# KIBS and the Dynamics of Industrial Clusters: a Complex Adaptive Systems Approach

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**Abstract**

*An important and highly debated question in economic geography is how to explain the dynamics of industrial clusters, i.e. their emergence and evolution through time. Two main theories are generally explored, without being confronted: the cluster life cycle theory - which mainly adopts an aggregate point of view - and the network-based approach. Although KIBS are an important actor of industrial clusters, these two theories pay little attention to them as a potential driver of clusters' dynamics.*

*We show in this paper that properly taking KIBS into account requires considering an alternative and integrative approach that conciliates these two theories. In particular, we argue that complex adaptive systems (CAS) constitute a promising basis for such a synthesis. We then operationalize the CAS approach by studying an existing industrial cluster - Skywin (aeronautics in Wallonia region, Belgium) - within this framework. For this purpose, we use an exhaustive list of the innovation projects undertaken within this cluster between 2006 and 2014 and we build temporal innovation networks linking the agents of the cluster. It appears that Skywin's innovation networks exhibit a small-world effect. This implies that any agent who takes part into an innovation project of this cluster can easily benefit from knowledge and information generated within another ongoing project. We argue that this effect is an interesting proxy of a cluster's attractiveness and an appropriate aggregate variable for studying clusters' dynamics as it shows cluster's potential for further growth. We also demonstrate that KIBS are the main responsible for the emergence of this small-world effect in Skywin's innovation networks.*

## Introduction

This paper aims at intertwining – in a theoretical and operational way – three strands of literature: (i) innovation through knowledge intensive business services (KIBS thereafter), (ii) industrial clusters' dynamics, and (iii) complex adaptive systems.

KIBS are services which are processing, generating, and diffusing knowledge within the economy, and as such they are largely regarded as important (co-)producers of innovations (Miles et al., 1995; Gadrey and Gallouj, 1998; Den Hertog, 2000; 2002; Gallouj, 2002), as well as a promising engine for economic growth (Desmarchelier et al., 2013a) and a key component of regional and national innovation systems (Muller and Zenker, 2001) and of technological and sectoral systems of innovation alike. Typical activities are training services, R&D, engineering services and consultancy in its various forms (technical or not). KIBS include both traditional professional services (such as legal services, audit and accountancy, market research, personnel services, management consultancy, etc.) and new technology based services. According to Miles et al. (1995), regarding "*their relation to new technology*", compared to the latter, the former are "*users rather than agents in development and diffusion*" (p. 27) of new technologies. Universities are often not included into the broad category of KIBS (ex. Muller and Zenker, 2001; Miles et al., 1995). They have indeed many functions (e.g. teaching and fundamental/academic research), which are not directly oriented towards businesses' technological (and non-technological) needs. However, some of their functions clearly fit into KIBS purposes, especially but not exclusively new technology based KIBS (ex. technical training, technical consultancy, business funded R-D, establishment of research centers in partnership with businesses) and industrial clusters' studies very often highlight their central role in explaining clusters emergence (Saxenian, 1994; Audretsch and Feldman, 1996a; 1996b). The present study itself also underlines universities' role in favoring the emergence of new technologies within an industrial cluster. In this paper we therefore include universities and research bodies within the KIBS category and the empirical part is mainly focused on such types of KIBS.

More generally, KIBS' central role within successful industrial clusters has been emphasized since the birth of this latter concept. Indeed, in Porter's words "*clusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (e.g. universities, standard agencies, trade associations) in a particular field that compete but also cooperate*" (Porter, 2000, p.15). In this definition, KIBS enter mainly into the "*associated institutions*" category, as it includes "*universities, think-tanks, vocational training providers*" (p.17).

An important and highly debated question in economic geography is how to explain the dynamics of these clusters, i.e. their emergence and evolution through time (Frenken et al., 2015; Boschma and Fornhal, 2011). Two main theories are generally explored, without being confronted[1]: the cluster life cycle theory (Menzel and Fornahl, 2010; Shin and Hassink, 2011; Audretsch and Feldman, 1996) - which adopts mainly an aggregate[2] point of view - and a network-based approach (Saxenian, 1994). Surprisingly, these two theories pay little attention to KIBS as a potential driver of clusters' dynamics.

[1] A notable exception is to be found in Martin and Sunley (2011), whose contribution will be discussed in this paper.
[2] This means that the age of the cluster is proxied by just one (or a limited number of) variable(s), which can be for example the number of employees or the number of firms, etc.

We show in this paper that taking KIBS into account requires considering an alternative and integrative approach that conciliates these two theories. In particular, we argue that complex adaptive systems – or CAS - (Martin and Sunley, 2011; Holland, 2012) constitute a promising candidate for such a synthesis. Since these systems are mainly encountered into the theoretical literature (Dilaver et al., 2014; Albino et al., 2003; Squazzoni and Boero, 2002; Boero et al., 2004), we choose to justify our theoretical stance by studying KIBS' leading role within an existing industrial cluster, conceived as a CAS: Skywin (aeronautics in Wallonia region, Belgium).

The remaining of the paper is organized in two parts: we begin by discussing about the competing theories of clusters dynamics and we advocate for the CAS approach, then we conduct our empirical analysis in order to illustrate the usefulness of this theoretical stance.

# 1. Life Cycle Theory vs. Network-Based Approach: the need for a synthesis

## a. From product and industry life cycles to cluster life cycle

The life cycle hypothesis in economics and management literature is, in its original form, a descriptive model aiming at synthesizing in a coherent manner a wide variety of stylized facts about the evolution through time of the marketed products.

Pioneers of the Product Life Cycle (PLC) theory, Utterback and Abernathy (1975) portray product evolution in three successive steps: (i) the "uncoordinated process", within which firms undertake mainly product innovations aiming at improving their technical performance, (ii) the "segmental process", where firms modify minor characteristics for increasing product variety and earning market shares, then (iii) the 'systemic process" where innovation efforts focus on reducing production costs. These three phases are also and more often labeled: "fluid", "transition" and "specific" phases (Abernathy and Utterback, 1978). Even though authors claim that "*there is reason to believe that in any cases the progression may stop for long periods, or even reverse*" (Utterback, and Abernathy, p. 645), they insist on the high degree of predictability/determinism in the way products evolve through time. Klepper (1996, 1997) systematizes this PLC into a model of Industry Life Cycle within which firms' entries, exit, growth and innovations in "*technologically progressive industries*" (p. 564) are the driving forces behind the PLC.

The general character of this theory has been challenged by the advent of service economies. In particular, Barras (1986) points out the existence of a "reverse product cycle" (RPC) within service sectors. In this view, service firms acquire innovations (mainly information technologies) coming from manufacturing sectors firstly for improving the efficiency of service operations.  Then comes the stage of service quality improvement, and eventually the production of totally new services. The PLC is supposed to be reversed as far as process innovations precede product innovation in the cycle. Likewise, this life cycle theory of the innovation dynamics in services proved to be incomplete. Gallouj (1998) argues that it reflects a "*technological bias*" (p. 128): indeed in Barras model (1986), services cannot innovate by themselves as their innovations mainly come from the use of the so-called "enabling technologies", i.e. information technologies. Non-technological forms of innovation which are important in services and which concern not only the organization and the process but also the product are not taken into account by the RPC theory. In contrast, Gallouj (1998) finds that many KIBS perform several types of non-technological innovation including "ad hoc" innovations, i.e. custom made innovations adapted to their clients' needs.

Gallouj and Weinstein (1997) proposed a more complete view of firms' innovations (whether they originate from industry or services). Adopting a characteristics-based approach of the product – good or service – conceived as a set of technical and service characteristics[3], they identify six different modes of innovation: radical, improvement, incremental, ad hoc, recombinative and formalization (see Gallouj and Weinstein, 1997 for details). These six modes are not exclusive to each other nor a priori ordered in a pre-determined sequence. Another important point as regards the life cycle theory is that, according to the authors, the PLC encompasses only "one point of entry" for innovations: the technical characteristics of the product. It follows that the Life Cycle conception offers a limited and deterministic view of innovation dynamics. Nevertheless, it is a popular metaphor for reporting industrial clusters' evolutions.

A first exploration of the Life Cycle theory applied to industrial clusters is undertaken by Audretsch and Feldman (1996a; 1996b). According to them, the main driver of firms' agglomeration is the low transferability of tacit knowledge through long distances. Following Klepper's Industry Life cycle, they postulate that tacit/ localized knowledge is important in early developments of a given industry, fostering a certain degree of firms' agglomeration. However, as the industry becomes mature, a dominant design emerges and the product becomes standardized. Firms thus mainly rely on codified knowledge and information, which are easy to share in long distances. The initial clustering is thus replaced by a movement of firms' dispersion when the industry reaches maturity.

Even though KIBS are not explicitly mentioned by Audretsch and Feldman (1996a; 1996b), universities are seen by these authors as an important source of tacit knowledge and are thus a key focal point for early clusters' developments. Moreover, knowledge codification process appears to be the driving force of the life cycle. Arguably, services and KIBS in particular are major actors in knowledge processing (Gallouj, 2002) and transmission (Miles et al., 1995; Lau and Lo, 2015) and should

[3] In the Lancasterian tradition (Lancaster, 1966, Saviotti and Metcalfe, 1984)

thus be regarded as key actors in explaining clusters' evolution. This service-friendly theory is questioned by Klepper (2010), who rather emphasizes the role of a "spinoff process", that is of the emergence of "*firms with one or more founders that previously worked at another firm*" (p. 16).

Menzel and Fornahl (2010) for their part also propose a knowledge-driven clusters' life cycle theory, summarized in Figure 1. Two dimensions of the cluster are considered: the number of employees and the heterogeneity of "accessible knowledge". The main driver of the cluster life cycle, addressed in terms of number of employees, is a gradual process of knowledge homogenization among the members of the cluster. Although similar to Audretsch and Feldman's approach (1996a; 1996b) by the role it attributes to the nature of knowledge in the dynamics of the cluster, this theory has the advantage to avoid too deterministic evolutions from emergence to death, since clusters can always enter into loops of self-sustainment, successive cycles of growth and decline, or even re-orient themselves through a process of "transformation". This adaptability is determined by the degree of knowledge heterogeneity and by the openness to new comers of incumbent firms' networks.

