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THE ROLE OF INTER-ORGANIZATIONAL PROXIMITY ON THE EVOLUTION OF THE EUROPEAN AEROSPACE R&D COLLABORATION NETWORK

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The role of inter-organizational proximity on the evolution of the European Aerospace R&D collaboration network.

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ABSTRACT: The influence exerted by five dimensions of inter-organizational proximity (geographical, organizational, network, institutional and technological) on the evolution of the collaboration networks subsidized by the European Union Framework Programmes in the Aerospace sector is studied. The role of the proximity dimensions is controlled by means of a longitudinal analysis with a stochastic actor-oriented model, which will be run on four observations of the network starting in the fourth (1994-1998) and ending in the seventh Framework Programme (2007-2013). Results show that organizational proximity is the most important driver for the longitudinal evolution of the network. Further, this form of proximity is constant in time, analogously to the geographical one which, on its side, only moderately affects network's evolution. Network proximity plays a weak but positive influence, while the institutional and technological dimensions do not affect the evolution of the network. Anyway, when proximity is evaluated on single institutional and technological types, different roles are detected. Regarding the former, research centres have a preference for inter-organizational mixing, while firms prefer to cooperate with firms. As for the latter, a repulsive tendency among system integrators is appreciated. Organizations' patenting activity, introduced as a control variable, does not play a significant role on network's evolution.

Keywords: Longitudinal network analysis; Stochastic actor-oriented models; European Framework Programmes; Inter-organizational proximity; R&D collaboration networks; Aerospace.

JEL Codes: O33; D85; C63

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1. INTRODUCTION

It is widely recognized as different forms of proximity could contribute to reduce uncertainty in inter-organizational relations, increasing reciprocal trust, enhancing coordination, and improving the chances of interactive learning and collective knowledge construction (Boschma, 2005; Broekel and Boschma, 2011). Besides the role of proximity, the evolutionary approach to the study of interaction of firms and other agents – such as research centres, higher education institutions and policy makers – underlines that, under uncertain and changing conditions, cooperative relations and networks often emerge because of complementarities between agents, which could permit a reciprocal integration of competencies and knowledge bases (Lundvall, 1993; Nelson and Rosenberg, 1993; Edquist, 1997; Fagerberg et al., 2004). The salience attributed to heterogeneity and complementarity for the genesis of innovations, jointly to the one acknowledged to homogeneity and proximity for the easiness of interaction, suggest the desirability of a trade-off lying on the different dimensions of similarity and distance. This way, knowledge creation and exchange in inter-organizational relations and networks is easy to be set up and could trigger fruitful learning process and innovative outcomes (Boschma, 2005; Broekel and Boschma, 2011; Nooteboom, 1999, 2000). The conceptual dichotomy between proximity and distance in social networks can be nested on the opposition between homophily and heterophily in the relational theory (Granovetter 1992, 1995; Wellman 1988; Wholey and Huonker, 1993; McPherson et al., 2001). In the field of inter-organizational relations, proximity had been widely studied by the French school of proximity dynamics starting from the early ‘90s (Rallet, 1993; Kirat and Lung, 1999; Torre and Gilly, 2000; Rallet and Torre, 1999) initially stressing on its geographical dimension. Afterwards, other relevant aspects of proximity had been defined, allowing an extension of the concept to cognitive, social, organizational and institutional dimensions too (Boschma, 2005; Broekel and Boschma, 2011). These dimensions often partially overlap, are not independent one from the other, so that they cannot be combined orthogonally. For example, co-location in a cluster (geographical proximity) often helps personal interactions and the creation of trust (social proximity) and usually implies the ownership of a similar technological and scientific knowledge stock (cognitive proximity). At the same time, two firms belonging to the same industrial group, or two departments of the same research centre (organizational proximity), can be geographically distant and linked by personal acquaintance among managers and executives (social proximity) while tied by similar knowledge bases (cognitive proximity). Hence, theoretical and empirical studies properly underline the lack of linearity in the combination of the dimensions and their partial overlap that prevents inter-changeability and substitutability (Autant-Bernard et al., 2007; Boschma, 2005; Broekel and Boschma, 2011; Maggioni and Uberti, 2009; Ponds et al., 2007; Aguiléra et al., 2012; ter Wal, 2013; ter Wal and Boschma, 2009; Broekel, 2012; Boschma and Frenken, 2009).

In this work we study the influence exerted by proximity on the evolution of the collaboration networks funded by the European Union (EU) Framework Programmes (FPs) for Research and

Technology Development in the AeroSpace (AS) sector. The role played by inter-organizational proximity will be controlled by means of a longitudinal analysis with a stochastic actor-oriented model (SAOM) which will be run on the network starting in the fourth FP (1994-1998) and ending in the seventh FP (2007-2013). Technical aspects about the model setting will be detailed in the dedicated section (par. 3), here we mention that the model will simulate the evolution of the network between the states surveyed by empirical observation (each one corresponding to a FP) as drove by the forms of proximity operationalized as variables. The model will be run on a restricted core of organizations composed by those actors who continuatively participated to all the FPs editions, from fourth to seventh, and structured the backbone of the ERA. Technical reasons led to this constriction for the difficulty of performing a reliable longitudinal analysis on large networks with the architecture of the models actually available, unless the observed networks on which the simulation is based would largely overlap.

Results show that the membership in the same industrial group or research institution – as specification of organizational proximity – is the most important driver for the longitudinal evolution of the network. Further, this form of proximity is constant in time, analogously to the geographical one which, on its side, only moderately affects network's evolution. A peculiar specification of social proximity – namely network proximity – has a weak positive influence, while the institutional and technological dimensions do not affect the evolution of the network.

By the way, when proximity is evaluated on single institutional and technological types different roles are detected. Organizations' patenting activity, introduced as a control variable, does not prove to affect network evolution.

The paper proceeds as follows: in the next section the literature about the different forms of proximity is discussed and for each dimension two concurrent propositions will be set; in one proposition it will be argued that organizations look for a similar partner in the creation of a collaborative tie on the dimension discussed, vice versa the concurrent proposition will ground on theoretical and empirical arguments which suggest a positive influence of mixing on partner's choice. Section 3 will detail the procedure of networks' construction and the model's architecture and implementation, while results of the longitudinal analysis will be presented in the fourth paragraph. Conclusions on the role of inter-organizational proximity on the evolution of the network will be drawn in the last section (4).

2. PROPOSITIONS ON THE ROLE OF PROXIMITY ON THE EVOLUTION OF THE AEROSPACE COLLABORATION NETWORK

It is not straightforward to hypothesize a univocal role played by inter-organizational proximity on the evolution of EU-funded collaboration networks. On the one side it could be argued that organizations would find easier to collaborate with similar partners. On the other side, it could be supposed that a tendency in looking for complementarities while the European Commission's (EC) guidelines and rules on organizational mixing (European Commission, 2000, 2002, 2003,

2007) could constitute a strong driver on the evolution of the network as well.

Different arguments can sustain the hypothesis of an influential role of proximity. Generally speaking, several studies demonstrated as a backbone of organizations that are similar on various aspects had structured since the early FPs (Breschi and Cusmano, 2004; Breschi and Malerba, 2009; Heller-Schuh et al 2011; Protogerou et al., 2010; 2012; Roediger-Schluga and Barber, 2008). Further, it is recognized that previous acquaintance – as a form of social proximity – between organizations is a determinant for the formation of R&D collaboration networks such as the ones funded by the EU (Pohoryles, 2002; Nokkala et al., 2008; Paier and Scherngell, 2011). Moreover, it should be hold on mind that the salient differences in the professional practices between scientific base research, typical of universities and many research centres, and industrial applied research – of engineering mould – could create obstacles to communication and joint knowledge creation by organizations cognitively and institutionally distant (Vincenti, 1990). Regarding the cognitive dimension, it is also important to consider that the high intensity of the tacit dimension of knowledge (Cohen and Levinthal, 1990; Nooteboom, 1999, 2000; Nooteboom et al., 2007) in the aerospace sector (Giuri et al., 2007), could favour the setting and the management of relations between organizations with a similar technological knowledge stock. Finally, there is to bear on mind that aerospace sector is largely organized in geographical clusters (Lublinsky, 2003; Niosi and Zhegu, 2005; Giuri et al., 2007; Sammarra and Biggiero, 2008; Biggiero and Sammarra, 2010) so that spatial proximity is supposed to play a relevant role in inter-organizational interaction.

On the other side, the EC plans the guidelines for the implementation of the FPs – considered the main instruments for the ERA structuring (Pohoryles, 2002) – stressing on knowledge complementarity and heterogeneity of the agents in order to create an integrated research area on the geographical, scientific and technological, and institutional dimensions (European Commission, 2000, 2002, 2003, 2007). Those guidelines are followed by the EC officers in the process of evaluation of the proposals and sometimes expressed as explicit rules in the calls, as in the case of geographical and institutional assortment of the organizations which jointly apply for a project.

In this work it is proposed an approach which, although being addressed to the control of a hypothetical propositions set, is grounded on an explorative space defined by the setting of two concurrent propositions for each form of proximity: the first one (namely *Pa*) will sustain a positive influence of proximity on link formation in the evolution of the aerospace network; the second one (namely *Pb*) will instead support an influence played by the distance. The five forms of proximity which will be examined, grounding on Boschma's review (2005) are reported in table 1 jointly to the advantages and disadvantages deriving from a too high or a too small proximity and the ideal trade-off between proximity and distance.

