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The role of research-based spin-offs in innovation ecosystems

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Abstract: The objective of the paper is to contribute to a better understanding of the various roles played by research-based spin-offs (RBSOs) in knowledge dissemination. It investigates if RBSOs act as connectors and knowledge translators, both between different types of organisations within an innovation ecosystem and across different geographical scales and knowledge environments. This latter role has been relatively less investigated but is important to open local innovation ecosystems. The paper analyses the networks formed by Portuguese RBSOs in the context of research, technology and product development projects. The results suggest that RBSOs play an intermediary role in the country's innovation ecosystem, which can assume different forms. In the national networks, they frequently bridge research and downstream organisations, contributing to the dissemination of knowledge within the ecosystem. In the international networks, their most important role may be as connectors and conveyors of advanced knowledge produced in external knowledge environments.

Keywords: spin-offs; innovation ecosystems knowledge dissemination; inter-firm relationships.

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1 Introduction

Research-based spin-off companies (RBSOs), that is, companies set up for the commercial exploitation of knowledge produced in research organisations (ROs), have recently become the focus of science, technology and innovation policies (Marzocchi et al., 2019; Mustar et al., 2008; Perez and Sanchez, 2003; Wright et al., 2007).

The increase in numbers and political visibility of spin-offs gave rise to a large body of research addressing the behaviour of these companies, as well as their impacts (Galati et al., 2020; Mustar et al., 2006; Shane, 2004; O'Shea et al., 2008; Thomas et al., 2020; Wright et al., 2007). This research can be useful to support entrepreneurial education, which is critical to boost entrepreneurial mindset and competences (Bhole et al., 2022). In fact, due to the growing relevance assumed by RBSOs, the university should be concerned with promoting an entrepreneurial and commercial environment to bolster the ability to innovate and, in this context, universities could offer their students programs and courses oriented to the understanding the entrepreneurial process (Bezanilla et al., 2020; Lehmann et al., 2020; Luna et al., 2022; Stephens, 2020).

The literature shows that RBSOs are characterised by the science-based nature of the knowledge being exploited, by a close relationship with the parent research organisation, and by specific organisational features, such as the high scientific qualifications of human capital and a frequent absence of business competences and experience (Bolzani et al.,

2020; Djokovic and Souitaris, 2008; Helm and Mauroner, 2007; Mustar et al., 2006; Phan and Siegel, 2006).

Given the particular characteristics of RBSOs, their impact cannot be exclusively measured by traditional indicators, such as employment and turnover. Several empirical studies focus, on the one hand, on the impact of spin-offs firms on ROs, in particular the parent institution (Ferretti et al., 2020; Heblich and Slavtchev, 2013; Semadeni and Cannella, 2011) and, on the other hand, on their economic and regional impacts (Bathelt et al., 2010; Buenstorf and Geissler, 2011; Prencipe et al., 2020).

RBSOs impact has been found to be more clearly expressed through the value they create in knowledge and innovation networks, as agents of knowledge acquisition, transformation and diffusion (Autio, 1997; Civera et al., 2020; Fontes, 2005; Harrison and Leitch, 2010; Perez and Sanchez, 2003; Walter et al., 2006). The literature suggests that small entrepreneurial businesses and scalable start-ups may play a crucial role in entrepreneurial and innovation ecosystems, contributing to structure the system (Berggren and Dahlstrand, 2009; Clarisse et al., 2014; Yoon et al., 2015; Kassicieh et al., 2002). However, most empirical studies have focused almost exclusively on the roles played by ROs (universities, research centres, public labs) and their knowledge intermediaries (such as technology transfer offices) (Akinwale, 2020; Cho et al., 2021; Hayter, 2016; Klimas and Czakon, 2021). We argue that RBSOs, by acting as intermediaries between the academia and the industry, are important actors in the structuration of innovation ecosystems. However, this role is not yet well understood in the literature.

Scholars have also started to stress the need for considering that local innovation ecosystems do not work in a vacuum and interact with other ecosystems – both in the same country and abroad. In this context, non-local knowledge interactions are pivotal (Trippl et al., 2009; Gertler and Levitte, 2005). We argue that RBSOs can also have a relevant role in opening up the ecosystem, performing their intermediary role both with local/national organisations and foreign ones, through the spatial reach of their activities.

Therefore, the objective of this paper is to study the role of RBSO in the structuration of a country's innovation ecosystems, as 'innovation intermediaries'. The paper contributes to understanding whether RBSOs are effectively acting as knowledge dissemination mechanisms, through their position in networks, simultaneously bridging between the academia and the industry, and bridging between national and foreign actors and their knowledge environments.

For this purpose, the paper analyses the networks formed by Portuguese RBSOs, in the context of research, technology and product development (RTD) projects, at two geographical scales.