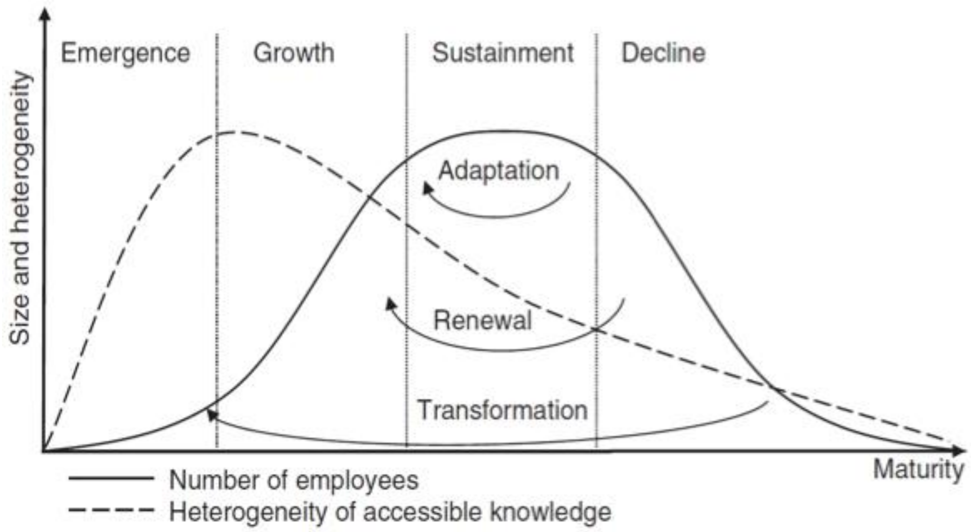


**Figure 1: Knowledge-based cluster life cycle (from Menzel and Fornahl, 2010 p. 218)**

Interestingly, cluster life cycle theory has moved away from the original product and industry life cycles, as it becomes less deterministic and more influenced by local drivers, notably clusters' ability to maintain a healthy degree of knowledge heterogeneity (especially through new intrant firms or new "imported" technologies). At the opposite of Audretsch and Feldman (1996a; 1996b), for whom clusters' life cycles are "shaped" by the industries that they belong to, Menzel and Fornahl (2010) consider clusters as more independent entities. However, we argue that this approach remains too restrictive and deterministic since, at least for incumbent cluster agents, it considers only one kind of innovation trajectory, i.e. only one kind of knowledge processing mode, namely: formalization (Gallouj, 2002). Actually, "renewal", "adaptation" and "transformation", i.e. the reverse innovation trajectory or knowledge processing mode (namely differentiation/localization) (Figure 1) are only possible through “external knowledge” (Menzel and Fornahl, 2010 p. 229), thus through exogenous/unexplained factors.

More generally (and beyond Menzel and Fornahl’s contribution) another point of criticism towards the life cycle theory is that it gives too few importance to cluster’s actors in explaining aggregate dynamics. Indeed, this approach generally considers the cluster – i.e. an aggregation of heterogeneous actors – as a relevant decision maker. Following Martin and Sunley (2011), one can wonder whether “products, technologies, industries and clusters [can] be treated as if they are the economic equivalent of biological organisms” (p. 1301). Besides, even though universities are sometimes cited in early clusters’ dynamics (Audretsch and Feldman, 1996a; 1996b), the main actors mentioned are very often the “firms”, but we neither know which primary sector of activity they belong to (or whether they all belong to the same sector) nor the nature of the interactions they entertain between each other. Klepper (2010) “spinoff process” is clearer on this point, since spinoffs generally belong to the same sector as the original company – or as the research team in the case of university spin-offs - and are, at first, of smaller size. The exclusive focus on firms is not satisfactory for addressing the clusters dynamics. Indeed, according to Porter (2000), firms are also supported by a number of *“associated institutions”* within clusters, mainly “*universities, think-tanks, vocational training providers*” (p. 17). Regarding the account for the diversity of the actors involved, the network-based approaches are obviously more appropriate.

## b. Networks and clusters dynamics

An alternative explanation of clusters’ dynamics is focusing on their internal organization in the form of networks of interacting entities. According to Newman (2003, p. 2), “ a network is a set of items [called] vertices or sometimes nodes, with connections between them, called edges. Systems taking the form of networks abound in the world”. Within clusters, nodes are companies and supporting institutions and the edges are all kind of relations between these actors: common investments in R&D, involvements in the same production processes, common patents or shared resources, etc. However, the network is not only a structure, it is also a mode of coordination that fits between market and hierarchy. From an innovation perspective, the network is considered as a coordination mode that is more effective than both market and hierarchy. Indeed resorting to the market assumes the establishment of explicit contracts, while in the field of research and innovation, projects are highly complex and uncertain. This makes it difficult to establish explicit contracts, which furthermore raise the risk that strategic secrets might be divulged (Hakansson, 1989; Callon, 1991; Hakansson and Johansson, 1993). The hierarchy for its part reduces transaction costs but involves the risk of bureaucratisation, which (as already foreseen by Schumpeter) may be prejudicial to innovation. In this network tradition, one can mention here Saxenian’s (1994) seminal work, comparing the “*network*” or system-based Silicon Valley and the “*independent* *firms-based*" Route 128. Saxenian argues that this is the prevalence of horizontal networks between firms and research institutions (e.g. Stanford) in Silicon Valley that allowed this cluster to successfully switch from semiconductors to microcomputers during the 1980s, whereas independent firms in Route 128 failed to adapt to the new technological conditions of that time. An horizontal network is in Saxenian's words a set of actors who "*deepen their own capabilities by specializing*" (p. 4), thus whose links are different from just input-output flows.

An interesting observation here is that, in a network perspective, clusters exist and develop because of a specialization process, which is the opposite of the knowledge homogenization generally invoked by the Life cycle literature. However, KIBS can be drivers of both dynamics: formalization of existing tacit knowledge or generation of custom-made (specialized) knowledge (Gallouj, 2002). It follows that if we recognize that KIBS are active members of industrial clusters, we have to acknowledge that both dynamics are possible. This remark about KIBS advocates for an integrative approach recognizing the influence of actors' interactions on the direction taken over time by the cluster as a whole. We argue in the following that Complex Adaptive Systems (CAS) allows integrating, within a single framework, both the aggregate perspective of the life cycle theory and the micro (or multi-agents based) perspective of the network-based approach, without falling into deterministic predictions.

### c. Complex Adaptive Systems: towards and integration of network and life cycle perspectives

Martin and Sunley (2011) recently proposed to consider industrial clusters as a particular type of CAS. According to them, a CAS is a system "*made up of numerous components with functions and inter-relationships that imbue the system as a whole with a particular identity and a degree of connectivity or connectedness*" (p. 1303). Furthermore, a CAS is "characterized by non-linear dynamics because of various feedbacks and self-reinforcing interactions amongst component (…). It is also characterized by emergence and self-organization". However, reading from these authors, it is not clear what improvements these CAS bring to Saxenian's network-based framework (Saxenian, 1994) nor to the Life Cycle theory discussed above. Indeed, Martin and Sunley (2011) use a typology of "*meta-models*" covering the various forms of CAS dynamics (inspired by Cumming and Collier, 2005). These meta-models range from deterministic (traditional) life cycles to totally random walks. Life cycle trajectories are envisaged as special case of CAS among others[4]. Among the proposed models, Martin and Sunley argue that clusters dynamics are well depicted by the so-called "*adaptive life-cycle model*"[5] and they try to adapt it to the

[4] The typology of meta-models of CAS includes the following meta-models (types of complex systems): life cycle, random walk, replacement, limitation, succession, adaptive cycle, evolutionary.

[5] The "adaptive cycle model of the evolution of a complex system" (Martin and Sunley, 2011 p.1307) is similar to the "modified adaptive cycle" represented in Figure 2, minus the alternative trajectories of "failure", "constant cluster mutation", "cluster disappearance", "cluster stabilization" and "cluster re-orientation".

cluster dynamics. The resulting "*modified cluster adaptive cycle*" that they propose is reproduced in Figure 2. Arguably, this "*meta-model*" is very similar to the knowledge-based life cycle proposed by Menzel and Fornahl (2010), as we can easily draw a parallel between their respective alternative trajectories: "*constant cluster mutation*" in Martin and Sunley (2011) stands for "*adaptation*" in Menzel and Fornahl (2010), similarly "*cluster stabilization*" stands for "*renewal*", and "*cluster re-orientation*" stands for "*transformation*". However, the two cycles are not equivalent: in Menzel and Fornahl (2010), knowledge heterogeneity between firms and other actors explains the emergence of a cluster, and the process of knowledge homogenization drives cluster's evolution. In Martin and Sunley (2011), there is no general mechanism of evolution, since there is no general principle explaining why a cluster shifts from one phase to another. Instead, these authors propose a descriptive list of potential drivers. For instance, cluster re-emergence is possible thanks to "sufficient resources, inherited capabilities and competencies" (p. 1313) left after a phase of decline, or a constant mutation comes from "high rates of spin-offs" (p. 1313). Apart from a chance factor, there is no explanation of why the rate of spin-offs is high or why the remaining capabilities are enough and up-to-date. Another weakness of their model is that, despite their definition of a CAS, they do not precisely ground clusters' dynamics in a network-based view of the actors, and the actors are not considered as heterogeneous entities.

