13th European Conference on Innovation and Entrepreneurship (ECIE 2018)

Aveiro, Portugal
20 – 21 September 2018

Volume 1 of 2

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ISBN: 978-1-5108-7209-7

Printed from e-media with permission by:

Curran Associates, Inc.
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Red Hook, NY 12571

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Printed by Curran Associates, Inc. (2018)

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Papers submitted to this conference have been double-blind peer reviewed before final acceptance to the conference. Initially, abstracts were reviewed for relevance and accessibility and successful authors were invited to submit full papers. Many thanks to the reviewers who helped ensure the quality of all the submissions.

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Knowledge Bases and Variety of Networking Behaviour among Research-Based Spin-Offs

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Abstract: The paper addresses the role played by research-based spin-off firms (RBSOs) as knowledge dissemination mechanisms, through their position in knowledge networks. Previous research found that, despite the continued relevance of links with research organisations, these firms frequently play an intermediary role between academia and industry, and started characterising the forms assumed by that role (Conceição, Sousa and Fontes, 2017; 2018). This paper extends this approach by proposing that the composition and structure of the knowledge networks and the position occupied by RBSOs are not homogeneous, but vary between industries, being associated with the nature of the knowledge prevalent in that industry. For this purpose, the paper draws on the notion that innovation process in firms and industries are strongly shaped by their specific "modes of knowledge creation" or "knowledge bases", which have been categorised as analytical, synthetic or symbolic (Asheim and Coenen, 2005). According to the literature these modes of knowledge creation influence the nature of interactions that take place (Moodysson et al, 2008; Plum and Hassink, 2011; Salavisa et al, 2012) and, therefore, they are expected to introduce some differentiation in the knowledge networking behaviour of the RBSOs. The empirical research is based on the data on the publicly funded collaborative research and technology development projects established by the population of RBSO created in Portugal until 2007, encompassing both domestic projects, funded by national programmes (237 projects) and international projects, funded by European Framework Programmes (216 projects) and covering a broad spectrum of industries. The industries were classified according to their knowledge bases. The knowledge networks, associated with the participation of RBSO in those projects, were (re)constructed and analysed using a set of measures from social network analysis, with a view to uncover and assess their composition and structure. The results show that, despite RBSOs common academic origin, there some differences in the structure of the knowledge networks of firms in different industries, in particular between those characterised by an analytical knowledge base (of which biotechnology emerges as the most paradigmatic case) and a synthetic knowledge base. These differences have implications for position and role of RBSOs in the networks.

Keywords: Analytical vs. synthetic knowledge bases; Knowledge network, Research-based spin-offs; Social network analysis

1. Introduction

This research addresses the roles played by firms whose activities are based on knowledge generated in research organisations. The literature offers different definitions and labels for this category of organisations.

In this paper we define them as firms whose creation was based on the formal and/or informal transfer of knowledge or technology generated in public research organisations (Djokovic and Souitaris, 2008; Mustar et al, 2006; Pirnay et al 2003) and label them research based spin-offs (RBSOs).

There is now a significant body of research on this group of firms, which have addressed their genesis, advantages or disadvantages and roles played (for reviews see, for instance Grimaldi et al, 2011; Miranda et al, 2017; Mustar et al, 2008; Rasmussen, 2018; Wright, 2014). The literature generally agrees that these firms can offer relevant contributions to innovation and technological development, although there is some debate on the extent and conditions in which these are achieved. Given RBSOs particular strengths and weaknesses, some authors have argued that one key role of these firms is to act as conveyors of knowledge across organisations, by accessing, transforming and translating knowledge between different knowledge, organisational and cultural contexts (Autio, 1997; Fontes, 2005; Harrison and Leitch, 2010; Perez and Sanchez, 2003; Walter et al, 2006). Accordingly, it has been argued that RBSOs impact is more clearly expressed through the value they create in knowledge and innovation networks (Conceição, Sousa and Fontes, 2017; 2018; Hayter, 2016; Rasmussen, 2018). But while there has been some recent research in the networking behaviour of RBSOs (Hagedoorn et al, 2018; Aaboen et al, 2016; Fontes and Sousa, 2016; Benghozi and Salvador, 2014), it only rarely addresses RBSOs knowledge networks.