At the national level, the paper analyses the networks of relationships established, over time, in the context of projects funded in Portugal, in order to uncover the organisational composition of these networks and the position occupied by RBSOs. The objective is to understand whether RBSOs act as connectors between academia and industry, by partnering with organisations located downstream in the value chain, or linking between these and ROs, thus playing a bridging role in the country's innovation ecosystems.

At the international level, the paper analyses the participation of RBSOs in the networks of relationships established, over time, in the context of European funded projects; and also identifies those RBSOs that are active in both national and international networks. The objective is to understand the role of RBSOs in processes that involve

linking to external knowledge environments and then acting as knowledge conveyors towards their national innovation ecosystems.

In order to identify the networks, we start from a self-collected dataset that encompasses the known population of RBSOs created in Portugal until 2007 (327 firms). We identify all the collaborative RTD projects, with spin-off involvement, funded by Portuguese support programmes (using the National Innovation Agency database) and the European framework programmes (FPs) (using the CORDIS database). The analysis is based on 289 national projects and 279 European projects involving a total of 115 Portuguese RBSOs.

The paper contributes to a better understanding of the various roles played by RBSOs in innovation ecosystems. It adds to the extant literature, by exploring the role of this type of actor in the formation, structuration and strengthening of national ecosystems. In particular, it shows that RBSOs act as connectors and knowledge translators, not just between different types of organisations within a given innovation ecosystem, but also across different geographical scales and knowledge environments. This latter role has been even less frequently addressed in the literature, but is particularly important in more peripheral regions, because it contributes to open local innovation ecosystems (Trippl and Todtling, 2007; Fontes and Capaldo, 2012). In fact, as research-intensive companies, RBSOs can profit from European RTD projects to gain access to frontier knowledge being produced in more advanced environments and, subsequently, use their local networks to convey that knowledge to other local organisations.

2 The nature of RBSOs technological relations: 'bridging' between organisations and ecosystems?

Research-based spin-offs (RBSOs) perform an important role in the transfer of academic knowledge to the society (Bathelt et al., 2010; Blankesteijn et al., 2021; Helm and Mauroner, 2007). In fact, they are setup to commercially exploit the results of academic research, transforming it in technologies, products or services and bringing them to the market (Conceição and Rodrigues, 2021; Mustar et al., 2008). Moreover, if successful in their endeavour, RBSOs are likely to continue co-creating knowledge for innovation with ROs and thus acting as sources and disseminators of new knowledge over time. This is because RBSOs competitiveness is dependent on high-level scientific capabilities and on the renewal of their knowledge base (Owen-Smith and Powell, 2004).

For analytical purposes, the transfer process enacted by RBSOs can be understood as a two-stage process. The first stage involves the interaction between the RO and the new firm, to support further development of the knowledge that is being commercialised as part of the spin-off process; or to joint-develop new or complementary knowledge in areas relevant for the firm. Therefore, it involves upstream relations with ROs (Walsh and Kirchhoff, 2002). The second stage involves the search for and interaction with potential users of the technology or its applications, and therefore downstream relations, in order to gain a better understanding of market needs and requirements; and/or to gain access to complementary competences and resources. Although the latter interactions are more frequently related with business and market development, relationships may also concern the development of new technological knowledge in areas that are critical for the success of the innovation and that go beyond the spin-off frequently specialised competences (Colombo et al., 2006).

These stages can overlap, i.e., these processes may take place simultaneously in the context of tripartite relationships that involve ROs, spin-offs and other firms. Research conducted on this type of alliance has found evidence of some division of work between those actors (Stuart et al., 2007). For instance, Hess et al (2013) concluded that in alliances between spin-offs, industry and academic partners, the different members had well-defined roles in the innovation process. In fact, product needs, access to markets and industrialisation ability were brought into the alliance by the industry partner, while the spin-off delivered agility and speed connected to in-depth technology know-how, plus its academic network, providing access to laboratories and relevant technological expertise.

The effectiveness of RBSO as a 'bridge' between academia and the industry depends on entrepreneurial actions, such as opportunity identification, risk-taking, resource mobilisation, which can be more effectively achieved through networks (Grandi and Grimaldi, 2003; Walter et al., 2006). The capacity to create external networks is presented as a competitive advantage of new high-technology firms, which supports the discovery of opportunities, the access to a variety of resources, and collaborative learning with partners (Grandi and Grimaldi, 2003; Sousa and Fontes, 2012; van Geenhuizen et al., 2014).

Despite the extensive literature on the role of networks for technological entrepreneurship and RBSOs (Elfring and Hulsink, 2003; Slotte-Kock and Coviello, 2010), there is still limited research on the nature of the relationships that are established as part of the bridging process potentially conducted by RBSOs. The literature tends to focus on the interaction between the spin-off and the parent organisation (Acs et al., 2013; Audretsch and Lehmann, 2005; Colombo et al., 2006; Heblich and Slavtchev, 2013; Semadeni and Cannella, 2011), giving much less attention to the downstream relationships spin-offs establish with other types of organisations to further develop and commercialise the technology, despite their relevance for this type of firm (Conceição et al., 2012).