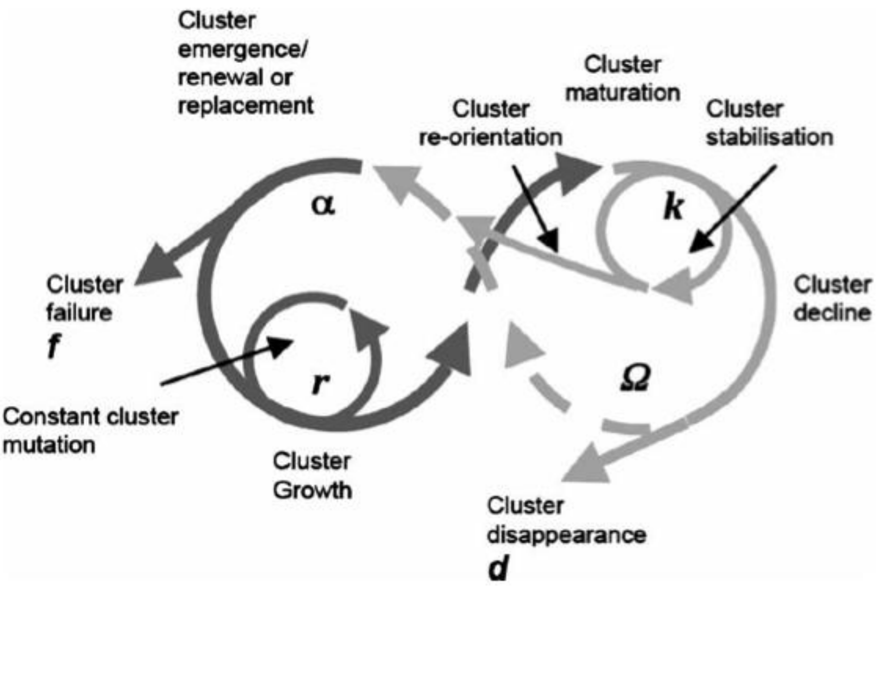


**Figure 2: Martin and Sunley (2011) "modified cluster adaptive cycle" (p. 1312)**

Although we point out limitations of Martin and Sunley's (2011) adaptive cycle, we find very relevant their proposition to rely on CAS for conceptualizing clusters' functioning and dynamics. Rather than trying to classify such systems, we consider that a general definition and a list of properties can justify this point of view.

According to Holland (2012) a CAS “*consists of a multitude of interacting components called agents […]. The agents are diverse rather than standardized, and both their behavior and their structure change as they interact*” (p. 57). Furthermore CAS display the following three main features:

1. “*There is no universal competitor or global optimum in a CAS*” (p. 58).
2. “*Innovation is a regular feature of CAS*” (p. 58).
3. “*In a CAS, anticipations change the course of the system*” (p. 60).

Clusters’ network structure has already been documented by many authors, including Porter (1998; 2000) and Saxenian (1994). All of them focus on the diversities of the “agents” involved: firms, universities, think-tanks, etc. It might thus be argued that, as structures, clusters are examples of CAS. But do they share CAS properties?

Applied to clusters, the first characteristic mentioned above implies (i) that networks of agents can be found in many technological or market niches, and (ii) that cooperation between specialized agents can always allow for improvements. The remark about niches is particularly relevant for clusters, since the clustering phenomenon reflects a tendency towards regional specializations in very distinctive activities including vine production, sportswear, semiconductors, etc.

Regarding the second characteristic, evidence shows that, within clusters, agents are specialized and that they cooperate in order to be more innovative (Porter, 1998; 2000; Saxenian, 1994). Innovations can take various forms, without following any pre-determined sequence (Gallouj and Weinstein, 1997).

Finally with regards to the third characteristics, it can be underlined that within a cluster, every agent can anticipate/forecast new technological or market opportunities, although their anticipation is imperfect because of bounded rationality (Frenken, 2006; Desmarchelier et al., 2013b). This characteristic is important, because it contradicts the very conception of a from birth to death pre-determined cluster cycle. In addition, unlike Menzel and Fornahl (2010), who introduce exogenous factors as the main drivers likely to change the course of a system, in a CAS approach, clusters adapt because of their agents’ individual anticipations.

In conclusion, and as we will try to confirm it in the empirical part of this work, these characteristics seem to fit well with what is known about clusters functioning. Then, how does the conception of clusters as CAS change the way we understand their dynamics?

Our literature review identified the very reason of clusters’ existence: the knowledge-seeking behavior of the firms. They seek knowledge from other firms or from other types of agents – notably KIBS, including universities. But we also identified an important difference between Life Cycle theory and network-based theory, regarding the way they address the knowledge dynamics within clusters: the life cycle theory postulates a knowledge homogenization process, whereas the network-based approach postulates a specialization process. The first CAS property (i.e. no global optimum) fits well with the idea of specialized agents, but the “anticipation” and “innovation” properties are not imposing any type of pre-determined process. Agents are heterogeneous, and KIBS may allow for both homogenization and specialization trajectories, admitting that a general/cluster-level trajectory can be found. The two other CAS properties (i.e. innovation and anticipation) indicate that the alternative routes in Menzel and Fornahl (2011) (i.e. adaptation, renewal and transformation) are the rule rather than the exception in CAS dynamics. It follows that a proper deterministic life cycle is likely to be the reflect of a degenerative cluster (ex. Route 128 in Saxenian, 1994).

Clusters have already been modelled as CAS thanks to agent-based modelling[6] (Dilaver et al., 2014; Boero et al., 2004; Squazzoni and Boero, 2002; Albino et al., 2003). Important question to tackle within this perspective are how specialized agents tie to each other and then how these ties evolve. In this respect, Boero et al. (2004) propose various matching strategies. As an example – for a specific agent – the strategy could be: “*look at the first agent with different technology/techno-organizational asset you meet*” (p. 12). These theoretical efforts are welcome, but the building of relevant models has to rely on a set of well-established stylized facts (Borrill and Tesfatsion, 2011). Discussing about clusters’ dynamics and their main drivers supposes to decide in a first step which aggregate indicators/variables (number of actors, quantity produced, number of patents, R&D expenditures, etc.) and which underlying networks to consider. Unfortunately, to our knowledge, there is still no such empirical study within a CAS framework. Indeed, although theoretically appealing, the CAS approach remains hard to put into practice. We thus propose, in the remaining of the paper, a strategy for operationalizing the CAS framework.

# 2. Clusters as CAS: empirical example and insights about clusters dynamics

In order to conduct an empirical investigation, we have to make several choices: (a) which industry to study? (b) Which cluster to focus on within this industry? (c) What kind of networks are we looking at? After making our choices, we explore the dynamics of the selected empirical network of agents and we draw general conclusions about clusters dynamics.

## a. Which industry to study?

[6] Applied to economics, agent-based modelling is “a computational approach that aims to explain economic systems by modeling them as societies of intelligent software agents. The individual agents make autonomous decisions, but their actual behaviors are constrained by available resources, other individuals’ behaviors, and institutions” (Osinga et al., 2011).

The "*non-universal competitor*" principle (Holland, 2012) advocates for the study of sectors with complex technology landscapes[7], because they are the most likely to offer many niches and thus many opportunities for clusters to emerge. According to Arthur (2009), all products display a tree-like recursiveness: "*the technology is the trunk, the main assemblies the main branches, their subassemblies the sub-branches, and so on, with the elemental parts the furthest twigs … The depth of this hierarchy is the number of branches from trunk to some representative twigs*" (p. 38). The more complex a product is, the more it relies on a complex technology – i.e. a technology with a high depth. Arthur (2009), among others (Frenken, 2006; Niosi and Zhegu, 2005), argues that the aircraft industry relies on very complex technologies, composed of many subparts.

The resulting hierarchy between producers of various airplanes' subparts is represented in Figure 3, from Niosi and Zhegu (2005). Following the CAS approach, clusters can be found in any layer of this hierarchy. The biggest clusters include agents involved in top layers, and more particularly the "prime contractors" or "airframe assemblers": Bombardier in Montréal, Airbus in Toulouse, Boeing in Seattle (Niosi and Zhegu, 2005) or Lockheed Martin in Los Angeles (Scott, 1990).

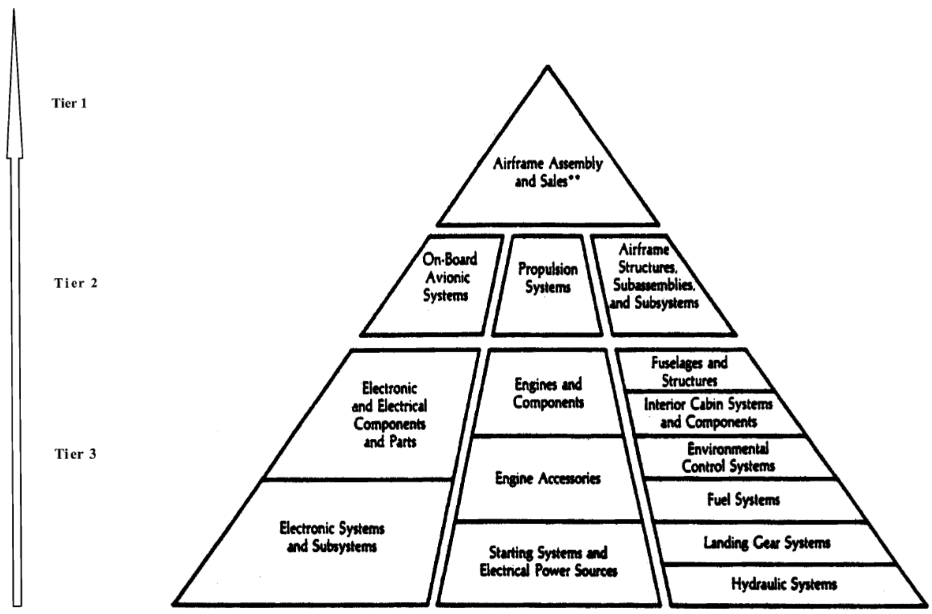


**Figure 3: Aircraft producers' pyramid (from Niosi and Zhegu, 2005 p.8)**

[7] Kauffman et al (2000) define a technology landscape as a set of values attributed to all the various possible "production recipes" (p. 8), which are represented as vertices of a "directed graph". A production recipe "encompasses all the deliberate organizational and technical practices which, when performed together, result in the production of a specific good" (p. 4).
Technology landscape is a metaphor originated from biology (Kauffman, 1993) for representing the choice of economic agents when they have to decide what to produce and how to produce it. It states that agents' initial choice has long term incidence on their adaptability since it constraints their innovation capabilities, this is the reason why production recipes are embedded into a directed graph: it is not possible to switch easily from a recipe to another.