Previous research addressing this issue found that RBSOs frequently play an intermediary role between academia and industry and started characterising the forms assumed by that role (Conceição, Sousa and Fontes, 2017; 2018). This paper extends this approach by proposing that the composition and structure of the knowledge networks and the position occupied by RBSOs are not homogeneous, but vary between industries, being associated with the nature of the knowledge prevailing in that industry. For this purpose the paper draws on the notion that innovation process in firms and industries are strongly shaped by their specific "modes of knowledge creation" or "knowledge bases", which have been categorised as analytical, synthetic or symbolic (Asheim and Coenen, 2005). According to the literature, these modes of knowledge creation influence the nature of interactions that take place (Moodysson et al, 2008; Plum and Hassink, 2011; Salavisa et al, 2012) and, therefore, they are expected to introduce some differentiation in the knowledge networking behaviour of the RBSOs.

The empirical research is based on data on the publicly funded collaborative research and technology development (RTD) projects established by the population of RBSO created in Portugal until 2007. The analysis encompasses both domestic projects, funded by national programmes (237 projects) and international projects, funded by European Framework Programmes (216 projects). The knowledge networks, associated with the participation of RBSO in those projects, were (re)constructed and analysed using a set of measures from social network analysis, namely for studying their composition and structure. The RBSO selected operate in a broad spectrum of industries, which were classified according to their knowledge bases.

The final goal is to understand whether different knowledge base affect the networks established by RBSOs, with impact on the roles played by these firms.

2. Conceptual Framework

2.1 RBSO intermediate role

Research-based spin-offs (RBSO) have been found to play an important role as knowledge transfer mechanisms (Bathelt et al, 2010; Helm and Mauroner, 2007). In fact, RBSOs are set-up to commercially exploit the results of academic research, transforming it in technologies, products or services and making them accessible to the society. Moreover, if successful in their endeavour, RBSOs are likely to continue acting as sources and disseminators of new knowledge over time. The effectiveness of RBSO as a "bridge" between academia and the industry depends on entrepreneurial actions, such as opportunity identification, risk taking, resource mobilisation that can be more effectively achieved through networks (Grandi and Grimaldi, 2003; Walter et al, 2006).

Previous studies (Conceição, Sousa and Fontes, 2017; 2018) indicate that the parent research organisation is an important actor in most firms' national knowledge networks. Moreover, half of these spin-offs only establish formal technological relationships with research organisations, reproducing a frequently depicted pattern among RBSOs. However, the other half was found to also establish relationships with non-academic organisations. Among these, a still substantial number emerge as a central element in tripartite technological relationships, including the RBSO, research organisations and firms or other organisations located downstream. This result points to a bridging role of RBSOs in entrepreneurial ecosystems, connecting academic and downstream organisations. Furthermore, when considering the network formed by the RBSO and its partners, several spin-offs are found to occupy a position as brokers between the other network actors, potentially facilitating the circulation of knowledge across them (Conceição et al, 2018).

Concerning the broader knowledge networks established by Portuguese RBSOs in the context of collaborative RTD projects at National and European levels, the authors concluded that these RBSOs have the conditions to play an intermediary role relatively to other Portuguese organisations, which can assume different forms in diverse contexts (Conceição, Sousa and Fontes, 2017). In the networks formed in the context of national projects they are frequently in a position to bridge between research organisations and firms. In the international networks formed in the context of European Union projects, where RBSOs will tend to assume a less relevant position, their most important role is as connectors and/or conveyors of advanced knowledge produced these international contexts and the Portuguese organisations with whom they collaborate, either in the EU projects or in other Portuguese projects (Conceição, Sousa and Fontes, 2017).

In order to better understanding the intermediate role played by RBSOs, it is crucial to assess whether are these roles are uniformly performed across the whole population of RBSOs, or differ between industries. The argument of this paper is that it is likely to be the latter case. The rationale is that the composition (i.e. the type of organisations involved) and structure of knowledge networks is associated with the nature of knowledge, which is likely to vary between industries. This will influence the type of partnerships established and the conditions in which RBSOs interact with their environment, thus affecting the roles these firms play towards other organisations. This argument is supported by the knowledge bases literature, according to which the contents of knowledge relationships are determined by firms and industries specific knowledge bases (Asheim and Coenen, 2005; Plum and Hassink, 2011). Thus, industries with different knowledge bases are expected to differ with regard to the structural dimension of knowledge networks (Martin, 2013).