In each of the following subparagraphs one proximity form will be detailed, paying attention to its empirical observability and its advantages and disadvantages in inter-organizational networks; a question about its role in network's evolution will be set; then

Table 1: The five forms of proximity, some features
(adapted and modified from Boschma, 2005)

	Key dimension	Too much distance	Too much proximity	Advisable solution
Geographical	Spatial distance	Lack of spatial externalities	Lack of innovative insights	Mix of local and global links
Social	Trust (based on social relations)	Opportunism Cheating	Too much reciprocity Group thinking	Mix of social and market relations
Organizational	Coordination	Opportunism Lack of coordination	Bureaucracy	Loosely coupled systems
Institutional	Trust (based on common values)	Opportunism Relational difficulties	Inertia on shared practices and values	Balanced institutional mix
Cognitive	Knowledge base	Misunderstanding	Lack of sources of novelty	Common knowledge base with diverse but complementary capabilities

the results of dedicated previous empirical contributions will be summarized. Grounding on those considerations the two concurrent propositions will be stated.

2.1 Geographical proximity

As mentioned, aerospace sector is highly concentrated in geographical clusters; by the way, the positions about the determinants of this aggregative form and its effects on the dynamics of knowledge construction and exchange do not always agree. On the one side, a reductionist approach in the study of geographical co-location in the aerospace sector (Niosi and Zhegu, 2005) underlines as the salience of spatial aggregations has been long overestimated by the literature on geographical advantages, pointing that regional agglomeration is mainly due to the settlement of a system integrator working as an attractor for the SMEs included in the aerospace value chain and for the higher education and research institutions. According to this position, knowledge streams and spillovers are highly contained and are only set on the vertical dimension flowing from the integrator to low-level suppliers. Such a vision contrasts with those ones which consider the industrial cluster as a collective learning system (Capello, 1999) fueled by interactive processes of (often tacit) knowledge creation and exchange (Maskell, 2001). There is to take in account that the empirical field on which Niosi and Zhegu conduced their studies – the aerospace clusters located in Toronto, Montreal, Seattle and Toulouse – is characterized by the final assembly settlements of three main players, i.e. Boeing, Bombardier and Airbus. This feature should reinforce the attractiveness of the integrators and the dependence of the SMEs.

A reductionist approach is adopted also by Lublinsky (2003) who underlines as some of the advantages of geographical co-location – such as the specialized workforce concentration, the knowledge spillovers, and the existence of local demand and of trust based relations – weakly operate in the northern Germany aerospace cluster.

On the other side, the literature on geographical advantages, while reducing in the last years the salience attributed to the role of co-location on knowledge transfer and innovation development and assuming a more cautious position about the uniqueness of the role of spatial proximity (Rallet and Torre, 1999; Breschi and Lissoni, 2001; Bathelt et al., 2004; Torre, 2008) still considers the cluster as a complex context where different kinds of relations – such as economic transactions and workers and knowledge exchanges – are formed and interweave between heterogeneous agents (Albertini and Pilotti, 1996; Biggiero and Sevi, 2009). In line with this vision, Biggiero and Sammarra (2010) show as in the Lazio region aerospace cluster various forms of knowledge (i.e. technological, organizational and market) are exchanged by the local firms; multinational enterprises play a gatekeeper role for they are able to intermediate on the knowledge flows entering and exiting the cluster.

Evaluations of the effects of geographical proximity on the formation of inter-organizational networks are difficult to be drawn for three main reasons: i) it often overlaps with other forms of proximity; ii) centripetal and centrifugal forces along with external and internal knowledge fluxes are in place; iii) there is a high heterogeneity in the strategies adopted for technological competitiveness, varying from region to region and from agent to agent (Cantwell, 2005). The research question in the field under investigation can be raised as follows:

Q1: *Which is the role of geographical proximity in the evolution of the aerospace collaboration network?*

The stress on the so called competitive advantages, jointly with the high spatial concentration observed in the AS sector (Biggiero and Sammarra, 2010; Giuri et al., 2007; Niosi and Zhegu, 2005; Sammarra and Biggiero, 2008), would suggest that the organization which participate to AS FPs prefer to collaborate with geographically close actors.

Further, several empirical contributions point as geographical proximity, along with other factors, is a more or less relevant determinant for the definition of collaborative patterns of EU-FPs (Paier and Scherngell, 2011; Scherngell and Barber, 2009; Scherngell and Lata, 2012; Maggioni and Uberti, 2009; Maggioni et al., 2007; Balland, 2012; Autant-Bernard et al., 2007). Also, an empirical study on the Dutch aviation industry (Broekel and Boschma, 2011) suggests a significant role of geographical closeness on inter-organizational collaborations. Such contributes favour a proposition according to which:

P1a: *Geographical proximity positively affects the evolution of the backbone of the AS collaboration network.*

On the other side centrifugal forces, due to industrial de- and re-location processes and the digitalization of informational and knowledge flows, contribute to the genesis of relations which cross the geographical boundaries, though this is not an automatic process and the role played by socio-cognitive variables is still relevant (Biggiero, 2006). Further, Gibbons (2004) underlines that beyond a natural tendency to create geographically bounded links, some "organizational fields" – those ones in which continuous innovation plays a crucial role – also show a preference for trans-regional links which could permit the access to external knowledge sources, according to patterns distinguishable on the more or less hierarchical position assumed by the regions.

More punctual clues sustaining the only partial explicative power of geographical proximity can be found in a study of Levy and colleagues (2009) on a prestigious French academic institution. According to their contribution, trans-national links are preferred in multi-partner collaboration agreements, while co-location characterizes dyadic relations. Similarly, Nokkala (2009) specifies that collaborative choices in FP6-NEST (*New and Emerging Science and Technologies*) projects are not affected by geographical closeness.

Furthermore, it is important to consider that the EU policy makers' aim to the construction of a territorially cohesive and integrated ERA would exert a centrifugal influence on network's evolution. This objective is pursued toward norms and rules that regulates the participation to the FPs explained in the calls for proposals or implicitly followed by the EU officers and evaluators (Scholz et al.2010; Caloghirou et al., 2003; Protogerou et al., 2012; Marín and Siotis, 2008; Matt et al., 2012). A proposition supposing the positive influence of geographical mixing can be grounded on the aforesaid considerations:

P1b: *Geographical distance positively affects the evolution of the backbone of the AS collaboration network.*

2.2 *Social and network proximity*

Social proximity is defined by the existence of direct, and informal, personal interaction of the employees or the managers of two different organizations (Boschma, 2005; Boschma and Frenken, 2009; Uzzi, 1996, 1997; Huggins, 2010; Huggins et al., 2012). It is highly related to geographical proximity because co-location enhances mutual personal acquaintance and interaction can be continuous in time triggering informal relations. Three main reasons determine its salience for the construction of collaboration links: i) the trust which follows from direct acquaintance; ii) the sense of reciprocity it implies; iii) the easiness of tacit knowledge exchange and mutual learning due to informal relations. The conceptualization of this form of proximity roots in the embeddedness literature (Granovetter, 1985; Uzzi, 1996) which focused the analysis of inter-organizational relations on the micro-level of social relations. Boschma (2005) underlines two disadvantages of a too high social proximity. First, it can lead to underestimate the risk of an opportunistic behaviour by a partner perceived as socially close. Second, it can drive through an excessive closure on some shared practices and perceptions and it can deny the access to outsiders which potentially can bring novel ideas, favouring a group-thinking phenomenon.

It is then reasonable to raise a question on how the social relations affect the formation of consortia in the AS FPs:

Q2: *Which is the role of social relations in the evolution of the aerospace collaboration network?*

Empirical contributions showed that relations based on mutual trust and previous acquaintance have been established among the backbone organizations since the early FPs (Breschi and Cusmano, 2004; Breschi and Malerba, 2009; Heller-Schuh et al 2011; Protogerou et al., 2010; 2012; Roediger-Schluga and Barber, 2008; Nokkala, 2009; Paier and Schnergell, 2011). Similarly Broekel and Boschma (2011) evidence that collaborative relations among a couple of organizations are more likely if in their executives there are at least two persons who previously belonged to the same organization. The operational definition they adopted for this form of proximity – i.e. the mutual acquaintance of the executives who formerly worked togheter – properly fits the concept of social proximity. Differently, other studies (Autant-Bernard et al., 2007; Paier and Scherngell, 2011) operationalized this dimension of proximity basing on the actor's extended egonetwork: in this case two organizations are considered as socially close if they are directly or indirectly tied. While the social dimension of proximity is related to the extensive concept of social capital (Granovetter, 1973), an operazionalization simply based on the ties established by an organization is coherent with the more intensive concept of network capital (Gulati, 1999; Huggins, 2010; Huggins et al., 2012). In this study we refer to this latter concept, and to the related dimension of **network proximity**, evaluating the role played by common partners in the creation of a link among two organizations. Therefore we argue that:

P2a: *Two backbone organizations which share a common partner are more likely to be tied*.

This proposition will be checked through the construct of network transitivity (Wasserman and Faust, 1994) whose effect is specified as the tendency of two organizations in forming a mutual tie – i.e. in engaging in the same research project – if they collaborated with a third organizations in another FP project. Therefore transitivity, although being a merely network construct, has important implications on the social level for the indirect trust lying on the sharing of a common partner. The tendency to transitivity, defined "network closure" in SNA for it accounts for the formation of closed triangles in a network, has been widely analyzed by Coleman (1988) who linked the transitivity construct with the concept of social capital, underlining how the actor-nodes embedded in high closure networks have the chances to build a relevant social capital based on trust, on control of opportunistic behaviour, and on the redundancy of links.