## b. Which cluster to study?

For every sector, it is common to find contributions focusing on successful/first class clusters: Route 128, Silicon Valley, Detroit, Los Angeles (Saxenian, 1994; Klepper, 2010; Scott, 1990). The most important ones for the aircraft industry have already been mentioned (Montréal, Toulouse, Seattle, Los Angeles) and won't be considered for the present study. Indeed, we rather choose to focus on a niche cluster, for highlighting the difference between the CAS and the more traditional/aggregate (or life cycle) approach of the clustering phenomenon.

In the traditional approach, authors generally study the geographical concentration of employment or companies by industry (Shin and Hassink, 2011; Niosi and Zhegu, 2005; Scott, 1990), or the geographical concentration of production (Shin and Hassink, 2011) or of the innovation activity (Audretsch and Feldman, 1996a; 1996b) for a given industry. Interestingly, there are very few accounts of the actual linkages between these actors, although Saxenian (1994) reported – with the example of the Route 128 – that spatial proximity does not necessarily imply strong cooperation. One can also highlight a very limited account for actors' diversity within this aggregate approach, since only "firms" are generally mentioned.

Figure 4 (left) displays the most recent account for the number of employees in aerospace industry within all European regions. We observe that aerospace employment is widespread, although quite concentrated in Western Europe and Russia. This dispersion is higher than what is observed in the United States and is generally explained by political reasons, notably the need to ensure countries independence (Niosi and Zhegu, 2005). In an aggregate view, we would consider studying the Southwest of France, Northern Germany or South England. However as far as we favor the CAS approach, we rather choose a small cluster. Figure 4 (right) displays a map of Belgium and the regional concentration of employment in aerospace. We distinguish two relatively major poles within the southern regions - surrounding the cities of Mons and Liège – and two smaller poles near Brussels and Leuven. In 2006, all the actors from these 4 poles joined to create an official association called Skywin.[8] We propose to study this cluster.

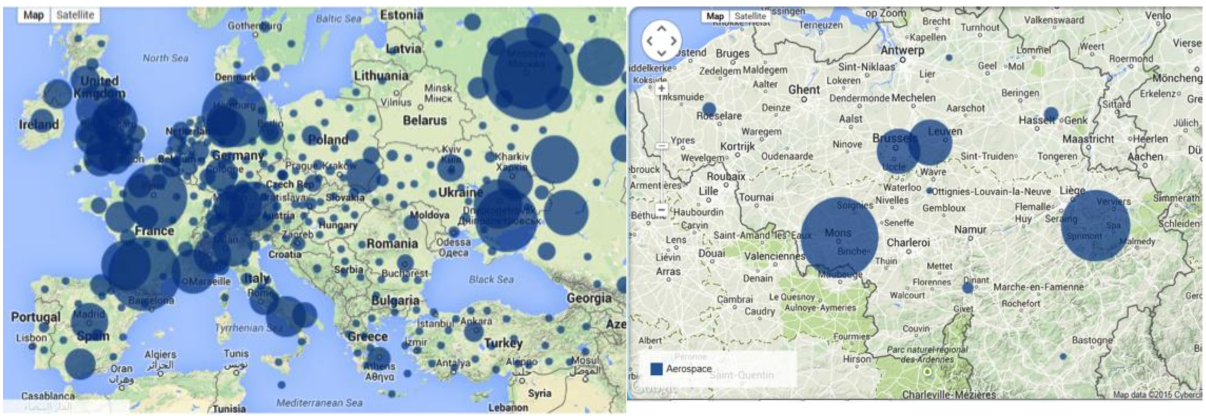


**Figure 4: Number of employees in the aerospace industry in Europe (left) and in Belgium (right) in 2011[9]**

[8] http://www.skywin.be/?q=en (last access: 10 Feb. 2015)
[9] www.clusterobservatory.eu (last access: 10 Feb. 2015, the numbers are for 2011)

## c. What kind of networks are we looking at?

As we have already pointed out, a CAS is primarily a network of heterogeneous and specialized agents, which can be described in the following terms: (i) it emerges within (technological or market) niches, (ii) it is strongly oriented towards innovation and (iii) it is quick to adapt to changes in its environment thanks to its agents' anticipations and innovations (Holland, 2012). Skywin is presented as "*a group of companies, training centers and research units engaged in public and private partnership and building synergies around common and innovative projects*".[10] These projects fit into six main axes that the agents anticipate to be of strategic importance for their future development[11]:

1. Composite materials and processes
2. Metallic materials and processes
3. Embedded systems
4. Airport services
5. Space applications and systems
6. Modelling and simulation

These six themes reflect the niche position of Skywin within the aircraft producers' pyramid (Figure 3), as they mainly fit into some of the third tier activities: fuselage and structure for the first two axes and the electronic systems for the third axe. Interestingly, the fourth one - airport services - is not part of the aircraft production process and it responds to a potential market in developing countries.[12] This exemplifies clusters ability to re-orient their activity through time. The sixth axe – "modeling and simulation" – arguably applies in every parts of the pyramid (Figure 3) since simulation is generally involved in the conception phase of any airplane components. Finally, the fifth axe on "space applications and systems" reveals a specialization relevant for the space industry (not considered in the present work).

Skywin is thus a group of heterogeneous agents, and the main interactions we should look at are those taking place within these "common and innovative projects". An exhaustive list is provided by the cluster website[13], which covers 46 common projects undertaken collectively between 2006 and 2014. The following informations are provided for every project: the agents involved - classified into two categories

[10] http://www.skywin.be/?q=en/mission_and_strategy (last access: 10 Feb. 2015)
[11] http://www.skywin.be/?q=en/mission_and_strategy (last access: 10 Feb. 2015)
[12] As an example, it has been reported that 25.2% of flights in Mainland China have been delayed in 2012, 14.9% of them for an "unidentified reason".
Beijing News, 23 May 2013:
http://www.bjd.com.cn/10beijingnews/201305/23/t20130523_3774403.html
[13] http://www.skywin.be/sites/default/files/kcfinder/1-vincent.marchal%40skywin.be/files/Fiches%20projets%20Skywin%20Calls%201-9.pdf (last access: 10 Feb. 2015)

("industries" and "research bodies" [14]) – as well as the total budget (in millions of Euros) and the duration of the project (start and end years).

These informations allow for the building of a bi-partite relational database linking two sets of nodes (cf. the definition of a network): the agents and the projects in which they are involved. This database makes it possible to draw Figure 5. In this figure, red ellipses represent the projects and the blue ones represent the agents, whether they are "industries" or "research bodies". Links represent somehow the involvement within a project or more exactly the level of expected involvement, as it may be expressed by the budget allocated to the project[15]. The thicker and darker they are, the higher the project's financial value (and the expected involvement) is. This Figure does not distinguish between time periods: it summarizes all the interactions that took part within Skywin from 2006 to 2014.

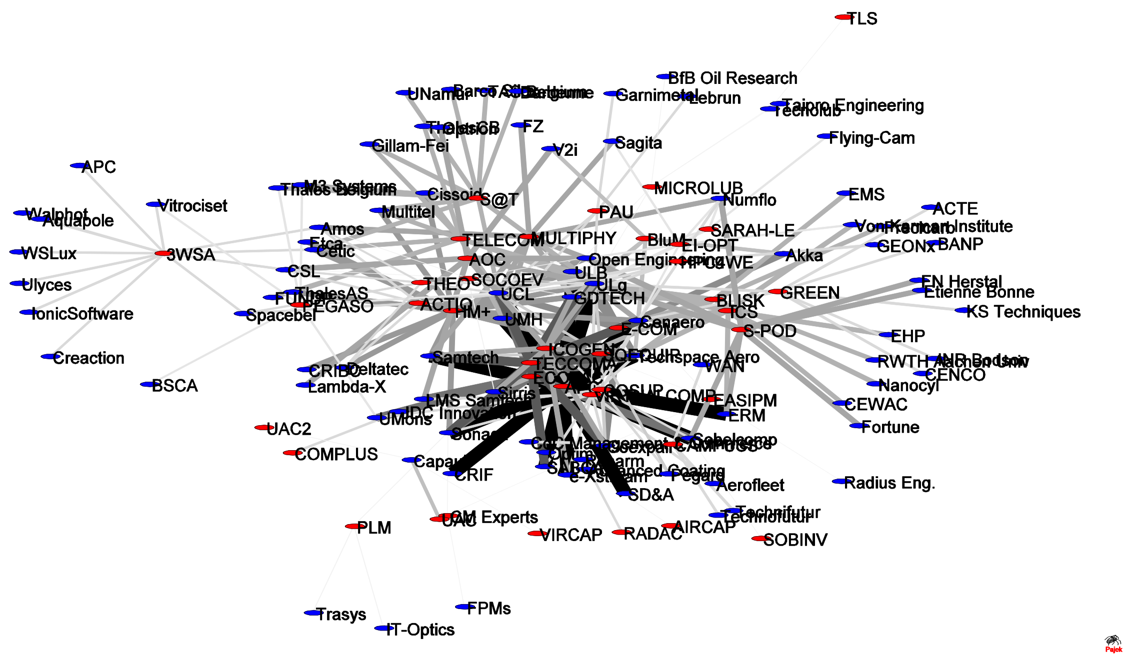


Figure 5: Skywin bi-partite innovation network (blue vertices = Agents; red vertices = projects)

## d. Studying clusters dynamics through innovation networks

In Figure 5, the agents are not directly linked, that's why we modify the network on the basis of the hypothesis that agents who are participating to the same project are in fact directly linked. We also consider the time dimension and obtain as a result the 9 configurations of the network for each year from 2006 to 2014 displayed in Annex 1. Table 1 summarizes some descriptive statistics of these configurations.