2.2 Knowledge bases Literature

The principal contribution of the knowledge bases literature was to advance the idea that innovation process of firms and industries are strongly shaped by their specific knowledge bases (Asheim and Coenen, 2005; Asheim and Gertler, 2005). The knowledge base approach was presented as an alternative to conceptualizations of knowledge such as high- tech, medium- tech and low- tech (OECD, 1996) and tacit versus codified knowledge (Boschma, 2018; Moodysson et al, 2008), which these authors considered insufficient to fully explain the nature of the processes at work.

This literature distinguishes three kinds of knowledge base: analytical (science based); synthetic (engineering based); and symbolic (creativity based). An *analytical knowledge base* is depicted as having the following features: innovation relies on the creation of new knowledge; scientific knowledge is very important; collaboration between firms and research organisations is relevant; knowledge creation is based on deductive processes and formal models and appeals to abstract “know-why”; codified knowledge is dominant due to the existence of extensive patenting and publication activities (even if tacit knowledge is also present); and the outcome is more frequently radical innovation. A *synthetic knowledge base* is described by the following aspects: innovation is mostly based on existing knowledge, either through application or novel combinations; knowledge creation arises from specific problem solving, through inductive processes of testing and experimentation; interactive learning with clients and suppliers is more relevant; tacit knowledge is dominant; and the outcome is mainly incremental innovation (Asheim and Gertler, 2005; Moodysson et al, 2008). Finally, the concept of *symbolic knowledge base*, which was introduced later, is related with processes that deal with the creation and communication of cultural meanings, symbols, ethics and aesthetics. In this sense, symbolic knowledge is mainly (but not exclusively) tacit, closely linked to specific socio-cultural contexts and difficult to transfer directly across the geographical space (Manniche, 2012).

2.3 Knowledge bases & knowledge networks

The distinct modes of knowledge creation associated with the different knowledge bases impact on the way firms develop their knowledge networks (Moodysson et al, 2008; Plum and Hassink, 2011; Martin, 2013). Thus, knowledge interactions with universities and other research-oriented organisations are more frequent in the analytical mode, acting as complementary sources to internal R&D activities. Relations with research organisations are also present in the case of the synthetic mode, but interacting with clients and suppliers for problem solving, often through face-to-face exchanges and/or informal bartering, is more relevant. The more formalised and codified nature of the knowledge being produced in the analytical mode makes personal interactions less important than in the synthetic mode, and also invites (or even recommends) a greater formalisation of the knowledge exchanges.

Plum and Hassink (2011), drawing on data on two groups of German firms (biotechnology and automotive), predict and empirically corroborate the existence of sharp differences between knowledge networks associated with each knowledge base - analytical and synthetic. Knowledge networks differ across fundamental dimensions: composition, link content, average importance of the relations and geography.

Comparing the two networks, they found that: the share of universities is much higher in biotechnology networks, while ties with suppliers and customers predominate in automotive networks; the average importance attributed to each kind of partner for the firms’ innovative performance is also distinct across the two groups, although not so strikingly; the content of the ties differs, with a much higher share of ‘scientific oriented’ ties on total ties in biotechnology networks, and a much higher share of ‘practical oriented’ ties in automotive networks; finally, regarding the geographical reach, a clear difference occurs, with a much higher share of international connections, and particularly of extra-European connections, in biotechnology firms, versus the overwhelming dominance of regional and domestic connections in automotive networks.

Similarly, Martin (2013) argues that industries with different knowledge bases diverge, not only with regard to the type of knowledge involved in innovation activities, but also with regard to the nature of innovation networks, namely their structural, relational and geographical dimensions. This author defends that, in the case of an analytical knowledge base, the innovation networks involve a relatively small number of actors and an intensive collaboration between those actors, based on formal collaboration between organizations, or, less formalized, within communities of scientists knowledgeable in a particular issue-area. As analytical industries deal with scientific knowledge that is not dependent on a particular geographical or social-cultural context, cooperation and knowledge exchange can take place between scientists and research units that are widely dispersed across great distances (Martin, 2013). Regarding the synthetic knowledge base, Martin (2013) defends that networks are predominantly national or regional. Synthetic industries are constantly engaged in solving engineering problems, which require know-how and practical skills. In this sense, the importance of tacit knowledge and interactive ways of learning implies that spatial proximity plays an important role for collaboration and knowledge exchange. Companies are more likely to engage in intensive cooperation with suppliers and customers, which are located within the regional or national milieu, where a common institutional framework facilitates interactive learning and knowledge exchange (Martin, 2013). Concerning the third type of knowledge base, the author argues that innovation in symbolic industries is dominated by creativity and artistic skills, while the dominant mode of innovation is flexible and based on temporary and project-based cooperation. The importance of cultural knowledge and sign values suggest that cooperation and knowledge exchange takes place first and foremost within the regional milieu, while national or international collaboration is less frequent (Martin, 2013).