On the opposite, Burt (1992, 2001, 2004) stressed on the role played by structural holes of a network for they set some nodes on an advantaged position respect to other nodes. Nodes which enjoy a benefit from the presence of a hole are those ones that lie in the middle of the constrained paths which are due to the scarcity of direct connections. The detection of a hole can be focused on different level (i.e. ego, sub-network, whole network), at the ego level we can suppose that there is an hole when a triangles only has two legs, in such a situation the only vertex which is connected to both nodes is advantaged for it can directly acquire resources from them and manage the flows among them. This definition allows controlling for a proposition which sustains the search for an advantageous position in a local structural hole as driver for the creation of edges in the AS collaboration network:

P2b: *Backbone organizations prefer the creation of cooperative links in a way that they can play as intermediaries among not directly connected couples of nodes.*

There are no insights in the regulative framework of the FP projects which could help to sustain (or discard) this second proposition, by the way its control on the evolution of the FPs networks is anything but trivial. In facts, it should be noticed that the cliquishness implied in the automatic projection of the FPs networks should widely favour a low transitivity. However this fact does not tell anything about the desirability of an intermediating position for the organizations. Longitudinal simulation, by its side, can instead inform us about the payoff of transitivity on organizations' "satisfaction" for the creation of a link, controlling for all the other effects included in the model.

2.3 Organizational proximity

This form of proximity can be defined by the sharing of relations in an organizational framework (Boschma, 2005). It can be properly referred to Williamson's transaction costs economics (1975) where the market extreme would correspond to zero proximity and the hierarchy extreme would represent the maximal proximity condition. According to this point of view, FP projects can be considered low-proximity alliances for their commitment is limited in time and concerns only some R&D activities. On the opposite, more committing joint-ventures, such as *Thales-Alenia Space* and, to a higher extent, the *Airbus* consortium in the aerospace sector, are characterized by a higher organizational proximity.

This form of proximity is firstly pursed in RJVs whenever there could be problems due to coordination in the collective construction of innovative knowledge and, mainly in the development of complex products systems, the capability to exchange and integrate complementary and partly tacit innovative contributions is strongly required (Boschma, 2005). Already formalized relations, established roles, tasks and future rewards, and the integrated coordination of two proximal organizations, can help the activity of the partners in a FP project.

On the other side, too much proximity can prevent innovation also triggering an organizational lock-in i) because its hierarchical relations could discourage the initiatives and the feed-backs coming from the lower-levels; and ii) because of the impermeability of an organizational framework from external contributions.

By this considerations a question about the role of organizational proximity on the evolution of the AS collaboration network is raised:

Q3: *Do the organizations participating to aerospace FPs prefer to rely on structured organizational frameworks?*

Therefore we want to understand if partners' choice is affected by a preference toward those organizations with which there are already formalized agreements, so that the organizational in-group is favoured, strategic knowledge is protected, and task partition and communications are eased. Empirical contributions show that the co-membership in the same industrial corporate positively affects firm's tendency to the creation of cooperative links (Kleinknecht e Van Reijnen, 1992; Tether, 2002; Negassi, 2004).

The European aerospace sector is characterized by a high vertical integration in which the vertex organization is often linked by more or less committing agreements with lower levels organizations (Niosi and Zhegu, 2005). For example the aircraft industry is dominated by the *Airbus* consortium which belongs to the *EADS* group which partially or totally owns many firms of the European aerospace value chain. Beside it, many other large corporate groups (for example *Finmeccanica*), are composed by different firms. Balland (2012) in a longitudinal analysis of the *GNSS* network found that collaborative choices are affected by organizational proximity and are nested on the opposition of the two main European players in the sector, namely *EADS Astrium* e *Thales Alenia Space*.

The existence of large competitors in the sector, in a condition in which often the winner takes all, should suggest a preference for those partners which belong to the organizational in-group in order to protect from unintentional strategic knowledge spillovers and stay on the edge of the European frontier research subsidized by the FPs. Furthermore, the sharing of the organizational framework should facilitate the coordination in research projects composed by a high number of partners (up to 60 in the so called "Integrated Projects"). Beside the industrial sector, many research organizations belong to the same national institution – like the *CNRS* in France or the *Helmholtz* network in Germany – so that they share the same organizational framework. These considerations suggest a proposition according to which:

P3a: *Organizational proximity positively affects the evolution of the backbone of the AS collaboration network*.

There are no formal norms in the FPs regulative framework which prevent the participation of organizations of the same industrial group or research institute. By the way the European Commission explicitly encourages SMEs and other peripheral organizations participation in the FP-subsidized projects (European Commission, 2000, 2002, 2003). Considering that industrial groups are mainly composed by large enterprises, the inclusion of small and peripheral players which are not likely to be part of an organizational framework can positively affect the success of a project proposal. Therefore, contrarily to the previous proposition, it could be supposed that:

P3b: *Organizational proximity negatively affects the evolution of the backbone of the AS collaboration network*.

2.4 Institutional proximity

An institutional framework can be defined as a set of habits and routines, of practices, of implicit and explicit norms, and of shared values and languages (Edquist and Johnson, 1997). Two organizations can be considered similar on this dimension if at least partially overlap on those procedural, normative and communicative aspects. Consequently, institutional proximity is supposed to play a relevant role to help inter-organizational cooperative relations i) in the perception and definition of cognitive problems referring to a shared set of values and expectations; ii) in the knowledge transfer and exchange – particularly in the case of tacit knowledge – thanks to a mutually understandable language; iii) in the research praxis characterized by shared routines and practices; iv) strengthening reciprocal trust thanks to the reference to common norms.

Tipically, the definition of institutional framework coincides with the distinction between firms, research centres and universities. The formers are oriented to manufacture, marketability of the products and aim to profit, research centres can be more or less focused on basic and applied research and often look at the chances of collaboration with the private sector, while universities mainly aim at basic research.

By the way, an excessive homogeneity on the mentioned aspects can limit the innovative output of cooperative research because of the *lock-in* due to perceiving and defining a research problem always in the same way and adopting the same set of practices. In such a situation, the contribution of actors with different institutional frameworks can be highly valuable, as underlined by Etzkovitz and Leydersdorff (2000) who proposed the Triple Helix model.

Therefore, the institutional dimension will be operationalized basing on an extension of the Triple Helix model to which the “Fourth Elix” of non-profit research institution is added (Leydesdorff and Etzkowitz, 2003).

These consideration rise a question about the role of institutional proximity in RJVs explicitly dedicated to innovative research:

Q4: *Does institutional proximity affect the evolution of the aerospace collaboration network?*

Some empirical studies on FPs projects suggest an affirmative answer (Nokkala et al., 2008; Nokkala, 2009; Balland, 2012) showing that there is preference to collaborate with institutionally similar partners. Further, regarding the private sector, Niosi and Zhegu (2005) underlined as inter-organizational relations in aerospace are mainly situated among the firms of the pyramid, while universities and research centres stand in a marginal position.

Therefore a positive effect of institutional proximity on the evolution of the AS collaboration network should be expected:

P4a: *Backbone organizations prefer the formation of cooperative links based on the sharing of the institutional framework.*

On the other hand Luukkonen (2001) underlined that EU-FPs successfully promoted the creation of inter-organizational relations with different institutional frameworks, and Tsakanikas and Caloghirou (2004) detected a high extent of mixing between firms on the one side and universities and research centres on the other. Further, the European Commission considers the integration of these actors as one of the most salient criteria for the construction of the ERA (European Commission, 2000, 2002, 2003, 2007) in order to find a fruitful mix between cooperation and competitivity, and exploration and exploitation. These targets guide the evaluations by the European officers of the projects proposals which among other requisites must include at least one firm, one research centre and one university.

According to these considerations, a proposition concurrent to the former should be confirmed:

P4b: *Backbone organizations prefer the formation of collaboration links based on the heterogeneity of the institutional framework.*

2.5 Cognitive proximity and technological proximity

Cognitive proximity of a couple of organizations is defined by the similarity of their knowledge bases. This aspect is relevant in the acquisition of external knowledge by an organization which should have the capability recognize it, decode it, and elaborate it, particularly when knowledge is tacit. The similarity of the knowledge bases possessed by a pair of organizations can greatly help the process of knowledge exchange.

However innovative processes are often the outcome of the successful integration of complementary knowledge possessed by heterogeneous agents (Nooteboom, 2000) so that a limited cognitive distance hardly triggers this kind of processes.

An organization's cognitive base is a multidimensional concept which could be decomposed in three forms of knowledge: technological, organizational, and market (Sammarra and Biggiero, 2008). In this study we will focus on the technological dimension for it is the most relevant in the context of R&D networks; therefore, it will be adopted a more proper operative definition of **technological proximity**. Also in the case of this form we raise a question about its role in inter-organizational cooperative relations in aerospace subsidized projects:

Q5: *Does organizations' technological knowledge base affect the evolution of the aerospace collaboration network?*

Empirical studies on EU FPs networks found technological proximity to play a significant role on the formation of links between organizations (Scherngell and Barber, 2009) in particular when geographical proximity is low (Scherngell and Lata, 2012). Broekel and Boschma (2011) pointed that cognitive similarity affects positively inter-organizational relations in the Dutch aviation industry while discouraging the innovative performance.

Therefore it is interesting to check if this form of proximity plays a role on partners' choices in the longitudinal evolution of the AS FPs:

P5a: *Technological identity positively affects the evolution of the backbone of the AS collaboration network.*

On the other hand we should bear in mind that FPs projects set challenges that are difficult, if not impossible, to be afforded with mono-disciplinary technological and scientific instruments. Even those ones which are more targeted on a defined field are composed by different topics requiring i) an inter-disciplinary pooling to hold all the techno-scientific areas; and ii) trans-disciplinary capabilities to integrate them. Moreover, the planning of the FPs aims at the creation of a critical mass of heterogeneous actors whose different and complementary competencies would be able to trigger innovation dynamics in the ERA. Therefore the scores attributed to projects' proposals surely depend on their capability to properly fit all the topics of a research project.

Coherently, some empirical contributions showed that cognitive differentiation of the organizations plays a significant role in the formation of wide-aim projects such as *NESTs* and *IPs* (Nokkala et al., 2008; Nokkala, 2009). Also, Tsakanikas and Caloghirou (2004), in a survey on a sample of firms which participated to FPs, found that agents of the private sectors perceive the participation in the FP-subsidized projects as a chance for diversification seeking partners from different technological areas in order to enter into new market segments.