[14] These "research bodies" include universities, training centers and private research institutions. We thus assimilate them to KIBS.

[15] It should be noted that as far as there is no information on how the budget is allocated between the different partners of a given project, the whole budget is associated with each of them.

| | Number of Actors | Av. Degree[16] | Density (No Loops allowed)[17] | Av. Path Length[18] among reachable pairs |
|---|---|---|---|---|
| **2006** | 15 | 7.33 | 0.52 | 1.00000 |
| **2007** | 44 | 13.54 | 0.31 | 1.72740 |
| **2008** | 52 | 13.57 | 0.26 | 1.88690 |
| **2009** | 61 | 14.46 | 0.24 | 1.90169 |
| **2010** | 67 | 14.68 | 0.22 | 1.90629 |
| **2011** | 61 | 13.97 | 0.23 | 1.84570 |
| **2012** | 62 | 13.45 | 0.22 | 1.76497 |
| **2013** | 60 | 10.53 | 0.18 | 1.82214 |
| **2014** | 56 | 9.53 | 0.17 | 1.79285 |

**Table 1: Properties of Skywin temporal networks**

In a traditional – aggregate – perspective, authors focus on the number of actors within a given geographical area. In table 1, we rather report the actors who actively cooperate on a set of common projects. Looking at first at the number of these actors – and abstracting from the European economic crisis during the period - we may consider that Skywin enters into a phase of decline starting from 2010. This general movement goes hand in hand with a decrease in the average degree and networks' densities, which means that the agents who take part to innovation projects are more and more loosely connected. In other words, the cluster loses its attractiveness for potential newcomers: knowledge-seeking agents cannot find enough useful knowledge for exploring their technological or market landscapes, or simply the niches within which Skywin is evolving are not promising enough. Overall, these evolutions are consistent with the life-cycle theory.

However, several elements contradict this pessimistic and deterministic conclusion. (i) The configurations of the network displayed in Annex 1 are particularly dynamic throughout the considered time span. From year to year actors are leaving and others are entering into the network, following projects life cycles. Active actors are thus changing: looking at the network's configurations, we count in total 92 different active agents from 2006 to 2014, although no more than 67 were operating at the same time. This suggests a positive rate of turnover among these agents. (ii) There remain plenty of opportunities for partnerships, as innovation networks' densities

[16] The average degree of a network gives the average number of links per agent within the network. For instance, the agents taking part to innovation projects in 2008 were, on average, linked to 13.57 agents.

[17] Network density is the ratio between the actual number of links and the maximum possible in a hypothetical situation where each agent is connected to all the others. For instance, a density equal to 0.52 means that 52 % of the connection possibilities are exploited by the agents.

[18] The path length between two agents *i* and *j* is the shortest distance between them (i.e. the shortest sequence of vertices). The average path length of a network is obtained by averaging all the path length between all the reachable agents of this network. Isolated agents are thus not taken into account.

always evolve within a range comprised between 17 % and 31 %.[19] In this respect, Skywin accounts for a total of 117 members.[20] Considering the 92 active agents, this highlights both a high rate of cooperation between Skywin members and the existence of unused opportunities. (iii) The path length values in table 1 are always much smaller than the number of agents within the network. This reveals the presence of a small-world effect (Newman, 2003): because of a high rate of overlap between the members of different projects, it becomes easy for any agent – even for a newcomer – to obtain information or knowledge coming from other projects. These short path lengths can thus be considered as a good proxy for evaluating the advantages of taking part in this cluster. Considering the relative stability of this measure in Table 1, we cannot sustain the declining hypothesis that results from the sole observation of the number of active agents.

We argue that, in a knowledge-seeking perspective, agents benefit from the existence of a small-world effect, which itself emerges from a certain degree of overlap between the various projects. It follows that the core agents of a given cluster are those who allow for overlaps to occur. A good way to identify them is to compute agents' degree centralities, i.e. for a given agent $i$, to count the number of links he/she has with the other agents in the network. We can also take into account the fact that different links are not equivalent, in the sense that – at least for our current networks – the financial values of the various projects are different. In order to take these links' values into account, we compute the weighted degree of centrality measure proposed by Opsahl et al. (2010).

Be $\alpha \in [0;1]$ a tuning parameter, $k_i$ the number of links connected to the agent $i$ and $s_i$ the average weight (or value) of these links, then $C_D^{W\alpha}(i)$, the weighted degree centrality of the agent $i$ is given by the following equation:

$$C_D^{W\alpha}(i) = k_i^{1-\alpha} \times s_i^{\alpha}$$

The more $\alpha$ is important, the more we attribute importance to links' values in computing agents' centralities. Top 10 weighted degree centralities for every year and for various $\alpha$ $\alpha$ values are reported in Annex 2. We observe that, in virtually all cases, the two most central actors belong to the "research bodies" category. The University of Liège and the Catholic University of Leuven are particularly central. Industrial firms are also well represented in these rankings and, even though we observe the recurrence of national leaders in the aerospace industry (e.g. Sonaca), they are much more "volatile" than universities in the sense that their relative positions are less stable and that there is a much higher rate of turnover among firms within the top 10.

[19] We omit the density of the network configuration in 2006 (date of the creation of the cluster) because its relatively high value is explained by the fact that the cluster included only one project with several actors.
[20] http://www.skywin.be/?q=en/members

These results give interesting insights about the drivers of clusters' attractiveness – measured in our case by a small-world effect within clusters' innovation networks. We show that this attractiveness relies on the presence of a stable core of highly connected knowledge intensive business services (universities or research bodies in general). Arguably, what determines if a cluster is declining is not the age of the cluster as a whole, nor the number of the (active) agents it includes, but the quality and connectivity of the knowledge intensive business services in its core part. When looking at the number of innovation-active agents, we could say that Skywin is entering into a phase of decline, but a closer look to its innovation networks' properties reveals an attractive cluster and thus show potential for new phases of growth.

## Conclusion

Clusters' dynamics are generally understood as the evolution of an aggregate indicator, like the number of firms operating in a given geographical area. Two competing theories aim at explaining the dynamics of this indicator: the life cycle theory and the network-based approach. Both consider knowledge processing as the main driver but in an opposite way. For the tenants of the life cycle, clusters evolve through a process of knowledge homogenization among their members, whereas the network-based approach considers that knowledge becomes more and more specialized. We argue that KIBS play a major role in both of these directions, and we thus advocate for an alternative/ synthesizing approach.

Such synthesis should combine the aggregate point of view of the life cycle theory with the actor-centered network-based approach, while avoiding their deterministic predictions. Complex adaptive systems are a promising candidate for such a purpose. In order to consider their implications for clusters' dynamics, we conducted within this framework an empirical analysis on a given industrial cluster (the aeronautics cluster in Belgium).

We discovered that this cluster's innovation networks exhibit a small-world effect. This implies that any agent who takes part into an innovation project of this cluster can easily benefit from knowledge and information generated in another ongoing project. We argue that this effect is an interesting proxy of a cluster's attractiveness and an appropriate aggregate variable for studying clusters' dynamics as it shows cluster's potential for further growth. We also demonstrate that KIBS are the main responsible for the emergence of this small-world effect in innovation networks.

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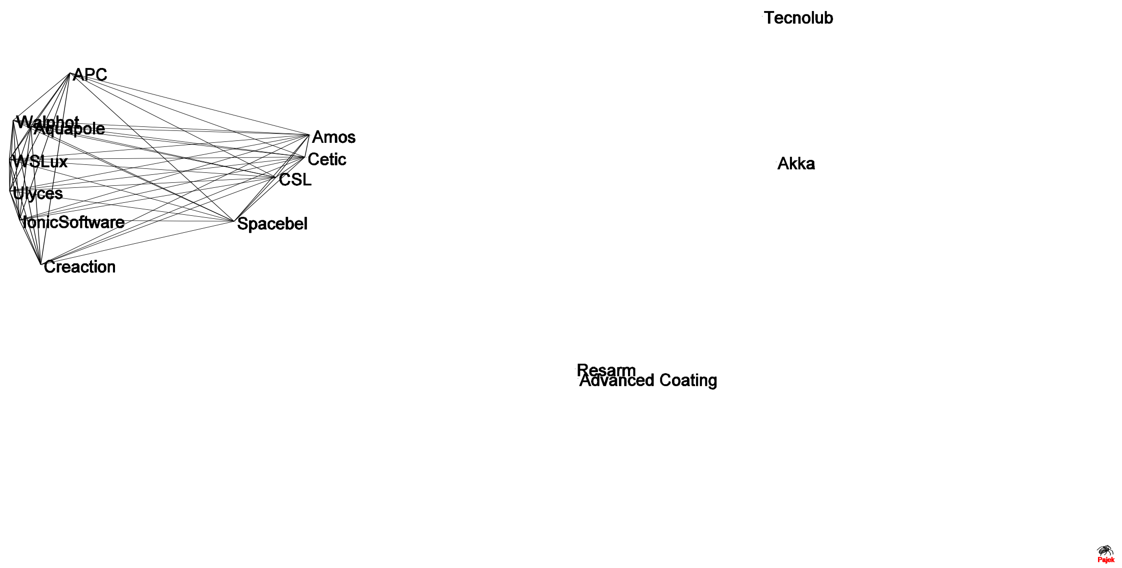
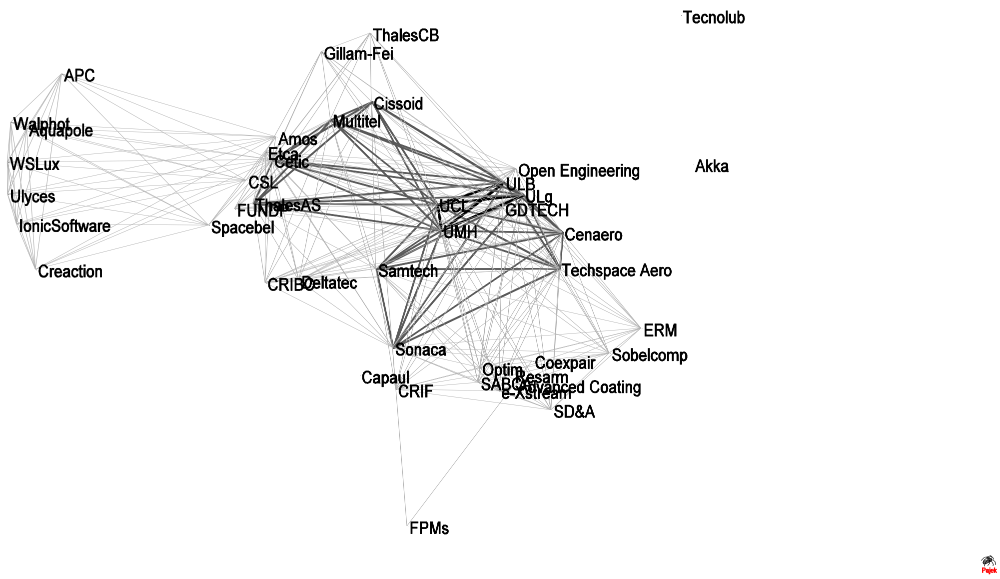
**Annex 1:** Skywin's innovation networks from 2006 to 2014