Moreover, it is necessary to consider that these interactions unfold in the context of innovation ecosystems. According to Granstrand and Holgerssonl (2020, p.3) "an innovation ecosystem is the evolving set of actors, activities, and artefacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors". Thus, RBSOs are part of innovation ecosystems formed by complex relationships and networks between different actors (Bagchi-Sen et al., 2020; Cai et al., 2019; Granstrand and Holgerssonl, 2020; Spigel, 2017). Their proximity to knowledge generators, such as universities and other public ROs, suggests that they can assume the role of knowledge disseminators across the ecosystem (Bathelt et al., 2010; Clarysse et al., 2014; Laage-Hellman et al., 2020; Helm and Mauroner, 2007).

However, this role has not been acknowledged by the ecosystem literature. In fact, most empirical studies have focused on the role performed by other actors, namely universities and their knowledge intermediaries and large (anchor) firms, in the structuration (or orchestration) of the innovation ecosystem, as shown by recent literature reviews (Schepis et al., 2021; Klimas and Czakon, 2021).

In what concerns RBSOs ability to 'bridge' between different geographical scales and knowledge environments, the literature puts some emphasis on the role played by RBSOs (and other technology-intensive companies) in processes of local and regional knowledge exchange (Asterbo and Bazzazian, 2011). At this level, the regional innovation systems literature has called the attention to the role played by entrepreneurs in the creation of

new development paths, based on new knowledge generated in ROs (Isaksen, 2015). However, innovation ecosystems are not closed systems and there is growing evidence of the importance of non-local knowledge interactions (Trippl et al., 2009; Gertler and Levitte, 2005). In an open innovation context, it is also necessary to take into consideration the globalisation of innovation ecosystems (Feldman et al., 2019; Malecki, 2011). The interaction between innovation ecosystems across national borders, gave rise to transnational innovation ecosystems, which enhance co-creation, exchange, and diffusion of knowledge on a global scale (Cai et al., 2019). But despite the potential relevance of these opening-up processes, there is still limited research on how they take place and their impact on the local innovation ecosystems.

RBSOs are likely to have a role in these processes. In fact, research has already shown that RBSOs tend to source knowledge from geographically distant locations (Fontes, 2005; Fontes and Sousa, 2016b). On the other hand, the majority of technology-based firms sell to international markets, which entails interaction with foreign actors to gather knowledge about these markets (Kirwan et al., 2006). Overall, it has been shown that international R&D partnerships afford new technology-based firms access to a broader range of competencies than domestic alliances and provide opportunities for inter-organisational learning (Colombo et al., 2009; Lavie and Miller, 2008).

Thus, RBSOs have strong motivations to engage in extra-local linkages. Knowledge access through extra-local collaborations can both complement firms' knowledge access in local networks (Bathelt et al., 2004; Asheim and Coenen, 2006; Cooke, 2002), and compensate for missing local knowledge sources and/or limited opportunities for local collaborations (Tödtling et al., 2012, Grillitsch and Nilsson, 2015). The latter is likely to be particularly pertinent for firms in more peripheral locations (Fontes and Sousa, 2016b). RBSOs that engage in international knowledge relationships may individually benefit from the knowledge thus accessed to compensate for local limitations. But may also act as conduits of that knowledge to their local environment, though their relationships with other local organisations. The extent to which knowledge, obtained through the individual firms' external linkages, impacts upon the regions where these firms are located will depend on nature of local knowledge interactions (Vale and Carvalho, 2012; Bathelt et al., 2004; Lowe and Gertler, 2009). This points to extensively connected RBSOs as potential conveyors of advanced knowledge generated in international networks to their local ecosystems, a role that is still largely underexplored.

Thus, the analysis of the role of RBSOs in innovation ecosystems requires not only the consideration of interactions within their country, but also the consideration of the relationships that go beyond national borders, opening the ecosystem to external knowledge and connecting it to other knowledge environments (Capaldo et al., 2015; Malecki, 2011; Trippl et al., 2009).

Considering the above, it is possible to raise the following research questions (RQ), that will guide the empirical research, enabling us to understand the intermediary role of RBSOs in the structuration and opening of a country's innovation ecosystem:

RQ1 Do RBSOs play a bridging role, in innovation ecosystems, between ROs and downstream organisations?

RQ2 Do RBSOs contribute to open the country's innovation ecosystem, by establishing foreign knowledge relationships?

RQ3 Do RBSOs play a role as conveyors of knowledge across innovation ecosystems, by acting as connectors and translators between knowledge originating from other knowledge environments and their innovation ecosystem?

3 Data and method

3.1 Data sample: the Portuguese RBSOs

There is not, in the literature, a single definition for the concept of academic or RBSOs. In this paper we use the following definition: *firms whose creation is based on the formal and/or informal transfer of knowledge or technology generated in public ROs* (Djokovic and Souitaris, 2008; Mustar et al., 2006; Pirnay et al., 2003). We consider as RBSOs both firms created by entrepreneurs who have some stable connection with a university or other research organisation – such as faculty members, researchers and graduate students – and 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 et al., 2017).