According to Balland (2012) cognitive proximity does not play a significant role in the evolution of the *GNSS* network, presumably because of the high technological heterogeneity of the sector.

These considerations and empirical contributions should then favour a concurrent proposition on the role of technological proximity:

P5b: *Technological identity negatively affects the evolution of the backbone of the AS collaboration network.*

3. METHODS AND DATA

3.1 Network's construction

Each FP can be represented as an "affiliation network" (Wasserman and Faust, 1994) where the organizations (the nodes-attendants) are "affiliated" – that is connected – to the research projects (the nodes-events) they participate. The "projection" of the organizations' network is gathered after the setting of an undirected link within the organizations which participated to the same project; the link represents a knowledge exchange between the organizations. Hence, each project is considered as a "clique" of organizations which work as a team in which knowledge is shared among all the organizations. A more proper representation should set links only among those organizations which participated in the same Work Package, and among Work Package leaders and the coordinator of the projects, following the common structure of FP-subsidized projects. Regrettably, data about task division are available only for few consortia; therefore the automatic "clique" projection is adopted. Nevertheless, the network is then reduced to the 142 backbone organizations which continuatively participated to the four FPs under investigation and it could be plausibly supposed that those "persistent" organizations are used to know each other and set intra-project collaborative links among them; therefore reducing the bias introduced by the "clique" projection.

Four observation of the AS collaboration networks (from FP4 to FP7) are drawn; the network is undirected – i.e. links do not have a specified direction – for knowledge is supposed to be exchanged among the organizations.

Data for the construction of the four states of the network observed have been gathered from the Community Research and Development Information Service (CORDIS)[1] archive where also information on the institutional type of the organizations – used to evaluate institutional proximity – is available. Technological profiles and organizational membership – respectively referred to technological and organizational proximity – have been collected from organizations' websites, while NUTS levels to measure geographical proximity are reported in the Eurostat website[2]. Data on patents are collected from the European Patent Office search engine[3].

3.2 Stochastic actor-oriented models for longitudinal network analysis

SAOMs are the outcome of the combination of Markov processes with random utility models (a multinomial logistic regression model is used) in a stochastic approach of Monte Carlo type; the package *RSiena* for "R"

[1] Freely available at: www.cordis.eu.

[2] http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts nomenclature/introduction

[3] Available at: http://worldwide.espacenet.com/?locale =en_EP

environment (Ripley et al., 2013) is used in the analysis.

First of all, the network is supposed to evolve according to a Markov Chain with a continuous time parameter observed at discrete time moments (Norris, 1997). The observation of the network at different time intervals corresponds to the discrete time moments (t_1, t_2,..t_m), and the evolution between t_{m-1} and t_m is assumed to be continuous and simulated with a Monte Carlo method.

Every node, in the moment in which has a chance to make a change (i.e. creating or interrupting a tie, or deciding to maintain its tie set unvaried), evaluates the whole configuration of the network, and decides to perform the action which mostly improves its "satisfaction". The change opportunity process – modeled by the so called *rate function* – and the change determination process – modeled by the *evaluation function* – will be detailed later on.

Actors are "memoryless" for Markov's chains assume that the next state only depends on the actual state and not on the sequence of events that preceded it. Moreover they are strategically myopic for they are not able to imagine conjectures about the countermoves of the other nodes and they cannot ally or coordinate their behaviours. On the other side, they are omniscient on the relational dimension because they perfectly know the state of the networks; that is all the nodes and their connections. Obviously, such an assumption is hard to be sustained for large networks; in those cases the interpretation of the model results should be aware of it.

The first observation (t_1) is not modeled and is assumed as given, consequently the history of the network until t_1 is not taken in account and does not contribute to the estimation of the parameters of the model.

The change opportunity process is given by the rate function, for each actor *i* of the network *x* the function is modeled as an exponential distribution with parameter λ because in continuous Markov chains time follows a Poisson process. The parameter describing the rate function of the model, defined $\lambda_+(x^0)$, where x^0 identifies the state of the network at a certain time, is equal to the sum of each actor's *rate* (Ripley et al., 2013):

$$\lambda_+(x^0) = \sum_i \lambda_i(x^0) \tag{1}$$

Events are called *mini-steps*, in each step an actor is given the opportunity to change one tie or to leave things as they are. In the simplest case the frequency of the change opportunity is the same for all the nodes and the model parameter for the rate of change is estimated only considering the number of changes in the ties of the network between the wave t_m and the wave t_{m+1}. In the case that other factors are considered relevant to determine nodes' change opportunity – in addition to the number of changes between the subsequent observations – the parameter can be function of other variables (Snijders, 2009) such as nodes' Dc or other attributes that could justify a more intense activity – that is greater chance to make a change – of a node[4].

In the model that has been run in this work no other factors are supposed to affect the change opportunity of the nodes, hence *rate* parameter of all nodes *i* during the *wave m* is a

[4] All the details on the *rate function* properties are explained in the *RSiena* manual (Ripley et al., 2013).

constant; the term *function* will be omitted because it implies the dependence on other variables.

At each *mini-step*, that is when just one node *i* can make just one tie change, the set of the new matrices that will potentially represent the next state of the network will be composed by x^0 – the network at the current state, in case no change occurs – plus the *n*-1 matrices which differ from x^0 in only one element of the row *i* (self loops, represented in the main diagonal do not make sense in the model), that element will be substituted by its opposite $x_{ij} = 1 - x^0_{ij}$.

When a node is given the opportunity to perform an action, the specific action he will do is modeled by an evaluation function[5] that defines the desiderability of a change of the network from the state x^0 to the state *x* for a node. Actors make the change that mostly improves their satisfaction – with a random element representing the partial predictability of an action – with their ego-network. The function of the actor *i* is basically expressed as follows:

$$f_i(x^0, x, v, w)$$

It depends on the current state of the network x^0, on the following state *x*, and on actor covariates (*v*) and dyadic covariates (*w*) which respectively represent nodes' and relations' attributes. Therefore, it models the attraction exerted on the actor *i* by a change of the network from the state x^0 to the state *x*, also taking into account the preference of the actor for the creation of a tie with nodes having a certain state on individual or relational attributes chosen[6].

Covariates, as mentioned, define the attributes of a network. Although they are not included in the basic definition of a network, attributes allow a deeper comprehension and a more extensive explication of networks structure and dynamics. Individual covariates correspond to nodes' attributes. For example the attribute "institutional type" in our collaboration network is an individual covariate because it is referred to an attribute of the organizations and can be employed to explore the tendency in the creation of ties between nodes of the same institutional type. The covariate is expressed as a vector in which each node's state on the attribute is recorded. Dyadic covariates are instead referred to relational attributes and are employed when the attribute is defined by the nodes of a dyad. For example, the spatial distance among two nodes is expressed as a relational covariate because the spatial position of both nodes has to be known in order to calculate their distance. The covariate is thus expressed as a matrix of size *N*x*N* – with *N* equal to the number of nodes – where each cell reports the state of the couple – namely their spatial distance – on the attribute. When covariate identity or similarity effects are included in the model, it is possible to account for the action of homophily in the formation of a tie between nodes which

[5] The evaluation function was formerly called *objective function* (Snijders, 2001).

[6] Also a *creation* and an *endowment* functions can be included in the model; the former models only the satisfaction gain after the creation of a tie, with the latter the loss associated to the dissolution of a tie is modeled (Ripley et al., 2013).

present the same or a similar state on a certain attribute[7].

In the Markov process, when actor i has the opportunity to change a tie – defined by the random variable[8] X_{ij} (j = 1, ... , n; $j \neq i$) – on the time depending matrix $X(t)$ corresponding to the state x^0 – the set of the possible future states of the network is defined as $C(x^0)$. All the $x' \in C(x^0)$ can differ from x^0 for no more than one element x_{ij} because only one tie can be changed or no changes can be made. Hence, the probability that the new state will be x is expressed as follows (Snijders, 2009):

$$\mathrm{P}\left\{\begin{matrix} X(t) \text{ changes to } x \mid (i) \text{ has a change} \\ \text{opportunity at time } t, X(t) = x^0 \end{matrix}\right\}$$

$$= p_i(x^0, x, v, w)$$

$$= \frac{\exp\left(f_i(x^0, x, v, w)\right)}{\sum_{x' \in C(x^0)} \exp\left(f_i(x^0, x', v, w)\right)} \qquad (2)$$

That is, the probability that the random variable $X(t)$ would bring to the state x – conditioned on the chance of the node i to make a change at time t with $X(t)$ corresponding to x^0, and given the covariates v and w – is defined by the ratio of an exponential transformation of the evaluation function of the actor i and an exponential transformation of all the possible changes x' belonging to the set C. This definition of the probability matches the one used in multinomial logistic regression assuming that the component not explained by the evaluation function has a Gumbel distribution (Snijders, 2001; 2009; Snijders et al., 2005).

The two components of the model – namely the change opportunity and the change determination – are expressed in one intensity matrix, called *transition rate matrix* or Q-matrix, whose elements $q_{x^0,x}$ are defined as follows:

$$q_{x^0,x} = \lim_{dt \downarrow 0} \frac{\mathrm{P}\left(X(d + dt) = x \mid X(t) = x^0\right)}{dt}$$

$$(x \neq x^0)$$

The probability in the numerator, which has been defined in the equation (2), is considered over small intervals of time ($dt \rightarrow 0$) representing the *ministeps*.

The elements of the Q-matrix are obtained combining for each actor i the rate function with the evaluation function:

$$q_{x^0,x} = \lambda_i \, p_i(x^0, x, v, w)$$

The algorithm used for the determination of the elements of the Q-matrix according to the Markov process basically iterates as follows (Snijders, 2009):

1. The process begins at the time t and at the state $X(t) = x^0$;
2. The change opportunity is given by the formula (1). Let U be a uniform random number between 0, while $dt = -\ln(U)/\lambda$ having a negative exponential distribution with parameter λ, t changes into $t + dt$.