These networks have been obtained by formulating the hypothesis that agents' participating to the same project are linked together. All nodes thus represent firms or research centers. Isolated agents are those who are taking part in projects in which they are the only actor involved. In a given graph, darker and thicker links represent partnerships in projects with relatively higher financial values.

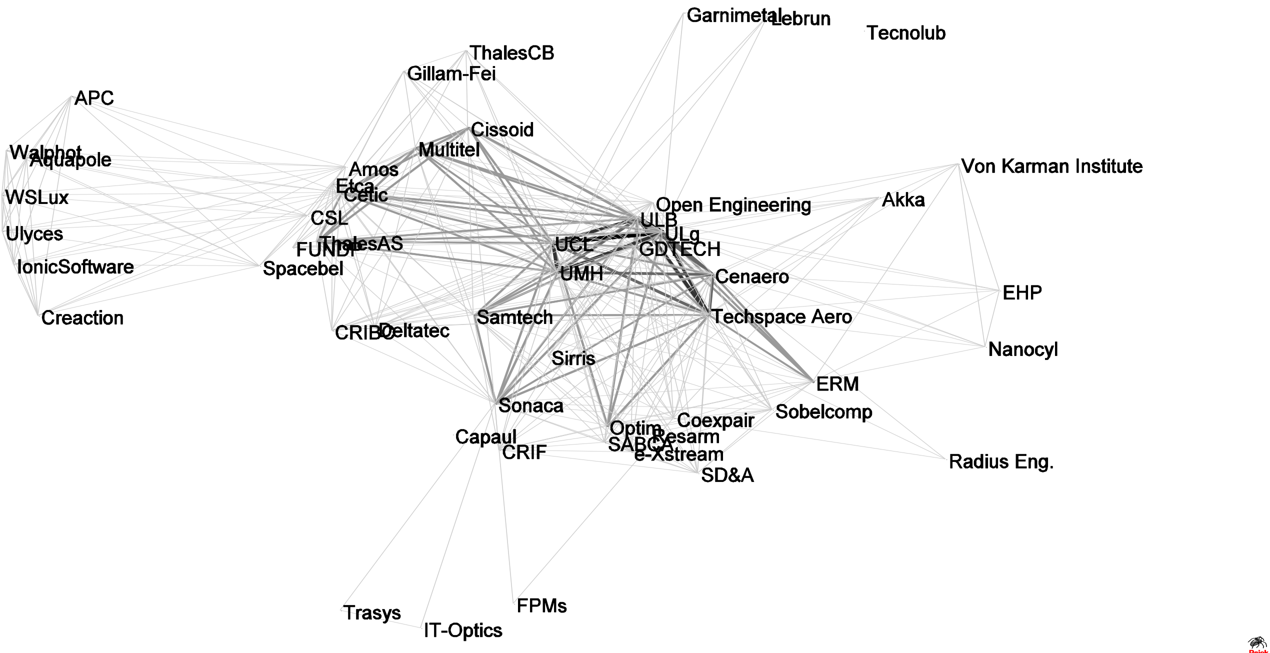
### i. Figure 6 : 2006



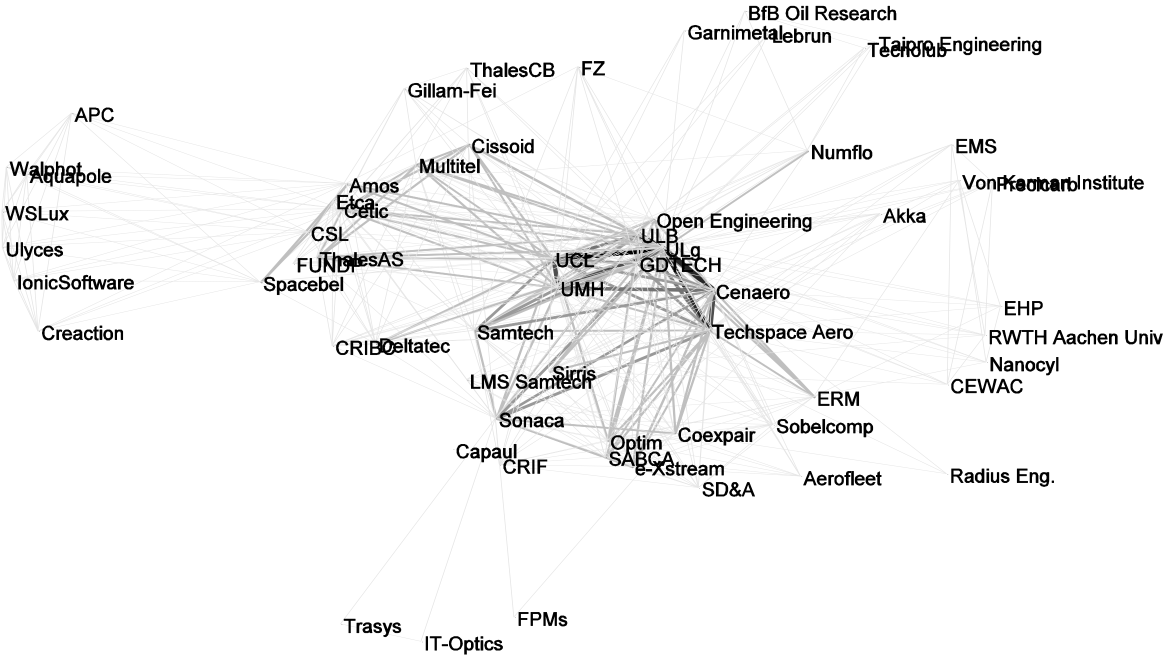

### ii. Figure 7: 2007



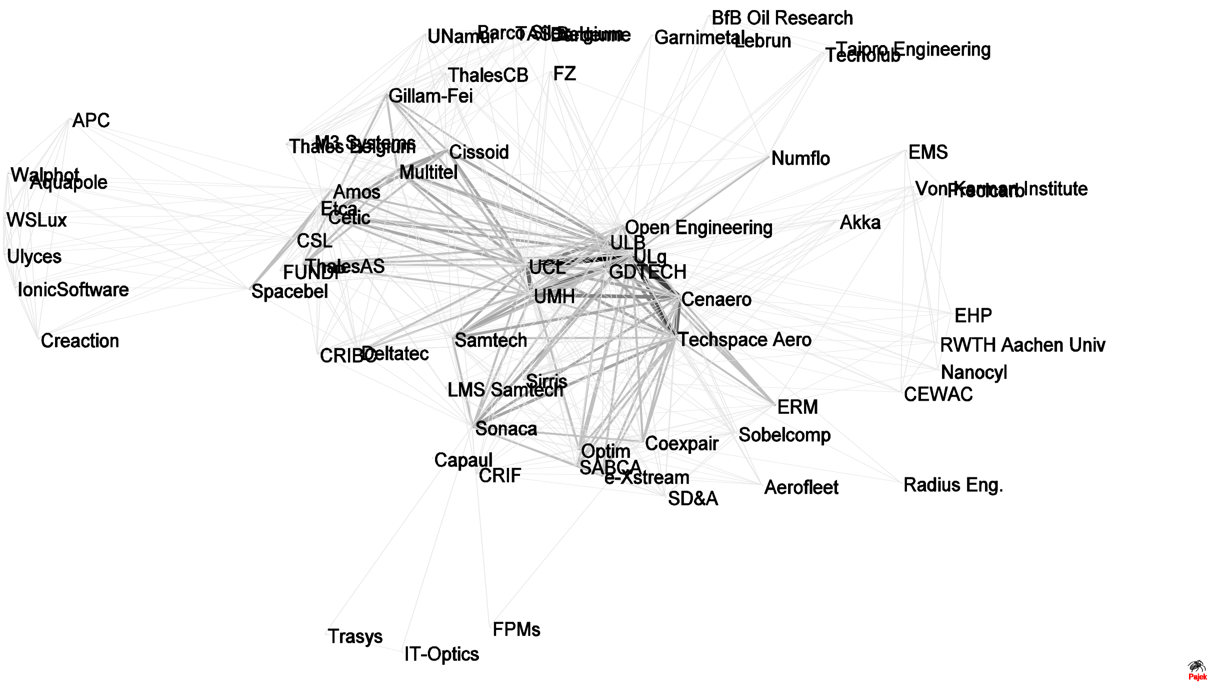
### iii. Figure 8: 2008



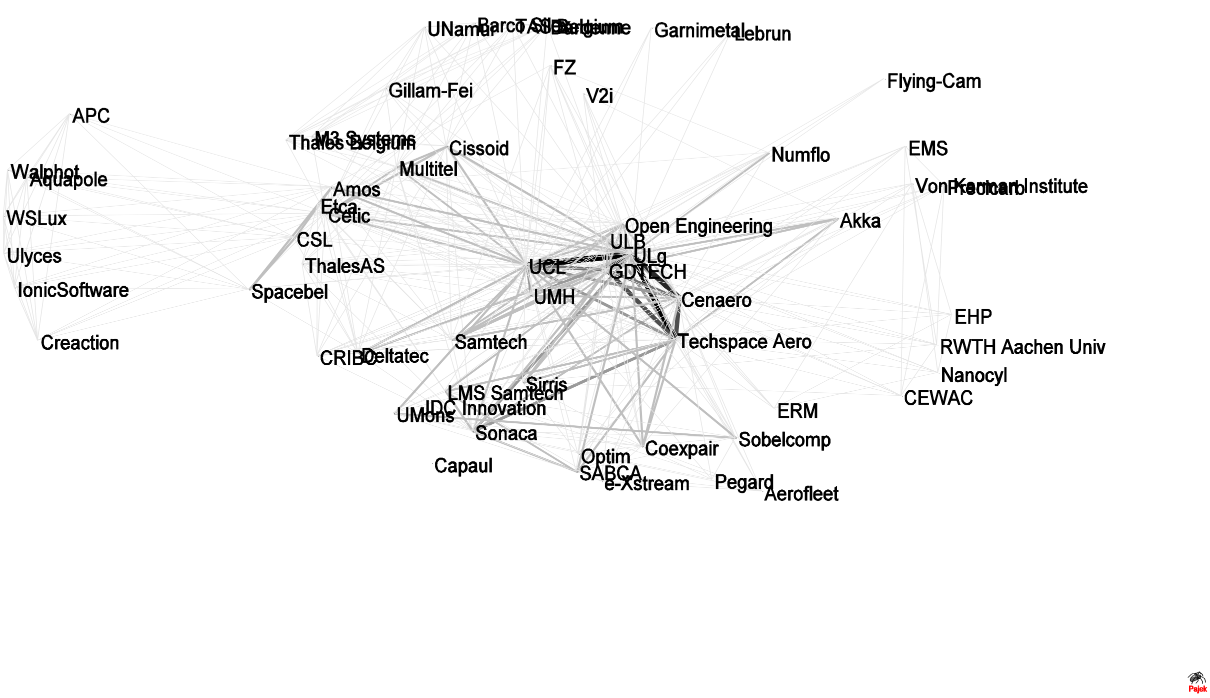

### iv. Figure 9: 2009



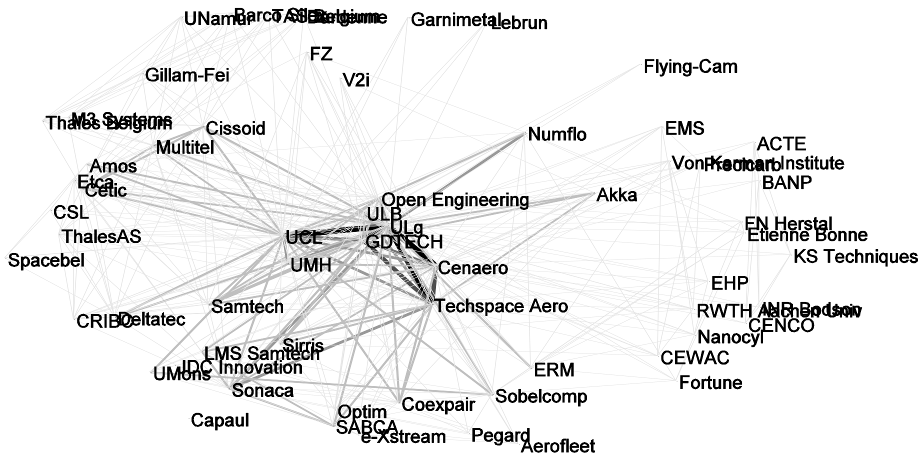
## v. Figure 10: 2010



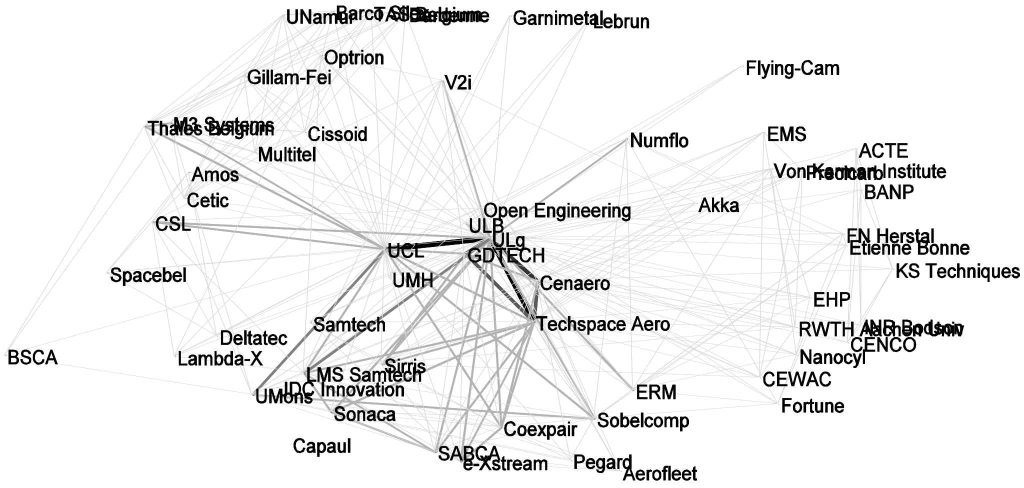

## vi. Figure 11: 2011



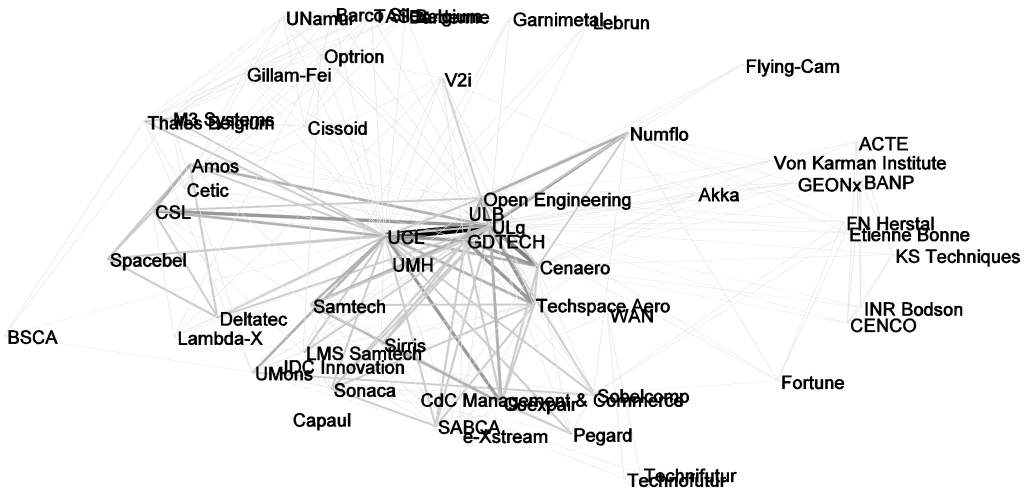
## vii. Figure 12: 2012




## viii. Figure 13: 2013



### ix. Figure 14: 2014



# **Annex 2:** Top 10 weighted degree centralities per year

| 2006 | | | 2007 | | | 2008 | | | 2009 | | | 2010 | | | 2011 | | | 2012 | | | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) |
| Aquapole | Research | 6.80948 | CetIndustryo | Research | 15.4418 | ULg | Research | 18.7524 | ULg | Research | 25.3146 | ULg | Research | 27.7763 | ULg | Research | 25.8309 | ULg | Research | 28.9931 | ULg | Research | 26.9847 | ULg | Research | 25.3146 |
| CSL | Research | 6.80948 | UCL | Research | 14.7705 | ULB | Research | 17.8305 | Cenaero | Research | 20.4387 | UCL | Research | 22.4516 | UCL | Research | 20.8232 | Cenaero | Research | 21.9441 | UCL | Research | 18.8493 | UCL | Research | 20.5866 |
| Spacebel | Industry | 6.30957 | ULB | Research | 14.7705 | UCL | Research | 17.2989 | UCL | Research | 19.8468 | Cenaero | Research | 20.4387 | Cenaero | Research | 20.3615 | UCL | Research | 20.8232 | Cenaero | Research | 16.0135 | Cenaero | Research | 13.4368 |
| CetIndustryo | Research | 6.30957 | ULg | Research | 14.7705 | UMH | Research | 17.0241 | ULB | Research | 19.4721 | ULB | Research | 19.4721 | Techspace A | Industry | 19.1457 | Techspace A | Industry | 19.1457 | Techspace A | Industry | 14.6372 | GDTECH | Industry | 13.2441 |