The empirical analysis is based on a self-collected dataset composed of the known population of RBSOs created in Portugal until 2007, totalling 327 firms (Conceição et al., 2017). These firms are active in a variety of industries: information and communication technologies (ICT) represent 40.67% of the population with 133 RBSOs, followed by biotechnology with 64 firms (19.57%). Other industries are less well represented: energy and environment (12.54%), high-tech services (11.01%), electronics and instrumentation (10.40%), and finally engineering (5.81%).

3.2 Collaborative RTD projects: data and analysis

The paper identifies the formal networks established by the RBSOs, in the context of collaborative research and technological development (RTD) projects funded by national programmes, as well as the formal international networks established by the RBSOs in the context of European funded RTD projects. Given RBSOs reliance on public funding for research and development (R&D) activities (Wright et al., 2007), this data is expected to offer a good coverage of the formal technological relationships established by these firms in this domain.

National funded projects intend to capture the knowledge linkages established within the Portuguese innovation ecosystem, while EU funded projects intend to capture the efforts to open the ecosystem to external knowledge, connecting it to other knowledge environments. European funded RTD projects, under the FPs launched in the early 1980s provide a context in which international knowledge partnerships are established in conditions relatively favourable to new technology-based firms. Thus, involvement in EU-funded R&D projects can be particularly beneficial for these firms, enabling them to share R&D costs and access partners' complementary competencies and assets, to receive financial resources and to be signalled as member of a consortium that was awarded a competitive grant from the EU (Colombo et al., 2016). The FPs not only stimulates collaborative research, but also promote the generation of knowledge spanning across national borders. So, they are seen as pivotal for transforming nation-based research networks into formal collaboration arrangements between organisations at European level (Heller-Schuh et al., 2011).

The national data, regarding the collaborative RTD projects funded by Portuguese support programmes, was obtained from the National Innovation Agency (ANI) database and covers the period 1992–2020. The European data, regarding the RTD projects conducted in the context of the European Framework Programmes, was obtained from the European commission community research and development information service (CORDIS) database and covers the same period. A search was conducted, in both databases, for projects with Portuguese spin-off involvement, resulting in a total of 568 projects (289 Portuguese projects and 279 European projects). These projects involved 115 RBSO. This means that only a sub-set of the identified population of 327 RBSOs had established formal relationships in the context of funded projects.

Given the extended period encompassed in the analysis, the projects were organised according to time periods that corresponded to the five National FPs Quadros Comunitários de Apoio (QCA) that funded them in Portugal[1].

Table 1 presents the distribution of Portuguese and European projects over time. The table shows that, in both cases, there is a consistent growth in the number of projects with RBSOs participation until the most recent period (2014–2020) that registers a significant decrease. In the first two periods, RBSOs were still relatively rare in Portugal (Conceição, et al., 2017), their numbers only starting to grow in the 2000s. The growth in the number of RBSOs was triggered by changes in the institutional environment, namely: a rise in interest from public ROs in the commercialisation of research results and the support to academic entrepreneurship; the advent of public policies supporting technological and academic entrepreneurship, leading to an increase in incentives for start-ups; and a greater involvement of private actors in the development and funding of technology-intensive start-ups (Fontes and Sousa, 2012b). This evolution of the number of RBSOs is reflected in the small number of projects funded in the early periods and in the growth registered in the 2000–2006 and 2007–2013 periods.

The decrease registered in the 2014–2020 can be explained as an outcome of the financial crisis that hit Portugal particularly hard (Conceição and Rodrigues 2021). The crisis had a strong impact on small technology intensive companies that can be especially vulnerable to changing economic conditions, resulting in several RBSO closures, and also reducing the surviving firms' capacity to engage in new RTD projects. Nevertheless, previous research has shown that during the crisis, as in the pre-crisis period, Portuguese RBSO continued to show lower mortality rates than other start-ups companies (Conceição and Rodrigues, 2021).

Table 1 Descriptive of Portuguese and European projects

	QCA I (1989 –1993)	*QCA II (1994 –1999)*	*QCA III (2000 –2006)*	*QREN (2007 –2013)*	*PT 2020 (2014 –2020)*	*Total projects*
Portuguese funded projects	1	20	62	137	69	289
European funded projects	1	23	60	120	75	279
Total PT and EU	2	43	122	257	144	568

Source: Own calculations

Data was collected on the characteristics of each project and on the partners. The data was treated in order to harmonise organisations' names (e.g., the same organisation appears named by its acronym and by its full name). Then the partner organisations were characterised by type: RBSOs; ROs, including universities and independent research centres, both public and private non-profit; and downstream organisations which includes other firms, business associations, government departments, regional agencies and other collective organisations. The 'parent' ROs of the RBSOs were also identified and their presence in the same project as their spin-offs was signalled.