This literature supports our argument that RBSOs in different industries are likely to have different knowledge bases and establish different networks. In fact, although RBSOs are companies created to explore knowledge and technologies developed in research organisations, and thus are often analysed as a group, the literature has shown that they not necessarily homogenous organisations (Conceição et al, 2012). In particular, they can use different types of knowledge in their innovation activities and thus establish different types of knowledge relationships (Lubik et al, 2013; Conceição et al, 2012; Bathelt et al, 2010). With respect to evidence on network differences at the industrial level, research that specifically compares the RBSOs networks in different industries is scarce. However, a comparison between innovation networks of biotechnology and software found differences between them, in particular in networks concerned with formal exchange of technological knowledge (Salavisa et al, 2012).

Thus, this paper draws on the knowledge base concept to uncover eventual differences between the knowledge networks formed by Portuguese RBSO in different industries, as a basis to understand whether the intermediary roles previously identified are dissimilarly distributed across industries. For this purpose, two industries are considered: biotechnology with an analytival knowledge base and environment and energy with a synthetic knowlwdge base.

While biotechnology was considered as representative of an analytical knowledge base in research on the knowledge networks of technology-intensive companies (Salavisa et al, 2012), the case of the energy and environment industries has not been previously addressed (to the best of our knowledge). However, some evidence on the characteristics of the knowedge developed/applied and the innovation activities conducted in these industries suggests they are more likely to fall within the synthetic knowledge based category. In fact, energy and environement industries are highly multidisciplinary, but predominantly encompass engineering activities, supported on disciplines - e.g. electrical, electronics and information engineering, mechanical engineering, materials engineering, environmental engineering - that are classified as under the “Engineering and technology” label in the OECD Fields of Science classification (OECD, 2007). This is the case even for some of the renewable energy technologies that have registered the greatest development in Portugal – wind and wave energy – therefore providing opportunites for the emergence of RBSOs (Fontes and Sousa, 2017). The knowledge base underlying wind energy technology was described as mostly encompassing disciplines such as mechanical and electrical engineering mixed with software and aerodynamics (Bergek and Jacobsson, 2003). Wave energy technologies are also reliant, to a great extent, on similar disciplines. This is supported in Portugal by the fact that the disciplinary bases of the main research centres where technologies were developed are mechanical engineering or naval engineering. Moreover, as the renewable energy technologies mature and utilities and other large firms occupy dominant positions, a significant part of the opportunities open to RBSOs in this field rest on developing advanced solutions for more specific problems associated with the operation of the technologies (efficiency, costs, reliability) or with grid integration, due to the renewable energies distributed and intermittent nature (Fontes and Sousa, 2017).

Another growing area of opportunity for new firms is the broad field generically identified under the "energy efficiency" designation, which has equally application-oriented and combinatorial characteristics. The activities conducted by RBSOs operating under the "environmental" label are also mostly concerned with solving complex problems in the areas of waste and water treatment or air quality in buildings, and will equally entail, to a large extent, applying existing knowledge and specialised competences to develop new solutions. Thus, in both cases, the activities are likely to involve combining, in new ways, knowledge originating from a variety of disciplines; interaction with users will be relevant given the problem solving perspective; and the knowledge produced will tend to be more context-specific and tacit, even if they may occasionally need to resort to scientific research to solve more complex problems.

A comparison between the composition and structure of the knowledge networks in these industries will enable us to assess eventual similarities and differences in terms of the type of organisations with whom RBSOs establish relationships (composition) and in terms of the structure of the networks, which give indications of the type of connections they may help to establish.