| CreactIndust | Industry | 6.30957 | UMH | Research | 14.7705 | Techspace A | Industry | 16.1466 | Techspace A | Industry | 19.2091 | Techspace A | Industry | 19.2091 | GDTECH | Industry | 17.7651 | GDTECH | Industry | 17.7651 | GDTECH | Industry | 11.3942 | Open EngInd | Industry | 11.1082 |
| Ulyces | Industry | 6.30957 | Sonaca | Industry | 14.213 | Cenaero | Research | 15.4421 | UMH | Research | 18.2283 | CetIndustryo | Research | 18.2331 | CetIndustryo | Research | 16.7783 | ULB | Research | 14.2981 | LMS Samtech | Industry | 10.2474 | Techspace A | Industry | 9.8875 |
| Amos | Industry | 6.30957 | Techspace A | Industry | 12.9557 | CetIndustryo | Research | 15.4418 | Sonaca | Industry | 15.9253 | UMH | Research | 18.2283 | ULB | Research | 14.2981 | Open EngInd | Industry | 13.4635 | Sobelcomp | Industry | 9.96496 | Sobelcomp | Industry | 9.51092 |
| Walphot | Industry | 6.30957 | Samtech | Industry | 12.9557 | Sonaca | Industry | 14.6256 | CetIndustryo | Research | 15.4418 | Sonaca | Industry | 15.9253 | Sonaca | Industry | 13.124 | Sonaca | Industry | 13.124 | CoexpaIndus | Industry | 9.24402 | CoexpaIndus | Industry | 8.79849 |
| IndustryonIn | Industry | 6.30957 | Cenaero | Research | 12.9557 | Samtech | Industry | 12.9557 | GDTECH | Industry | 15.1836 | GDTECH | Industry | 15.1836 | CIndustrysso | Industry | 12.6856 | CetIndustryo | Research | 12.6856 | UMons | Research | 9.05126 | UMons | Research | 8.58552 |
| WSLux | Industry | 6.30957 | ThalesAS | Industry | 11.2266 | GDTECH | Industry | 11.3936 | Samtech | Industry | 14.6959 | Samtech | Industry | 14.6959 | MultIndustry | Research | 12.6856 | CIndustrysso | Industry | 12.6856 | M3 Systems | Industry | 8.48205 | Numflo | Industry | 8.48344 |
| APC | Research | 6.30957 | CIndustrysso | Industry | 11.2266 | ThalesAS | Industry | 11.2266 | Amos | Industry | 11.3936 | CIndustrysso | Industry | 14.2038 | UMH | Research | 12.1846 | MultIndustry | Research | 12.6856 | Thales BelgIn | Industry | 8.00911 | CSL | Research | 8.24125 |