[7] Models of co-evolution of networks and behaviour – also available in *RSiena* – permit the exploration of influence played by the formation of ties on the behavioural characteristics of the actos, in this case the change determination functions are extended to behavioural changes also. This kind of analysis is not performed in the present contribution, for a complete description see Snijders et al., 2007; Ripley et al., 2013.

[8] Random variables are indicated with capital letters while observable variables are identified by small letters in line with the common notation in statistics.

3. A random actor i is chosen with probability λ_i / λ. Actor i chooses a random actor j with probability defined by the formula (2) and the random variable $X_{ij}(t)$ changes into $1 - x^0_{ij}$.
4. Back to step 1.

The evaluation function is specified as the linear combination:

$$f_i(x^0, x, v, w) = \sum_k \beta_k \, s_{ki}(x^0, x, v, w)$$

where s_k are statistics defining the effects which drive the evolution of the networks and their β parameters are estimated with a procedure which will be described afterwards.

However, when it is theoretically and statistically reasonable to suppose that the intensities of the β parameters vary from wave to wave, it could be necessary to explore model's temporal heterogeneity (Lospinoso et al., 2010). From the theoretical side, is often plausible that the strength of the effects driving the evolution of a network could vary during time, in particular when the periods defining the waves of the model are quite large, and the assumption of total temporal homogeneity could lead to distortions on the estimation of all the parameters. From the statistical side, asymptotic degeneracy of the model has to be considered. Since SAOMs are based on a continuous time Markov process with $t \rightarrow \infty$, a temporally homogeneous parametrization could lead to the attribution of a high probability on a set of graph which hardly resembles real world networks.

The evaluation function in models admitting temporal heterogeneity is defined as:

$$f_i^{(a)}(x^0, x, v, w) =$$
$$\sum_k (\beta_k + \delta_k^{(a)}) \, s_{ki}(x^0, x, v, w)$$

in which time dummies for the waves a and the effects k are estimated. Their direction (positive or negative sign of the dummy) and their strength (value of the dummy) account for the variations of the parameters respect to the base estimation given in the first wave (a=1).

The selection of the waves and the effects for which temporal heterogeneity has to be considered is based on Schweinberger's test (2012) – provided in the package *RSiena* – which compares the hypothesis of temporal heterogeneity vs the temporal homogeneity one (considered as the null hypothesis).

The model can be built selecting some effects which reasonably drive the evolution of the network among the several effects defined and provided in *RSiena*; below only the effects used in the model presented in this work are described[9]. First there are three topological effects which aim to model network evolution only according to the position of the nodes in the network, that is their connections and the connections of their neighbours. The other three effects instead describe the role of individual and dyadic attributes.

1. *Degree (or density) effect:*

models the generic tendency to the creation of ties. It has to be specified inserting the other effects and its interpretation is conditioned on

[9] Exhaustive presentations of the effects which can be included in the model using *RSiena* are in dedicated contributions; also effects defined by the user can be set (Snijders, 2001; 2005; 2009; Ripley et al., 2013).

their strengths. It represents the cost associated to the creation of random arbitrary ties, where the arbitrariness stands for absence of reasons attributable to other effects. Since the cost of an arbitrary tie is commonly higher than its benefits, the corresponding parameter (β_1) should be negative. Its algebraic definition is:

$$s_{1i}(x) = x_{i+} = \sum_{i} x_{ij}$$

2. Transitive triads effect:

models the tendency to network closure (Coleman, 1988) calculating the formation of a direct tie between a couple of nodes *i* and *h* in presence of one or more indirect connections – paths of length 2 in the form *i* ↔ *j* ↔ *h* – between them. It is defined by the following formula:

$$s_{2i}(x) = \sum_{i,h} x_{ij}\, x_{ih} x_{jh}$$

3. Betweenness effect:

This effect models the intermediation or brokerage dynamics in the evolution of the network which are present if actors are inclined to position between not directly connected couples of nodes. Hence for each node *i* connected to nodes *j* and *h*, the effect looks for the absence of *h* ↔ *j*.

$$s_{3i}(x) = \sum_{j,h} x_{hi} x_{ij} \left(1 - x_{hj}\right)$$

Contrarily to the "transitive triads" effect which was focused on the creation of closed triangles, the betweenness effect centres on the triangles with two legs which could be seen as local structural holes (Burt, 1992, 2001, 2004).

4. Same covariate effect (or covariate-related identity):

The influence of homophily-based mechanisms on the evolution of the network can be evaluated by means of this effect. It models the tendency to tie creation in couple of nodes which have identical stats on the attribute *v*.

$$s_{4i}(x) = \sum_{j} x_{ij}\, I\{v_i = v_j\}$$

where the indicator function *I* will be 1 if $v_i = v_i$ and otherwise 0.

The identity effect is used in case of categorical covariates, "covariate similarity effects" can be included if the attribute is expressed in an ordinal, interval or ratio scale.

5. Dyadic covariate main effect (centered on the mean):

Models the role played by a dyadic attribute on the creation of a tie in a couple of nodes. When the covariate is observed on an ordinal, interval or ratio scale, the similarity effect is calculated multiplying for each tie *x* between two nodes *i* and *j* the difference between the value of the covariate on that couple of actors (w_{ij}) and the average value of the distribution of the covariate over all the couples of actors ($\overline{w}$).

$$s_{5i} = \sum_{j} x_{ij} (w_{ij} - \overline{w})$$

6. Covariate related popularity:

Simply models the attractiveness of a node *i* basing on its state on an individual covariate *v*:

$$s_{6i} = \sum_{j} x_{ij} v_j$$

The estimation of the parameters of the rate and the evaluation function can be performed choosing one between three different methods: moments (Snijders, 2001; Snijders et al., 2007), maximum likelihood (Snijders et al., 2010) and bayesian (Koskinen and Snijders, 2007). Method of moments has been used in this work, hence the estimation of the parameters vector θ is based on the condition of equality of the random variable U (defining the vector of the expected values) with the moments observable (u) on the network states:

$$E_{\hat{\theta}}U - u = 0 \quad (3)$$

Obviously, the efficiency of the estimator will depend on the statistics included in U, namely the effect selected in the model.

Since the expected values cannot be calculated analytically, the moment equation (3) is solved by a stochastic approximation method based on a variant of the Robbins-Monro algorithm (1951). A sequence of estimations $\theta^{(N)}$ which converges to the solution of the equation is produced by the algorithm. The derivative matrix (D), or Jacobian matrix, of $E_{\hat{\theta}}$ used to estimate the covariances of $\hat{\theta}$. Since the variance of the estimator of D can result very high, its reduction is obtained by a Monte Carlo method. For a detailed description of the generation of the sequence $\theta^{(N)}$ and the estimation of the Jacobian matrix, dedicated contribuitions by Snijders and colleagues can be constulted (Snijders, 2005; 2007; Snijders and van Duijn, 1997; Ripley et al., 2013). Here we point on the assumption stating that the estimator's values around the correct estimator θ have a normal distribution implying that a Student's t-test for the statistical significance of the parameter can be applied dividing the standard deviation for its average value. Convergence of the algorithm is evaluated comparing the deviations (*d*) of the simulated parameters from the observed ones. Ideally there should be no differences, but the stochastic nature of the algorithm should lead, in case of sufficient convergence, to values close to zero. Therefore another t-test is performed dividing the standard deviations of d by the average value of d: convergence is excellent with values lower than 0.10, reasonable when the ratio is under 0.2, moderate if under 0.3. Notice that this test is referred to the capability of the algorithm to estimate values close to the target (the observed values), while the previous one is used to decide between the acceptation of the value estimated for each parameter and its rejection (null hypothesis).

Last, the modeling of edge direction has to be explicited. As explained in paragraph 3.1, the Aerospace R&D collaboration network is undirected. SAOMs offer five options to model the initiative of the actors in the creation of ties. The most suited in this work is the "Unilateral initiative and reciprocal confirmation" one (Ripley et al., 2013) according to which actor *i* takes the initiative to propose or dissolve an existing tie with actor *j*, then the tie offer has to be confirmed by *j*, if he refuses no tie is formed. Contrarily, tie dissolution does not require a confirmation. This form of modeling resembles properly the process of consortia formation in FP-funded projects where organizations spontaneously decide to pool and submit a project proposal, in this phase all the organizations embedded in the proposal have to mutually agree the partnership and each of them is free to reject an offer or give up before the proposal is accepted. Hence, the simulation performed in the model should resemble – in a really simplified way – the phase of consortia formation, while the observed states of the network at each FP actually correspond to the steady connections after the proposal have been submitted and accepted. One limitation of the adoption of SAOMs in the modeling of FP-funded networks evolution is due to the assumption that actors cannot coalesce, while the concrete practice of partnerships is often a collective process in which more than two organizations simultaneously agree to join in the design and submission of a proposal and in the search for other partners.

3.3 The operationalization of the variables

Network proximity will be investigated by transitivity and intermediation tendencies which will be respectively controlled by *transitive triads* effect and *betweenness* effect. Three forms of proximity – namely institutional, technological and organizational – will be controlled by individual covariate identity effects. The institutional dimension has been operationalized as a nominal variable observable in three modalities basing on an extension of the "Triple Helix" model to which the "Fourth Elix" of non-profit research institution is added (Leydesdorff and Etzkowitz, 2003): industrial organization (*ind*); higher education institution (*edu*); and research centre (*res*). Cognitive proximity is defined by the similarity of the knowledge bases of a couple of organizations. As specified in paragraph 2.5, an organization's cognitive base is a multidimensional concept; in this study we will focus on the technological dimension as it is the most relevant in the context of R&D networks, therefore it will be adopted the more proper operative definition of technological proximity. It will be defined by five modalities representing the technological profile of an organizations; three of them are typical technological sub-sectors of aerospace (Niosi and Zhegu, 2005): avionics (*avionics*), aerostructures (*aero struct*), and propulsion systems (*prop sys*); one is referred to the system integrators (*sys int*); the last comprehends all those organizations dedicated to general system engineering activities (*sys eng*). The "same covariate effect" will check for the influence of technological overlap.