3. Methodology

3.1 Data sample: the Portuguese RBSOs

For this study RBSOs were defined as firms created by entrepreneurs who have some stable connection with a university or other research institution - such as faculty members, researchers and graduate students - and who are applying knowledge obtained or technology developed as part of their research activity; and firms created by external entrepreneurs based on the transfer of technology developed by a research organisation (Conceição, Faria and Fontes, 2017).

The empirical analysis is based on the set of RBSOs created in Portugal between 1979 and 2007 and surviving to this date, which corresponds to the known population created during this period. It should nevertheless be noted that although the first firm identified was established 1979, spin-offs creation only took-off in the 1990s, the majority of the firms included having been established already in the 2000s (Conceição, Faria and Fontes, 2017).

These RBSOs firms are active in a wide variety of industries. In what concerns industry distribution, information & communication technologies (ICT) represent 40.67% of the population with 133 RBSOs, followed by the Biotechnology with 64 firms (19.57%). The smaller proportion corresponds to Engineering with 19 RBSOs (5.81%) (Conceição, Faria and Fontes, 2017).

3.2 Collaborative RTD Projects: data and analysis

To identify the formal networks established by the RBSOs, the paper draws on data on collaborative projects established by Portuguese RBSOs, at national and European level, in the context of all public programmes.

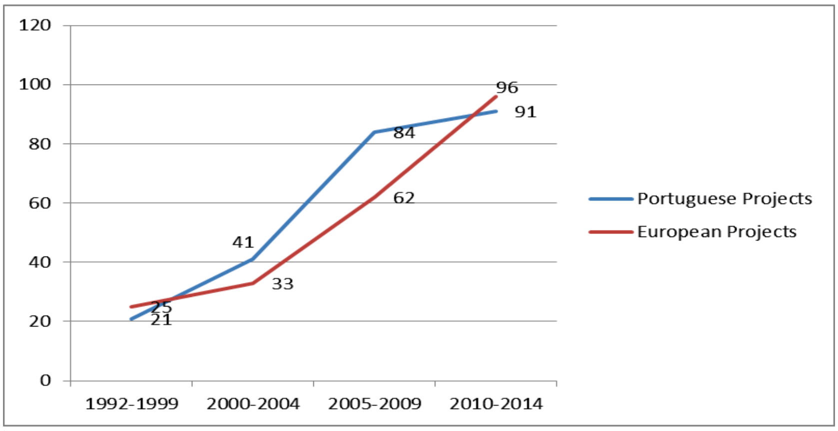
Given RBSOs reliance on public funding for research and development activities (Wright et al, 2007), this data is expected to offer a good coverage of the formal technological relationships by established these firms in this domain.

The Portuguese data, regarding the collaborative RTD projects funded by national support programmes, was obtained from the National Innovation Agency (AdI later ANI) database and covers the period 1992-2014. The European data, regarding the joint RTD projects conducted in the context European Framework Programmes, was obtained from the European Commission Community Research and Development Information Service (CORDIS) database and covers the same period. All National and European projects with Portuguese spin-off involvement were identified (table 1), totalling 453 projects (237 Portuguese projects and 216 European projects). Since not all RBSOs were involved in at least one type of project, the analysis ended-up including 112 RBSO, which totalled 510 project participations: 281 participations in Portuguese projects and 229 participations in European projects. Figure 1 presents the distribution of Portuguese and European projects over time.

Table 1: Descriptive of Portuguese and European projects.

	Number of projects	Number of RBSOs involved	Number of project participations of RBSOs
Portuguese funded projects	237	92	281
European funded projects	216	64	229
Total PT & EU	453	112*	510

Source: Own calculations.
* 44 spin-offs participated in both types of project



Source: Own calculations.

Figure 1: Distribution of Portuguese and European projects by start year (1992 – 2014)

Data was collected (in May 2016) on the characteristics of each project and on the partners. Then, both RBSOs and partner organisations were characterised by type and location. The RBSOs were also classified according to the industry where they conducted their principal activity: biotechnology, energy & environment, electronics, engineering and ICT. The "parent" research organisations of the RBSOs were identified and their presence in the same project of their spin-offs was signalled (table 2). As mentioned above, in this research only two industries are considered: biotechnology representing an analytichal knowledge base and energy & environment representing a systhetic knowedge base.