**Table 1: Weighted Degree Centralities (α=0.2)**

| 2006 | | | 2007 | | | 2008 | | | 2009 | | | 2010 | | | 2011 | | | 2012 | | | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) |
| Aquapole | Research | 3.31662 | UCL | Research | 6.32456 | ULg | Research | 7.68115 | ULg | Research | 9.69536 | ULg | Research | 10.247 | ULg | Research | 9.59166 | ULg | Research | 10.247 | ULg | Research | 9.27362 | ULg | Research | 9.69536 |
| CSL | Research | 3.31662 | ULB | Research | 6.32456 | ULB | Research | 7.4162 | UCL | Research | 8.12404 | UCL | Research | 8.77496 | UCL | Research | 8.12404 | UCL | Research | 8.12404 | UCL | Research | 7.14143 | UCL | Research | 8.544 |
| Spacebel | Industry | 3.16228 | ULg | Research | 6.32456 | UCL | Research | 7.2111 | Cenaero | Research | 8.06226 | Cenaero | Research | 8.06226 | Techspace A | Industry | 7.74597 | Cenaero | Research | 8 | Techspace A | Industry | 6.55744 | GDTECH | Industry | 6.63325 |
| CetIndustryo | Research | 3.16228 | UMH | Research | 6.32456 | UMH | Research | 6.9282 | Techspace A | Industry | 7.81025 | Techspace A | Industry | 7.81025 | Cenaero | Research | 7.68115 | Techspace A | Industry | 7.74597 | Cenaero | Research | 6.245 | Cenaero | Research | 6 |
| CreactIndust | Industry | 3.16228 | CetIndustryo | Research | 6 | Techspace A | Industry | 6.7082 | ULB | Research | 7.74597 | ULB | Research | 7.74597 | GDTECH | Industry | 7.34847 | GDTECH | Industry | 7.34847 | GDTECH | Industry | 5.2915 | Open EngInd | Industry | 5.38516 |
| Ulyces | Industry | 3.16228 | Sonaca | Industry | 5.74456 | Cenaero | Research | 6.32456 | UMH | Research | 7.48331 | UMH | Research | 7.48331 | CetIndustryo | Research | 6.08276 | ULB | Research | 5.83095 | LMS Samtech | Industry | 4.79583 | Techspace A | Industry | 5.2915 |
| Amos | Industry | 3.16228 | Techspace A | Industry | 5.47723 | CetIndustryo | Research | 6 | Sonaca | Industry | 6.48074 | CetIndustryo | Research | 6.85565 | ULB | Research | 5.83095 | Sonaca | Industry | 5.65685 | CoexpaIndus | Industry | 4.47214 | CoexpaIndus | Industry | 4.89898 |
| Walphot | Industry | 3.16228 | Samtech | Industry | 5.47723 | Sonaca | Industry | 5.83095 | GDTECH | Industry | 6.40312 | Sonaca | Industry | 6.48074 | Sonaca | Industry | 5.65685 | Open EngInd | Industry | 5.65685 | Sobelcomp | Industry | 4.47214 | CSL | Research | 4.69042 |
| IndustryonIn | Industry | 3.16228 | Cenaero | Research | 5.47723 | Samtech | Industry | 5.47723 | Samtech | Industry | 6.245 | GDTECH | Industry | 6.40312 | UMH | Research | 5.38516 | UMH | Research | 5.38516 | UMons | Research | 4.24264 | Numflo | Industry | 4.47214 |
| WSLux | Industry | 3.16228 | ThalesAS | Industry | 5.09902 | ThalesAS | Industry | 5.09902 | CetIndustryo | Research | 6 | Samtech | Industry | 6.245 | CIndustrysso | Industry | 5.19615 | CetIndustryo | Research | 5.19615 | M3 Systems | Industry | 4 | Samtech | Industry | 4.47214 |
| APC | Research | 3.16228 | CIndustrysso | Industry | 5.09902 | CIndustrysso | Industry | 5.09902 | ThalesAS | Industry | 5.09902 | CIndustrysso | Industry | 6.08276 | MultIndustry | Research | 5.19615 | CIndustrysso | Industry | 5.19615 | Sonaca | Industry | 4 | Sobelcomp | Industry | 4.3589 |

**Table 2: Weighted Degree Centralities (α=0.5)**

| 2006 | | | 2007 | | | 2008 | | | 2009 | | | 2010 | | | 2011 | | | 2012 | | | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) | Agents | Type | Cwd(i) |
| Aquapole | Research | 1.61539 | UCL | Research | 2.7081 | ULg | Research | 3.14626 | ULg | Research | 3.71328 | ULg | Research | 3.7802 | ULg | Research | 3.56163 | ULg | Research | 3.62155 | ULg | Research | 3.18699 | ULg | Research | 3.71328 |
| CSL | Research | 1.61539 | ULB | Research | 2.7081 | ULB | Research | 3.08461 | UCL | Research | 3.32547 | UCL | Research | 3.4296 | UCL | Research | 3.16954 | UCL | Research | 3.16954 | Techspace A | Industry | 2.93772 | UCL | Research | 3.54599 |
| Spacebel | Industry | 1.58489 | ULg | Research | 2.7081 | UCL | Research | 3.00598 | Cenaero | Research | 3.18024 | Cenaero | Research | 3.18024 | Techspace A | Industry | 3.13386 | Techspace A | Industry | 3.13386 | UCL | Research | 2.70567 | GDTECH | Industry | 3.32224 |
| CetIndustryo | Research | 1.58489 | UMH | Research | 2.7081 | UMH | Research | 2.81953 | Techspace A | Industry | 3.17558 | Techspace A | Industry | 3.17558 | GDTECH | Industry | 3.03966 | GDTECH | Industry | 3.03966 | GDTECH | Industry | 2.45739 | Techspace A | Industry | 2.83186 |
| CreactIndust | Industry | 1.58489 | CetIndustryo | Research | 2.33133 | Techspace A | Industry | 2.78696 | ULB | Research | 3.08134 | ULB | Research | 3.08134 | Cenaero | Research | 2.89763 | Cenaero | Research | 2.91651 | Cenaero | Research | 2.43545 | CoexpaIndus | Industry | 2.72774 |
| Ulyces | Industry | 1.58489 | Sonaca | Industry | 2.32181 | Cenaero | Research | 2.59032 | UMH | Research | 3.07215 | UMH | Research | 3.07215 | Sonaca | Industry | 2.43828 | Sonaca | Industry | 2.43828 | LMS Samtech | Industry | 2.24447 | Cenaero | Research | 2.6792 |
| Amos | Industry | 1.58489 | ThalesAS | Industry | 2.31594 | CetIndustryo | Research | 2.33133 | GDTECH | Industry | 2.70028 | GDTECH | Industry | 2.70028 | UMH | Research | 2.38005 | UMH | Research | 2.38005 | CoexpaIndus | Industry | 2.16356 | CSL | Research | 2.6695 |
| Walphot | Industry | 1.58489 | CIndustrysso | Industry | 2.31594 | Sonaca | Industry | 2.32469 | Samtech | Industry | 2.6538 | Samtech | Industry | 2.6538 | ULB | Research | 2.37793 | ULB | Research | 2.37793 | Sonaca | Industry | 2.06913 | Open EngInd | Industry | 2.61069 |
| IndustryonIn | Industry | 1.58489 | MultIndustry | Research | 2.31594 | ThalesAS | Industry | 2.31594 | Sonaca | Industry | 2.63731 | Sonaca | Industry | 2.63731 | Samtech | Industry | 2.2444 | Open EngInd | Industry | 2.3768 | SABCA | Industry | 2.06913 | Amos | Industry | 2.50622 |
| WSLux | Industry | 1.58489 | Techspace A | Industry | 2.31558 | CIndustrysso | Industry | 2.31594 | CetIndustryo | Research | 2.33133 | CIndustrysso | Industry | 2.60494 | Open EngInd | Industry | 2.2444 | Samtech | Industry | 2.2444 | Sobelcomp | Industry | 2.00703 | Samtech | Industry | 2.47352 |
| APC | Research | 1.58489 | Samtech | Industry | 2.31558 | MultIndustry | Research | 2.31594 | ThalesAS | Industry | 2.31594 | MultIndustry | Research | 2.60494 | CetIndustryo | Research | 2.20523 | CetIndustryo | Research | 2.12841 | UMons | Research | 1.98867 | Spacebel | Industry | 2.40225 |

**Table 3: Weighted Degree Centralities (α=0.8)**