In order to go beyond the analysis of the projects and consider the ecosystem, social network analysis (SNA) is used. SNA involves the characterisation of the actors and their relationships (Wasserman and Faust, 1994). More specifically, SNA was applied to data on collaborative projects funded by Portuguese funds, in order to uncover and depict relationships between organisations in the ecosystem and to capture the role of RBSOs. Collaborative projects constitute two-mode networks (Breiger, 1974), that link organisations (the actors) to an event – the project. From these we have extracted one-mode inter-organisational networks, for each period, considering that a tie joins two organisations that collaborate in the same project. Each project was assigned to a period by considering the project's starting date. To construct the networks, symmetric adjacency matrices were built. SNA measures were computed using the UCINET software and network diagrams are built using NetDraw software.

In order to characterise the networks several measures were considered. First, to characterise the general pattern of the networks, some characteristics related to the number of elements (size) were taken into account. According to Burt (2000), all things being equal, larger networks mean that an actor can access to a more diverse and complete set of resources from his/her network – in this case knowledge. Moreover, the size has an impact on some structural network characteristics like density and connectivity (for example, it is more likely for two actors to be connected if the network has few actors) (Wasserman and Faust, 1994). Since networks are made up of actors and relations, we can analyse the size of the network considering both the number of actors and the number of relations. The analysis of the general pattern of the network size also encompasses: the number of components: if a network is composed of a large number of small components, the capacity to access resources is lower; the average degree: average of the number of nodes adjacent to each organisations, which summarises the degree centrality of all actors in the network, giving a representation of the 'activity' of the network (Wasserman and Faust 1994).

Second, to characterise the network composition, the type of the actor was considered. The organisations were divided in three groups: RBSOs, ROs (universities, research centres) and downstream organisations (firms, non-profit organisations and public organisations). The share of each type of actor in the total number was considered to analyse its the relevance in the network.

Third, the structural properties of the networks were analysed using three indicators. Density gives us a measure of the degree of dyadic connection in a network, being the ratio between the number of ties that are present in the network and the total number of possible ties. Connectedness shows us the extent to which all actors are embedded in the same structure, that is, the number of pairs in the directed graph that are reachable relative to the number of ordered pairs. Small world index enables to detect the presence of small world properties: organisations that are not directly, but their partners tend to be

linked and most actors can be reached from every other node by a small number of hops or steps.

4 The role of RBSOs in innovation ecosystems

4.1 Bridging role in innovation ecosystems

In order to analyse the 'bridging' role of RBSO in the Portuguese innovation ecosystem, we analysed the 289 RTD projects funded by national programmes in order to assess the nature and weight of the different types of organisations involved.

These projects involved 519 organisations, namely 70 ROs and 349 downstream organisations (Table 2). Only 110 of the 327 Portuguese RBSOs had established collaborative relationships in the context of these projects.

Table 3 allows assessing the presence of different types of partner organisations in the project teams: ROs, in general, and the parent organisation, in particular; and downstream organisations. We have also investigated the presence of tripartite teams, which include RBSOs, ROs and downstream organisations.

Table 2 Descriptive of organisations in Portuguese projects

Organisation type	*N° individual organisations*
Portuguese RBSOs	100
Research organisations	70
Downstream organisations	349
Total	*519*

Source: Own calculations

Table 3 Descriptive of partners in Portuguese projects

	QCA I (1989–1993)	*QCA II (1994–1999)*	*QCA III (2000–2006)*	*QREN (2007–2013)*	*PT 2020 (2014–2020)*	*Total*	*%*
Project includes a RO	1	18	56	109	55	239	83%
Project includes the parent	1	14	36	58	24	133	46%
Project includes a downstream organisation	0	8	24	77	35	144	50%
Tripartite project (spin-offs + ROs + downstream organisation)	0	6	20	51	27	104	36%
Spin-off coordinator	0	14	49	104	48	215	74%
Average number partners	3	3.7	4.4	4.1	4.9	4	

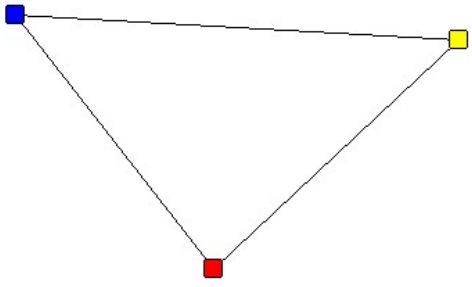
Source: Own calculations

In what concerns ROs, the data shows that they were an important partner in these projects: more than 80% included at least one RO, although their presence has slightly diminished in the more recent periods (from 90% in the 1994–1999 and 2000–2006 periods to 80% in the 2007–2013 and 2014–2020). A more in-depth analysis of the nature of the ROs involved shows that half of national projects integrated the spin-offs' parent institution. However, the number of projects that includes them decreases over the period under analysis (100%, 70%, 60%, 48% and 38%, respectively). This suggests a growing independence of the spin-off in knowledge terms.