Table 2: Descriptive of Portuguese and European projects by Industry

Industry	Portuguese funded projects		European funded projects	
Biotechnology	47	20%	52	24%
Energy & Environment	14	6%	17	8%
Electronics	47	20%	56	26%
Engineering	9	4%	9	4%
ICT	109	46%	73	34%
Services	9	4%	9	4%
Total number of projects	237		216	

Source: Own calculations.

Collaborative projects constitute two-mode networks that link organisations to an event - the projects. From these we have extracted a one-mode network, considering inter-organisational networks, where a tie joins two organisations, if they collaborate in the same project. We have built symmetric adjacency matrices, valued by the number of common projects and conducted Social Network Analysis (SNA), using UCINET software. The diagrams were obtained with NetDraw software.

SNA provides information on the realtions and structure, as well as on the position of the actors in the network (Wasserman and Faust, 1994). From the vast set of SNA measure we will focus our attention on: i) the size of the network, in terms of number of actors and ties; ii) the network composition, in terms of the share of each type of partner, both considering a tipology of actors (spin-offs, other companies, reseach organizations, other type of organizations; and their location); iii) the positioning of actors, assessing their centrality; iv) the structure of the networks, considering the measures of density, distance, centralization and cohesiveness.

4. RBSOs knowledge networks: Analytical KB (biotech) vs Synthetic (Energy & Environment)

The RBSOs knowledge networks are represented in Figures 2 and 3, where the colour of the nodes represents the type of actor (spin-offs in blue, other companies in red, research organizations in yellow and other type of actors, including public and non-profit organizations, in green), the shape represents the nationality of the organization (Portuguese in squares and foreign in clircles) and the size is proportional to degree centrality.