Also in the case of organizational proximity the same covariate effect will be used to control whether two actors which belong to the same institutional framework (i.e. the same industrial group, or national research centre institution/network) show a tendency to the creation of a tie, without taking into account the extent of the membership.

Geographical proximity will be evaluated as a "main effect of the dyadic covariate" because it is observable at four different levels obtained by the Eurostat NUTS (Nomenclature of Territorial Units for Statistics) classification. Score 0 is assigned to couples of organizations territorially unrelated, 1 to organizations from the same country, 2 to couples of the same NUTS-1 region, 3 to dyads of the same NUTS-2 region. Last, organizations' patenting activity will be controlled as "covariate-related popularity" effect in order to check if the number of patents registered by an organization during the period close to the formation of each of the FPs exerts an attraction for the formation of ties with other nodes.

4. MODEL’S SPECIFICATION AND RESULTS

Before showing and discussing the results drawn by the longitudinal analysis, some descriptive measures of the backbone network on the four observations are presented (table 2). First, it is appreciable that the network is fully connected until the last observation (FP7) when 5 organizations are instead isolated from the backbone as the size of the giant component (GC[10]) drops to 0.96. The networks gets increasingly denser until FP6, while in FP7 the backbone is some sparser, also as a consequence of the reduced size of the GC. Coherently, the average distances (Apl) among the organizations exhibit a decreasing trend until FP6 and enlarge in FP7; while the diameter is not affected by the average increase of the distances. Clustering (Cl) is always high (around 75%), the average degree centrality has the same trend of the density and the Apl, with a number of cooperative links possessed on average by the backbone organizations which varies between almost 33 (in FP4) and almost 47 (in FP6).

Summarizing on these measures, the organizations are more and more cohesive in the cooperation network until FP6 (as witnessed by the density values); they are directly connected or separated by a small number of cooperative links – that is the knowledge exchanged by a couple of organizations potentially spreads quickly in the network – which gets smaller and smaller until FP6. Considering that the diameter is stable on 3 steps, it is straightforward that the number of direct connections increases until FP6 and slightly decreases in FP7.

The degree centralization (Dc Ce) increases of about 10 points between FP4 and FP5, suggesting an increase in the prominence of a restricted group of organizations with a higher number of cooperative relations, respect to the number of connections possessed by the other organizations. Contrarily, and coherently with the evidences on the cohesiveness of the network, the brokerage activity is evenly distributed among the organizations, as shown by the low values of the betweenness centralization (Bc Ce). Finally, the increasing trend of the closeness centralization (Cc Ce) suggests the emergence of a small group of

[10] Some details on the measures presented in table 2 are provided in this note, for an exhaustive exposition see Wasserman and Faust (1994). The size of the giant component (GC) is calculated as the fraction of nodes of the largest subset of network in which there exists at least a path connecting each couple of nodes; a path is measured by counting the number of links that separate two nodes. The density is defined as the number of existing links over the number of possible links in the network. The average path length (Apl) is calculated as the average of all the shortest paths connecting all the couples of nodes. The diameter is the longest among the shortest paths connecting each couple of nodes. The clustering (Cl) is calculated dividing the number of closed triplets (i.e. subsets of three nodes connected by three links) over the number of triplets with at least two legs (i.e. subsets of three nodes connected by two or three links). The average degree centrality (Adc) is the average value of the number of links possessed by the nodes (Dc), while the degree centralization (Dc Ce) is calculated as the sum of the differences of the Dc of all the couples of nodes over the sum of the differences of the Dc of the node with the highest Dc and all the other nodes. Analogously the betweennes centralization (Bc Ce) and the closeness centralization (Cc Ce) are calculated on the distribution of the betweennes centrality and the closeness centrality of the nodes. The former is defined by the number or shortest paths in the network connecting each couple of nodes and passing for a specific node over the total number of shortest paths of the network. The closeness centrality is defined as the inverse of the shortest paths between a specific node and all the other nodes of the network.

Table 2: Descriptive measures of the backbone network from FP4 to FP7

	N	L	GC	Dens (%)	Diam*	Apl*	Cl	Av Dc	Dc Ce	Bc Ce	Cc Ce*
FP4	142	2333	1	23.30	3	1.82	0.76	32.86 (24.76)	48.30%	5.58%	43.64%
FP5	142	2776	1	27.73	3	1.73	0.73	39.10 (26.75)	58.92%	6.32%	58.73%
FP6	142	3329	1	33.25	3	1.68	0.75	46.89 (28.67)	56.19%	5.65%	59.14%
FP7	142	3034	0.96	30.31	3	1.72	0.76	42.73 (28.69)	57.02%	6.86%	61.41%

Legend: "N" = number of nodes; "L" = number of links; "GC" = size of the giant component; "Dens (%)" = density; "Diam" = diameter; "Apl" = average path length; "Cl" = clustering; "Av Dc" = average degree centrality, standard deviation in parenthesis; "Dc Ce" = degree centrality centralization; "Bc Ce" = Betweenness centrality centralization; "Cc Ce" = closeness centrality centralization.
* Calculated on the GC.

organizations which can reach the other nodes more quickly (i.e. by a small number of cooperative links) than the other organizations. Notice that the highest values of cohesion and the lowest distances in the network are registered during FP6, that is, when specific instruments to improve the cohesiveness of the ERA – i.e. the Integrated Projects and the Network of Excellence – have been adopted by the policy maker. On the other side an erosion of the backbone is appreciable in FP7, when the network is no more fully connected, and the average distance among the organizations is increased as well as the gap separating a small group of "close" organizations and all the other nodes of the backbone. After this brief description of the states of the network on the four observations, the longitudinal analysis is presented. As declared in the former paragraphs the propositions about the role of proximity dimensions on the evolution of the backbone network will be controlled by means of a stochastic actor-oriented model.

First, it is important to verify the amount of change among a wave and the following one. This is done using Jaccard's similarity coefficient (*J*). In table 3 it is possible to appreciate as the backbone networks are increasingly similar meaning that the network undergoes less modifications in the creation and dissolution of collaboration links. It is recommended to run models on longitudinal networks whose *J* is generally higher than 0.3 or does not decrease under the value of 0.2 in order to keep realistic the assumption on the graduality of the network's evolution (Snijders et al., 2007); the values found in the network under investigation do not violate this suggestion. It is also advised to include only basilar network effects in the first phases of the construction of the model, in order to check for endogenous dynamics, and progressively add further effects and drop the

Table 3: Jaccard indexes for subsequent observations

Wave	0 ==> 0	0 ==> 1	1 ==> 0	1 ==> 1	Distance	Jaccard
1 ==> 2	6265	1413	970	1363	4766	0.364
2 ==> 3	5644	1591	1038	1738	5258	0.398
3 ==> 4	5628	1054	1349	1980	4806	0.452

Legend: "Wave" = time lapse between an observation and the next one (1 ==> 2 stands for FP4 ==> FP5; 2==>3 for FP5==>FP6; 3==>4 for FP6==>FP7). Absent edges unchanged: 0 ==> 0; edges created: 0 ==> 1; edges interrupted: 1 ==> 0; present edges unchanged: 1 ==> 1.

ones that are not significant, following a forward selection procedure (Snijders, 2001; 2005).

This way is possible to avoid model's instability when running the algorithm and get reliable estimations of the parameters. Consequently, the first model presented (**Model 1**, table 4) is very simple and only includes *degree*, *transitive triads* and *betweenness* effects. The first one must be included in all evaluation functions and, as stated in paragraph 3.2, it is a sort of intercept of the model and represents the tendency to form arbitrary edges. Since building and managing relations is a costly activity and a scarce resource, the parameter relative to the density effects should be negative and high in comparison to the other ones. The value estimated in Model 1 is coherent with this. *Transitive triads* effect is also generally included in the SAOMs since it specifies a very common dynamic in networks: the tendency to close triangles (par. 3.2); by this effect we can model the influence of **network proximity**.

The positive sign and the low strength of the parameter show that the evolution of the backbone of the Aerospace sector is affected by a modest tendency to the closure of collaboration triads. Hence, two organizations which are not directly linked at time t_m, but share one or more common partners, have a low probability to be directly connected, that is to be partners in the same project, at time t_{m+1}, leading to a form of closure of knowledge streams. *Betweenness* effect, on the other side, is almost irrelevant and not significant excluding the tendency to intermediation and the creation of local structural holes from the factors affecting the evolution of collaborative relations. The algorithm is quite unstable in model 1 as two of the t-ratios for the convergence are not excellent. Next model (**Model 2**, table 4) is composed by the effects which operationalize the other forms of proximity considered in this work: geographical, organizational, institutional, and technological[11]. As described in the methodological section of the chapter geographical proximity has been operationalized as dyadic covariate, while institutional, technological and organizational dimensions are evaluated as individual covariates. Also the effect of patenting activity is included in this model.

[11] Also in this case I preceded adding one effect for each simulation in order to avoid instability in algorithm's convergence; here only the final model with six effects is presented.

Table 4: Tendencies in the formation of collaborative ties in the evolution of the backbone of the ERA in the Aerospace sector – Initial Models and model with temporally heterogeneous parameters.