Turning to the collaboration between RBSOs and downstream organisations, we found that, in the periods under analysis, half of the projects integrated at least one firm or collective organisation in the team.

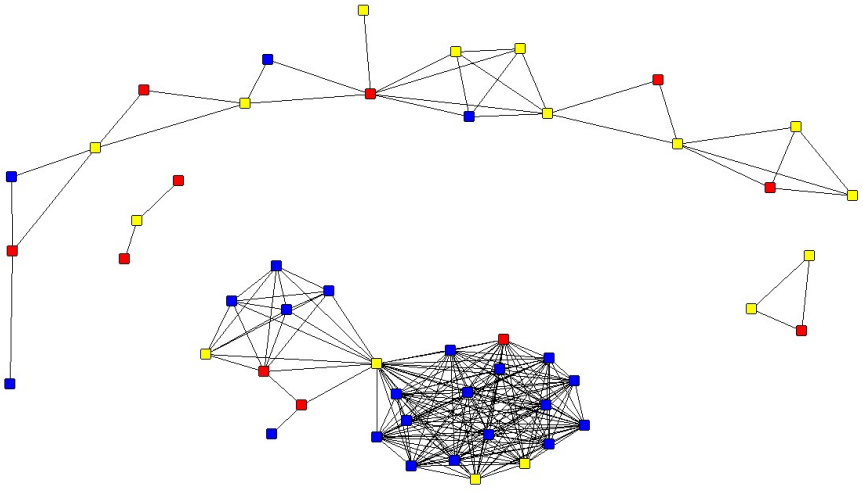
Finally, concerning tripartite teams – including RBSOs, ROs and downstream organisations – the data shows that more 1/3 of the projects involved this type of team, a result that was maintained over time.

Figure 1 Innovation ecosystem – 1990–1993 (see online version for colours)



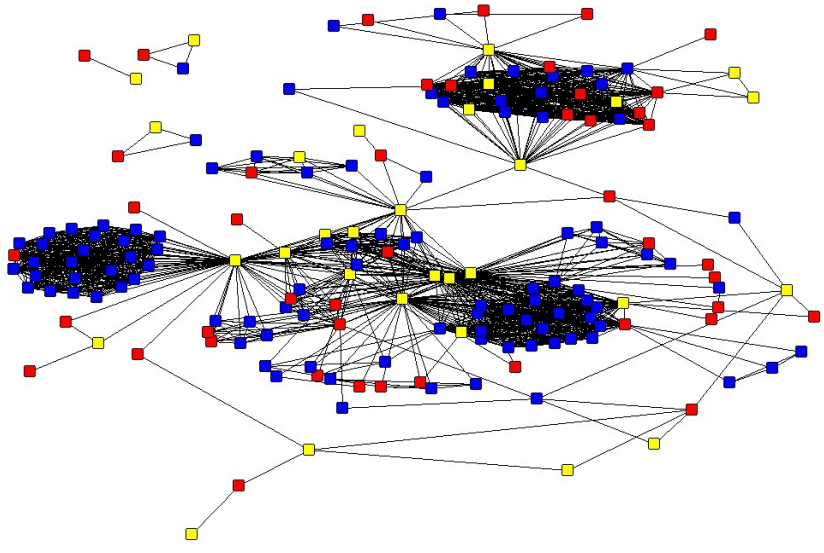
Notes: Red squares – RBSO; blue squares – downstream organisations; yellow squares – research organisations.

Figure 2 Innovation ecosystem – 1994–1999 (see online version for colours)



Notes: Red squares – RBSO; blue squares – downstream organisations; yellow squares – research organisations.

Figure 3 Innovation ecosystem – 2000–2006 (see online version for colours)



Notes: Red squares – RBSO; blue squares – downstream organisations; yellow squares – research organisations.

In order to assess the position of spin-offs we have also analysed the frequency at which they are project coordinators. In the Portuguese projects, spin-offs coordinate 3/4 of the projects in which they are involved.

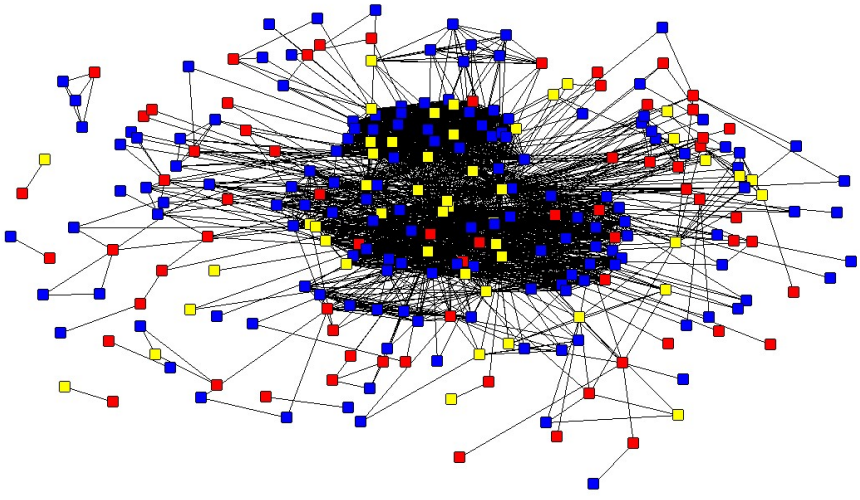
Going beyond the analysis of the projects, Figures 1 to 5 depict the evolution of relations in the innovation ecosystem. It is possible to see the growth and complexification of the network as time goes by. The growth is particularly strong in periods 2, 3 and 4, where both the number of organisations and the number of relationships are increasing (Tables 4 and 5).