Figure 2: Knowledge network of Biotechnology RBSOs

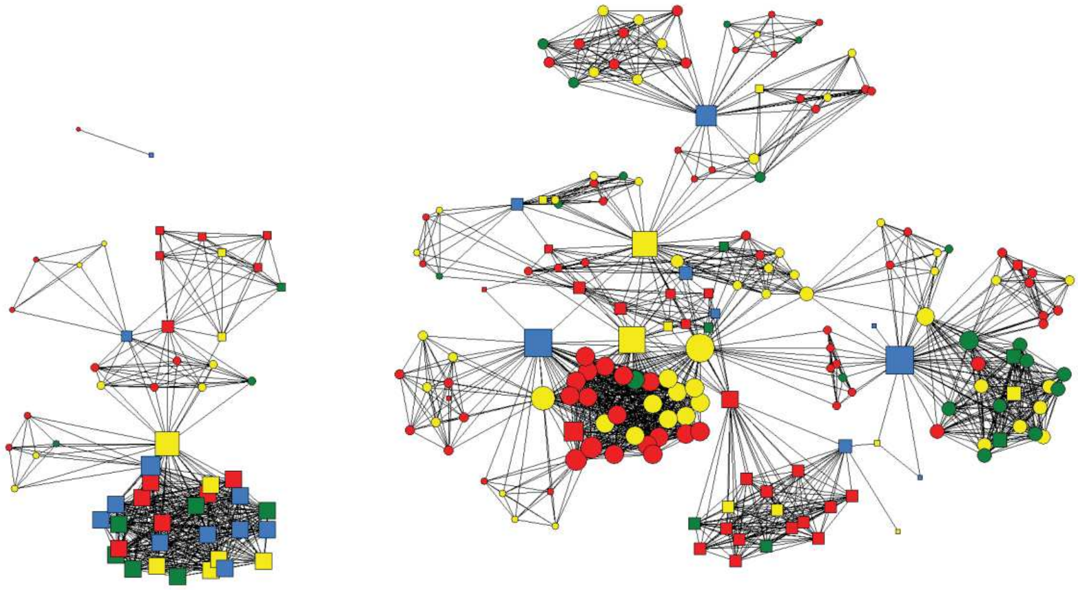


Figure 3: Kowledge network of Energy and Enviroment RBSOs

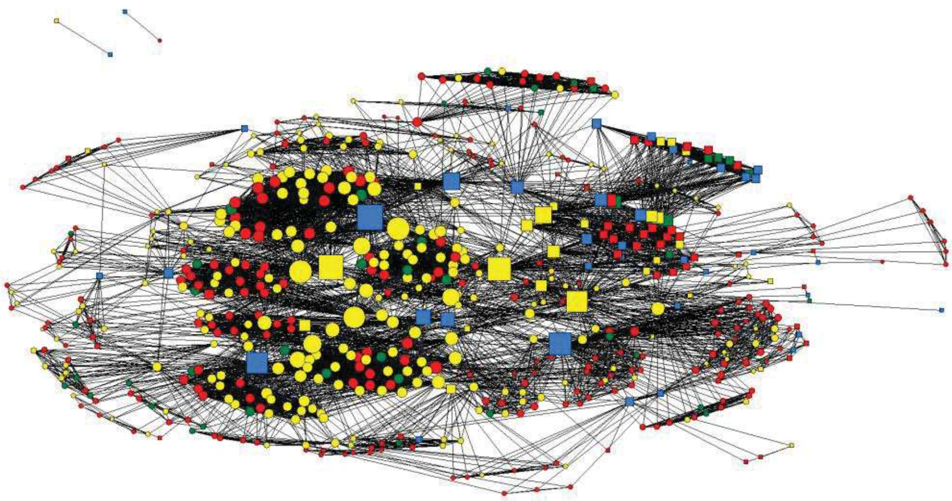


Table 3 presents the size and composition of the RBSOs knowledge networks in the two industries. It shows that the knowledge network of biotechnology is larger, notably in respect to the number of ties, stressing the importance of research collaborations in the industry. It also shows, that the frequency of interaction with research organizations is higher in biotechnology and that the frequency of interaction with other companies is higher in energy & environment, which in line with previous research, being consistent with the presence of an analytical knowledge base in the former and a synthetic knowledge base in the latter. Similarly, it also shows that national partners are more frequent in the industry with a synthetic knowledge base - energy & environment - while international partners are more frequent in the industry with an analytical knowledge base - biotechnology.

Table 3: Network size and composition

		Biotechnology	Energy & Environment
Size	Number of actors	612	240
	Number of ties	6785	1970
Composition	Spin-offs	6.2%	8.3%
	Other companies	43.9%	45.0%
	Research organizations	42.6%	31.7%
	Other organizations	7.2%	15.0%
	National organizations	19.9%	35.8%

Source: Own calculations.

Table 4 presents two centrality measures for the whole network and for the particular types of actors. Centrality measures enable to detect more favourable network positions, enabling access to new business opportunities access to the most relevant knowledge sources and access to better information about what is happening in the network, leading to a increase in innovative performance (Gilsing et al, 2008; Van Der Valk and Gijbers, 2010). In this paper two different centrality measures are used: degree centrality, enabling to capture those actors that are more active in the network and betweenness centrality, enabling to capture those actors that lie between the various other organisations, acting as knowledge brokers.

Table 4: Degree and Betweenness Centrality

		Biotechnology	Energy & Environment
Average Degree Centrality	Overall network	22.7	16.6
	Spin-offs	30.4	23.1
	Other companies	17.7	15.0
	Research organizations	26.9	7.2
	Other organizations	21.7	16.8
	Centralization Index	2.4%	7.7%
Average Normalised Betweenness centrality	Overall network	0.302	0.519
	Spin-offs	1.44	2
	Other companies	0.03	0.12
	Research organizations	0.46	0.89
	Other organizations	0.02	0.04
	Centralization Index	14.9%	26.1%

Source: Own calculations.

It is possible to observe differences across the two industries. Firstly, the biotechnology network exhibits a higher activity, refelected by the higher average degree centrality – each actor has in average 23 partners. Secondly, the distribution of the degree centrality across actor type shows that research organizations are the most relevant knowledge provider in biotechnology, while other organzations (followed closely by other companies) perform this role in the energy & environment network. Thirdly, in the energy & environment network, it is possible to observe a higher ability to broker between groups, expressed by a greater betweeness centrality. Fourthly, the energy & environment network shows a higher centralization index (both for degree and betweeness), indicating a higher variation in the centrality scores among the organizations and, therefore, reflecting a larger separation between the core and the periphery of the network. Since, more skewed distributions can give more benefits to central actors relatively to more peripherical ones, the most central actors in the energy & environment network can see their power reinforced by this structure. Table 4 also shows that, in both industries, research organzations are performing the role of brokers.