Parameter	**Model 1**		**Model 2**		**Model 3 TH**	
	Estimate	**t-ratios**	**Estimate**	**t-ratios**	**Estimate**	**t-ratios**
rate: constant Var1 *rate* (wave 1)	74.979*** (3.530)	-0.018	80.147*** (4.096)	0.072	91.831*** (7.122)	0.049
rate: constant Var1 *rate* (wave 2)	83.625*** (4.829)	0.039	86.736*** (5.206)	-0.199	94.665*** (6.253)	0.016
rate: constant Var1 *rate* (wave 3)	49.624*** (1.875)	0.016	50.276*** (2.043)	-0.047	76.712*** (5.018)	0.000
eval: ***degree*** (density)	-0.677*** (0.030)	0.213	-0.762*** (0.014)	0.050	-0.896*** (0.012)	0.055
degree (density) Dummy (wave 2)					-0.030 (0.029)	0.001
degree (density) Dummy (wave 3)					-0.145*** (0.030)	-0.045
eval: ***transitive triads***	0.039*** (0.001)	0.027	0.039*** (0.001)	-0.079	0.045*** (0.001)	0.039
transitive triads Dummy (wave2)					-0.004*** (0.001)	0.009
transitive triads Dummy (wave 3)					-0.007*** (0.001)	-0.026
eval: ***betweenness***	-0.002 (0.001)	-0.197				
eval: ***geo prox***			0.043*** (0.013)	0.005	0.047*** (0.014)	0.010
eval: ***same org***			0.479*** (0.081)	0.044	0.388*** (0.087)	-0.060
eval: ***same inst***			-0.009 (0.015)	-0.067		
eval: ***same tech-s***			0.236*** (0.018)	-0.054	0.177*** (0.019)	0.041
same tech-s Dummy (wave 2)					0.156*** (0.044)	0.000
same tech-s Dummy (wave 3)					-0.008 (0.047)	-0.036
eval: ***patent***			0.002 (0.006)	0.039		

Legend: "Estimation" = average of parameters' estimations, standard deviation in parenthesis; "t-ratios" = test for the convergence of the algorithm.
Significance of the estimation values (probability of acceptation of the null hypothesis): *** < 0,01; ** < 0,05; * < 0,10.

The addition of these effects and the drop of the *betweennes* effect due to its irrelevance have no consequences on the estimation of the *transitive triads* parameter. Looking at the effects added to the model, it is possible to appreciate that the evolution of the network is moderately affected by **geographical proximity** (*geo prox*) meaning that there is a certain tendency to create collaborative ties basing on the location in the same NUTS region (at different levels, as described in the operazionalization of the variables). The membership in the same industrial group, research centre, or academic institution (*same org*), is a stronger driving factor in the collaborative choices of the backbone-organizations and in the evolution of the network (**organizational proximity**). Differently, the sharing of the institutional framework (*same inst*) seems to be irrelevant for the explication of the evolution of the network, suggesting that organizations decide to be partners independently of their institutional type.

Next, *same tech-s* effect, whose estimation is positive and significant, identifies a moderate preference for tie creation between organizations which possess an analogous techno-scientific profile (**technological proximity**). Last, patenting activity (*patent*) of the organizations does not exert any attractiveness for the creation of collaborative ties.

T-ratios are close to zero for all the effects showing an improvement of the convergence of the algorithm after the specification of the models with more effects.

Once a first framework of the factors driving the evolution of the network has been drawn by “model 2”, it is important to considerate if and how the mentioned factors change in the large time lapse between the first observation (FP4, started in 1994) and the last observation (FP7, ended in 2013). Schweinberger’s time test showed that many of the parameters included are, as expectable, temporally heterogeneous. Also, when checking for time heterogeneity and adding *time dummy variables*, forward selection procedure has to be followed: dummies are first added for the most heterogeneous parameter (in the waves in which heterogeneity is detected), then the test is run again because the insertion of time dummies can modify the temporal heterogeneity for the other effects (false positives) or the value of their parameters.

The opposite could also occur in the case that the introduction of new time dummies dissolves the effect of time dummies included before. The procedure is repeated until no temporal heterogeneity can be detected, obtaining the final estimation (**Model 3 TH**, table 4). Notice that *same inst* and patenting effects have been dropped because they were neither significant nor influential in model 2 and remained unchanged even after cleaning the temporal heterogeneity. The effects which accounted for the temporal heterogeneity of the model are density, transitive triads and same technological profile; the introduction of time dummy variables for these effects also modified some of the estimations provided in model 2. Looking at table 4 it is appreciable that the cost associated to the creation of arbitrary ties (*degree*) increased in absolute value its base estimation (0.896) respect to Model 2. It does not change relevantly between FP5 and FP6 (dummy wave 2) and is decreased in the following wave (i.e. between FP6 and FP7) after the inclusion of time dummies for transitive triads.

The tendency to the closure of triangles (*trans triads*) is a little more pronounced in the base estimation of the TH model respect to the one in model 2, and decreases very slightly during the following FPs, namely from the fifth to the seventh Programme, plausibly because many of the triadic relations in the network have been closed and no new triangles are opened as witnessed by the irrelevance of the betweenness effect.

Effects related to geographical (*geo prox*) and organizational (*same org*) proximity affect the evolution of the network without temporal heterogeneity; notice that the strength of the geographical proximity covariate is almost unchanged respect to Model 2, while the attraction attributable to the sharing of the organizational structure is reduced suggesting that a portion of the longitudinal evolution intercepted by this effect in Model 2 is more properly defined by the time dummies of other effects.

Last, the attraction exerted by the techno-scientific overlap (*same tech-s*) on the creation of collaborative relations grows in intensity between FP5 and FP6 (Dummy wave 2) but is keept constant in the final wave.

An extended model, based on the analytical decomposition of some of the covariates which have been operationalized, has been defined in order to investigate for which institutional types and which techno-scientific profiles the tendency to create collaborative ties based on homophily is stronger (or lower).

Same tech-s effect and *same inst* effect (the latter resulted not significant in the previous model), have been disaggregated in the **Extended Model** setting a dichotomous variable for each of the modalities which define them (table 5).

Therefore, the effect of three dummies is checked in the case of the technological framework: *same ind*, *same res*, and *same edu* which respectively model the reciprocal attractiveness among industrial firms, among research centres and among higher education institutions.

The techno-scientific profile covariate is transformed into the six profiles which characterize the backbone organizations creating a covariate identity effect for each of them: aeronautics integrator (*same aer int*), avionics (*same avionics*), propulsion systems (*same prop*); aerostructures (*same aero struct*), and system engineering (*same sys eng*).

The estimations of the parameters of the effects kept unchanged (*degree, trans triads, same geo, same org*) largely overlap with the ones gathered in the previous temporally homogeneous model (i.e. Model 2), hence focus can be centered on the new effects obtained by disaggregation.

Regarding the institutional dimension which in Model 2 was not relevant in the explanation of the longitudinal evolution of the network we can appreciate a slight attraction between industrial actors, and a moderate repulsion between research centres, while universities decide to create ties independently of the institutional form of the partner (table 5).

The estimation of the effects on the techno-scientific profiles show general tendency to a homophily-based attraction on this dimension except that in one case.

The attractive tendency on the covariates of the techno-scientific profile is moderate for system engineering organizations and is more clear for i) organizations working in the field of aerostructures and materials science (*same aero struct*); ii) organizations dedicated to electronics and opto-electronics and more generally (*same avionics*); and iii) organizations dealing with mechanical engineering and thermodynamics and more generally propulsion systems (*same prop sys*). Contrarily final integrators of aeronautics systems – i.e. vertex-firms of the aerospace industrial sector, research centres and university departments with broad and integrative competencies which gravitate around the aerospace pyramid (Niosi and Zhegu, 2005) – prefer the creation of collaboration ties with actors characterized by a different profile (table 5). Notice that the convergence of the algorithm (t-ratios) benefited the broader specification of the model obtained by the disaggregation of two of the covariates.

Last, an extended model with temporal heterogeneity is set (**Extended Model TH**, table 5). Topological position effects (*density* and *trans triads*) show comparable strength and temporal behaviour with those ones observed in the Model 3 TH (table 4), therefore they are not relevantly affected by the introduction of time dummies for the disaggregated covariates; same as happens with geographical proximity.

Regarding institutional proximity, *same firm* effect is constant in time and slightly increases its strength respect to the temporally homogeneous extended model; research centres, on their side, during the evolution from FP5 to FP6 (wave 2) dissolve the tendency to mutual repulsion registered in the base estimation (from FP4 to FP5, wave 1) and in the temporally homogeneous model, the effect is constant in the last wave.

The covariate identity effect has been dropped for higher education institutions (*same edu*) because it was not influential on the evolution of the network (table 5).

Focusing on techno-scientific profiles, organizations which operate in the propulsion systems sector have a tendency to the formation of collaborative ties among them in the base estimation (i.e. between FP4 and FP5, wave 1) which moderately diminishes in the following wave, that is in the evolution of the network from FP5 to FP6, and is unchanged in the last wave.

Contrarily, the basically modest reciprocal attraction for avionics dedicated organizations on the one side and aerostructures dedicated actors on the other results to be slightly increased in the evolution from the fifth to the sixth FP (wave 2).

Finally, the tendency to mutual repulsion showed by system integrators in the temporally homogeneous model is confirmed also when time dummies are included, even if its intensity is diminished between FP5 and FP6. The identity covariate effect for system engineering organizations (*same sys eng*) has not been included in this model because its influence on network's longitudinal evolution is null, as appreciated even in the temporally homogeneous model (table 5).

Table 5: Tendencies in the formation of collaborative ties in the evolution of the backbone of the ERA in the Aerospace sector – Extended Models with temporally homogeneous and heterogeneous parameters.