In a longitudinal analysis, we start by a very simple network – a system embryo related to a single project – in the first period. In the second period, the system is starting to take form – several RBSOs are active and some are performing a bridging role in the system – facilitating the flow of knowledge between cliques of actors, although they are the less represented type of actor (they represent 22% of the organisations, against 32% of the ROs and 46% of downstream organisations). All the RBSOs active in this period are newcomers, since the only RBSO active in the first period exited the network. In this period the network is quite dense and weakly connected.

In the third period, the growth of the network is mainly due to an increase in the number of downstream organisations that increase their share to around 60% (value that remains more or less constant in the remaining periods), and to an increase in the number of ties, which is also reflected in the average degree. Therefore, the activity in the system increases, largely coordinated by RBOS that, as mentioned previously, lead almost 80% of the projects. A set of RBSOs appears at the centre of the network, not only connecting ROs and downstream organisations – at project level as discussed above but also by bridging different projects. This latter role is shared with ROs. Most of the RBSOs that were active in the previous period have maintained their activity in the network. The ecosystem becomes more connected and exhibits more signs of a ‘small world’ network.

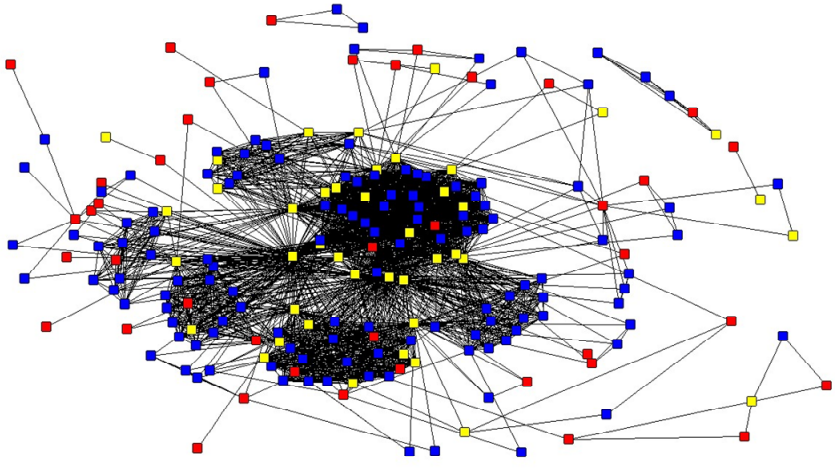
In the fourth period, the network continues to grow, both in terms of actors and relations. RBSOs strengthen their presence in the network, representing 26% of the organisations in the ecosystem. There is a rejuvenation of the RBSOs present in the network, since around 40% of those active in the previous period exited the network, and a new set of RBSOs have joined the ecosystem. The network becomes more fragmented (it has more components) and less connected and dense. In this period, the bridging role of RBSOs between projects is more visible, particularly outside of the dense centre of the network, where ROs are less active.

Figure 4 Innovation ecosystem – 2007–2013 (see online version for colours)



Notes: Red squares – RBSO; blue squares – downstream organisations; yellow squares – research organisations.

Figure 5 Innovation ecosystem – 2014–2020 (see online version for colours)



Notes: Red squares – RBSO; blue squares – downstream organisations; yellow squares – research organisations.

Finally, in the fifth period, there is some evidence of the consolidation of the ecosystem. While the number of actors declines (this is the only period were the number of organisations exiting the ecosystem is larger than the number of organisations entering) – particularly the number of RBSOs and downstream organisations – the number of ties and the average degree exhibit slight increase. This evolution translates into a densification and higher connectivity of the ecosystem. Although they are less, RBSOs maintain their bridging role between projects, particularly outside of the dense centre of the network, as in the previous period.