Table 5 presents a set of measures to characterize the structure of the networks. Knowledge circultes more easily when networks are connected and dense and have shot paths between the actors (Van Der Valk and Gijbers, 2010). In this case, althoug the networks have the same number of components - there is a path conecting all the organizations - in biotechnology the largest component includes a higher proportion of the total number of actors, and this is reflefted in a higher connectedness (proportion of the organizations that can be reached in the network. In the energy & environment industry we found a denser network, reflecting that the proportion of the relations that are possible, taking in to account organizations present in the network, were established by the RBSOs. Previous research has found that networks with a higher density favour the sharing and transfer of knowledge since they promote trust (Tortoriello et al, 2012), and provide better oportunites to asses the reliability of parters (Gilsing et al, 2008), to establish a share language (Obstfled, 2005) and to build absorptive capacity (Gilsing and Nooteboom, 2005), being very important to exploitation processes. On the other hand, less dense networks – case of biotechnology – facilitate the acquisition of valuable non-redundant information contributiong to bring new ideas and to identify new opportunities (Burt, 2004; Zaheer and Bell, 2005; Zheng, 2010), being very important for exploration processes.

Table 5: Network structure measures

	Biotechnology	Energy and Environment
Number of components	3	3
Share of the largest component	99.3%	77.1%
Density	3.6%	6.9%
Connectedness	98.7%	64.2%
Average distance	2.9	2.9
Diameter	5	5
Clustering coefficient	0.496	0.974
Small-world index	21.6	9.6

Source: Own calculations.

No differences were found across the industries rearding the diameter and the average distance: in both cases the longest geodesic distance is 5 and the average geodesic distance is 3, meaning that to reach any other organization in the same component it will take 3 steps.

Efficiency in knowledge transfer is also related to the small-world characteristics of a network (Watts and Strogatz, 1998; Cowan and Jonard, 2004), i.e., the combination of many local ties and few more distant ties. Small-world networks tend to be formed by sub-groups, exhibiting a higher clustering coefficient (the density in the neighberhood of an actor) that is reflected in a fast diffusion of knowledge in the sub-group, and by the fact that most pairs of nodes will be connected by at least one short path, indicating that the knowledge can reach the whole network. This has important consequences for the easiness of information and knowledge flows and therefore for the innovation processes. Table 5 shows that the biotechnology industry exhibits a higher small-world index due to it more connected nature. This reflects a more descentralized search process (Easley and Kleinberg, 2010) that can be explained by the distributed nature of knowledge production in this industry (Whittington et al, 2009).

5. Conclusions

This paper proposed that, despite RBSOs common research-based origin, the composition and structure of their knowledge networks might vary between industries, being associated with the nature of the knowledge bases prevailing in the industry. This proposition was explored on the basis of a comparative analysis of the formal knowledge networks (national and international) formed by RBSOs in two industries - biotechnology and energy & environment - which exhibit characteristics that suggest the predominance of substantially different knowledge bases: analytical for biotechnology and synthetic for energy & environment.

The results show that there are indeed relevant differences in the composition and structure of the networks formed by RBSOs in these industries, which denote substantially different networking behaviours. In particular, the findings concerning the size (higher number of ties and greater component size) and the composition (greater weight of international partners) of the biotechnology network, as compared with the energy & environment, are in line with previous research on the characteristics of the networks in industries with the two types of knowledge bases (Martin, 2013). Similarly, concerning the structure, the finding that the biotechnology network exhibits a higher activity, reflected in the higher average degree centrality, is equally in line with previous reseach, which indicate that companies in analytical industries interact with a higher number of partners than those in synthetic industries (Martin, 2013).

The consistency of our results with features identified by previous research, involving a broader range of companies, supports our association of RBSOs active in these industries to the two generic knowledge bases, in particular our tentative association of the energy & environment industry to the synthetic knowledge base. More importantly, it suggests that despite RBSOs distinctive characteristics, their networking behaviour is strongly influenced by the dominant knowledge base in the industries where they operate. In addition, our research identified other differentiating features that reinforce the industry-specificity of the RBSOs knowledge networks studied. This variety is relevant since it has implications for the position and role of RBSOs in these networks. Thus, subsequent research will explore in greater detail the influence of these diverse network features in the RBSOs potential bridging role.

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