently incentivize network participation. The literature has, however, has been underlining that is not network participation per se but the "right" type of links that matters most. From a network perspective, a challenge is the alignment of private incentives in an organization's network involvement with social goals and consequent opportunities for policy intervention. Although, for instance, incumbents can have a lot to gain from cooperation with new small firms they may also be tempted to use the network to erect barriers to entry and form a "knowledge-based networked oligopoly" (Delapierre and Mytelka, 1998) if they perceive new firms as (potential) competitors. That is to say, while networking seems ubiquitous and policy should try to accommodate it, antitrust vigilance is strongly recommended.

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