Parameter	**Extended Model**		**Extended Model TH (final)**	
	Estimation	**t-ratios**	**Estimation**	**t-ratios**
rate: constant Var1 rate (wave 1)	81.267*** (4.204)	-0.077	90.531*** (5.809)	-0.058
rate: constant Var1 rate (wave 2)	87.172*** (4.833)	-0.107	91.894*** (6.692)	-0.021
rate: constant Var1 rate (wave 3)	51.448*** (1.991)	0.002	75.951*** (4.310)	-0.024
eval (base): **degree** (density)	-0.830*** (0.021)	0.076	-0.937*** (0.023)	0.0212
degree (density) Dummy (wave 2)			-0.082* (0.048)	0.022
degree (density) Dummy (wave 3)			-0.159*** (0.043)	0.001
eval (base): **transitive triads**	0.038*** (0.001)	-0.018	0.045*** (0.001)	-0.053
transitive triads Dummy (wave 2)			-0.006*** (0.002)	0.013
transitive triads Dummy (wave 3)			-0.007*** (0.002)	0.007
eval: **geo prox**	0.033*** (0.014)	-0.025	0.036*** (0.014)	-0.017
eval: **same org**	0.485*** (0.084)	0.019	0.379*** (0.090)	-0.049
eval: **same edu**	-0.008 (0.016)	-0.043		
eval (base): **same res**	-0.095*** (0.016)	-0.059	-0.085*** (0.016)	-0.031
same res Dummy (wave2)			0.081*** (0.034)	0.015
eval: **same ind**	0.045*** (0.016)	-0.036	0.058*** (0.015)	-0.032
eval: **same sys eng**	0.054*** (0.016)	-0.045		
eval: **same prop sys**	0.165*** (0.014)	-0.046	0.189*** (0.015)	-0.042
same prop sys Dummy (wave 2)			-0.060* (0.035)	0.013
eval (base): **same avionics**	0.103*** (0.015)	-0.045	0.051*** (0.015)	-0.008
same avionics Dummy (wave 2)			0.073** (0.035)	0.025
same avionics Dummy (wave 3)			-0.039 (0.038)	0.007
eval (base): **same aero struct**	0.086*** (0.015)	-0.016	0.032** (0.016)	-0.017
same aero struct Dummy (wave 2)			0.101*** (0.031)	0.016
eval (base): **same aero int**	-0.126*** (0.015)	-0.032	-0.112*** (0.016)	-0.027
same aero int Dummy (wave 2)			-0.072** (0.033)	0.016

Legend: "Estimation" = average of parameters' estimations, standard deviation in parenthesis; "t-ratios" = test for the convergence of the algorithm.
*** p-value < 0,01; ** p-value < 0,05; * p-value < 0,10.

5. CONCLUSIONS

The longitudinal network analysis presented in this work focused on the evolution of the network of organizations which composed the backbone of the ERA in the aerospace sector from the fourth to the seventh FP. SAOMs allowed the modeling of the behaviour of the organizations in the creation of ties controlling the influence of some effects defined after the five dimensions of inter-organizational proximity identified in the literature (Boschma, 2005).

The membership in the same industrial group or research institution – as specification of **organizational proximity** – proved to be the most important driver for the longitudinal evolution of the network. Further, this form of proximity is constant in time, analogously to the geographical one which, on its side, only moderately affects network's evolution.

As discussed in section 3.2, organizational proximity in inter-organizational collaboration networks is sought in order to reduce the uncertainty related to the coordination of the joint effort (Boschma, 2005; Kleinknecht e Van Reijnen, 1992; Tether, 2002; Negassi, 2004). The evidence about the role played by this form of proximity suggests that coordination in the process of collective knowledge construction is perceived as a relevant matter in the FP-subsidized AS network. This interpretative key can be supported by considering that i) the expected research outcomes of the project require a complex joint effort in which different – sometimes tacit – knowledge contributions have to be exchanged and integrated; ii) time is scarce because projects have a predefined deadline subscribed and accepted in the proposal; and iii) average size of the projects is of about 15 partners but some can involve up to 60 members. Hence a certain extent of already formalized relations in established organizational frameworks – where roles and tasks are largely set – can trigger a sort of self-management inside the projects facilitating the knowledge exchange, the planning of the time deadlines, and the task division among many partners.

The weak but steady influence of **geographical co-location** on the evolution of the network in the Aerospace sector is coherent with the evidences provided by other studies focused on the EU-subsidized collaboration networks (Autant-Bernard et al., 2007; Maggioni et al., 2007; Maggioni and Uberti, 2009; Scherngell and Barber, 2009; Paier and Scherngell, 2011; Scherngell and Lata, 2011; Balland, 2012). Therefore, although partnerships are characterized by the geographical mixing required by the participation rules established to meet the targets of the ERA, the longitudinal simulation of the network evolution is able to demonstrate that backbone organizations constantly rely also on the advantages typical of geographical proximity.

Network proximity exerts a weak but positive influence on edge formation – also found in other studies on FPs collaboration networks (Autant-Bernard et al., 2007; Paier and Scherngell, 2011) – and decreases over time, plausibly because the number of collaborative triads to be closed progressively diminishes as reported by the descriptive measures of the network (table 2).

The mutual attractiveness between organizations which share a common partner inside the backbone and can be related to the trust which can be granted by the indirect acquaintance and pushes the actors toward the creation of a sort of "network capital" based on the control of opportunistic bahaviours, on the redundancy of knowledge streams, and on the creation of dense and closed relational patterns coherently with Coleman's theorization (1988). It is instead absent the opposite tendency, that is the search for local brokerage positions, reasonably because the analysis has been realized on an organizational backbone in which relations have been consolidating during time, as observed also by other scholars (Breschi and Cusmano, 2004; Breschi and Malerba, 2009; Heller-Schuh et al 2011; Protogerou et al., 2010, 2012; Roediger-Schluga and Barber, 2008).

Regarding the **techno-scientific dimension**, organizations with the same profile generally propend for the mutual attraction in tie formation; however the analytical outlook provided by the disaggregation into different single profiles, shows that the collaborative ties are preferentially created with partners who possess an analogous knowledge base for the three sub-sectors of aerospace, namely avionics, aerostructures and propulsion systems.

Contrarily, aeronautics integrators show a tendency to reciprocal repulsion. The propension by these leading actors to avoid the participation in the same FP-subsidized project can be interpreted referring to two reasons: one is related to coordination, the other to the preservation of strategic knowledge. According to the former, the co-presence of more than one top-level actor in a research consortium can create problems in the partition of the tasks, of the responsibilities, and of the funds. Regarding strategic knowledge, it is plausible to suppose that integrator firms are reluctant to share knowledge with competitors in order to avoid the risk of unintended spillovers. This is still truer in a "winner takes all" sector, and aerospace is the case (Giuri et al. 2007). Also higher education institutions and research centres possessing a broad integrative knowledge in aerospace can be reluctant to the exchange of knowledge with similar actors, because of reasons related to prestige and identity – and this could be the case of universities – or because of national aerospace policies (which also include military research) in the case of national aerospace agencies and research centres.

Organizations operating in the sub-sector of propulsion systems have a tendency to collaborate with partners characterized by an analogous technological profile, to a greater extent than in the case of avionics or aerostructures dedicated actors. Therefore the formers prefer to choose their partners inside the backbone, meanwhile it cannot be excluded that –in the case of the research in avionics and aerostructures – resources could also be found among the peripheral actors – those ones outside the backbone – hence suggesting a higher substitutability of the actors in these fields.

System engineering organizations do not show a tendency toward homophily-based attraction or repulsion; hence they create cooperative links independently of the identity of the technological profile.

In general terms, the identity on the **institutional dimension** does not affect the evolution of the FPs networks in Aerospace. However, a deeper analysis shows that research centres are more likely to create collaborative relations with organizations which have a different institutional framework. Firms, by their side, have a certain tendency toward the collaborations with partners of the industrial sector, maybe referring to relations already set inside the industrial pyramid.

Last, there is no effect of patenting activity by the organizations on their attractiveness: it seems that actors of the backbone do not need a codified proxy on the width of their partners' knowledge base; maybe the better rely on the informal channels set in a collaborative framework which has been consolidating during years.

The focus on the mechanisms and the dynamics occurring in a restricted sub-network – i.e. the backbone – constitutes the main limitation of this contribute. Although this sub-network represents the most relevant component sector because it granted FPs continuity and integration, the evidences cannot claim for a generalization. The relational approach itself suggests that the identified mechanisms can be emphasized, weakened, or dissolved when all the actors and all the relations are taken into account. Therefore, when drawing concluding remarks on the proximity dynamics in the evolution of the network under investigation, it must be considered that the backbone is neither a self-sufficient nor an autonomous component because its topological configuration and temporal evolution are also affected by all the other relational patterns which define the whole network. It is important to figure that the resources can also be acquired externally – that is seeking for peripheral actors – even if it could be reasonably supposed that the relational patterns of the backbone have a high structuring power on the surrounding framework. Moreover, a cliquish structure of the research projects has been assumed in the network projection (see paragraph 3.1) and future efforts should be addressed to the investigation of projects' internal network structure.

Further, results can be biased by the fact that the operazionalization of the proximity dimensions followed the dichotomous criterion of identity/diversity, except in the case of geographical proximity which has been defined by four levels. Last, network proximity is a raw proxy of the micro aspects rooted in the direct personal interactions which properly define the social proximity.

Future perspectives of research grounding on this contribution can be addressed to the reduction of the biases deriving from the mentioned limitations in order to widen the theoretical and empirical scopes. Anyway a growth of network's size – so to also include peripheral actors – can be hardly matched with the actors' relational omniscience assumed by SAOMs.

A deeper specification of the proximity dynamics can be obtained analyzing their interactions in order to ascertain if some dimensions can substitute, inhibit, or favour the effects of other dimensions (Broekel, 2012).

Last, a really interesting challenge would deal with the analysis of the co-evolution of the EU sub-subsidized networks and other networks in which the same actors are embedded – such as supply networks, spontaneous RJVs, co-patenting networks – in order to investigate the interactions of the different relational forms included in the multiplex.

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