Table 4 SNA measures

		1989–1993	*1994–1999*	*2000–2006*	*2007–2013*	*2014–2020*
Network size	Organisations (No.)	3	50	176	262	210
	Ties (No.)	3	212	1,474	2,432	24,45
	Components (No)	1	4	4	8	4
	Average degree	2	8.48	16.655	18.424	23.286
Network composition	RBSO (No.)	1	11	45	68	41
	RO (No.)	1	16	29	42	42
	Firms (No.)	1	23	102	152	127
Network structure	Density	1	0.173	0.095	0.070	0.111
	Connectedness	1	0.265	0.912	0.876	0.907
	Small World Index	-	23.404	27.673	24.300	16.964

Source: Own calculations

Table 5 Organisation entering and exiting the ecosystem in each period

		1989–1993	*1994–1999*	*2000–2006*	*2007–2013*	*2014–2020*
Entering organisations	RBSO (No.)	1	11	37	41	14
	RO (No.)	1	15	15	24	21
	Firms (No.)	1	23	91	137	101
Exiting organisations	RBSO (No.)	-	1	3	18	41
	RO (No.)	-	0	2	11	21
	Firms (No.)	-	1	12	87	126

Source: Own calculations

4.2 Opening innovation ecosystems to external knowledge

In order to analyse the role of RBSOs in 'opening' the innovation ecosystems through non-local knowledge interactions, we analysed the 279 European projects with Portuguese RBSO involvement. There was a smaller number of RBSOs involved in

European projects – 64 – as compared to those involved in national ones. RBSOs were also much less frequently project coordinators (only in 8% of projects).

This can be explained by the extremely competitive conditions of the European funding programmes. In fact, on the one hand, European funded RTD projects provide a context where international knowledge partnerships are established in conditions relatively favourable to new technology-based firms. Thus, involvement in EU-funded R&D projects can be particularly beneficial for technology-based firms, enabling them to share R&D cost and to access partners' complementary competencies and assets, to receive financial resources and also of being signalled as member of a consortium that was awarded a competitive grant from the EU (Colombo et al., 2016). However, not only these projects have very stringent requirements, but participation also has costs, namely of finding and selecting suitable partners; of negotiating and managing the projects, as well as risks of knowledge misappropriation by partners (Colombo et al., 2016).

We analysed the European project teams in order to assess the types of partners involved. We verified that 92% of the projects included at least one RO (Portuguese or foreign) and this percentage has increased over time (87%, 92%, 93% and 95%, respectively) (Table 6). Overall, only 20% of these teams included the spin-offs' parent organisation. However, the weight of the parent institution changes over time: in the period 1994–1999 the number of projects including it reaches 39%, while in the period 2014–2020 this number decreases to 9%. This suggests a growing independence of the spin-off in knowledge terms.

Table 6 Descriptive of partners in European projects

	1989–1993	*1994–1999*	*2000–2006*	*2007–2013*	*2014–2020*	*Total*	*%*
Project includes a research organisations	1	20	55	111	71	258	92%
Project includes the parent	1	9	12	23	7	52	19%
Project includes a downstream organisation	1	21	54	116	73	265	95%
Tripartite project (spin-offs + research organisations + downstream organisation)	1	18	49	106	71	245	88%
Spin-off coordinator	1	2	2	8	8	21	08%
Average number partners	7	8.2	14.7	12.3	16.8	13.7	

Source: Own calculations

Concerning the interaction with downstream organisations (other firms; business associations, public organisations) we found that 95% of the projects included them and, likewise, that this trend was accentuated in more recent periods.

As a result of the high weight of downstream relations in European projects, the proportion of tripartite teams including spin-offs, ROs and downstream organisations, is also high in these projects (Table 6). In fact, more than 4/5 of the European projects are composed of this type of team, thus allowing access to knowledge developed simultaneously in universities and downstream in the value chain.

Finally, we analysed in more detail the European project teams, in order to uncover the presence of other Portuguese organisations. In 57% of these projects the Portuguese RBSO are accompanied by other Portuguese partner. Overall, The European projects involved, besides the 64 RBSOs, 34 Portuguese ROs and 90 Portuguese downstream organisations (Table 7). This suggests that the opening of the Portuguese innovation ecosystems may not be done exclusively by RBSO, or that this role may be shared with other types of organisations. Of the 123 project teams with Portuguese partners, 94% involved other Portuguese ROs and 44% involved other Portuguese downstream organisations. It was also possible to identify some tripartite Portuguese teams, which were present in about 1/3 of the projects (Table 8).

Table 7 Descriptive of Portuguese organisations in European projects

Organisation type	*Nº individual organisations*
Portuguese RBSOs	64
Portuguese research organisations	34
Portuguese downstream organisations	90
Total	*188*

Source: Own calculations

Table 8 Descriptive of Portuguese partners in European projects

	Nº EU projects	*%*
EU projects without other Portuguese partners	120	43%
EU projects with other Portuguese partners	123	57%
with Portuguese ROs	116	94%
with other Portuguese firms	54	44%
with Portuguese ROs and firms	25	29%

Source: Own calculations

4.3 Conveyors of knowledge across space

RBSOs that participate in Portuguese projects and European projects may play an important function by bringing knowledge developed in the European projects to their country's innovation ecosystem. Therefore, we compared the data from National and Europeans projects in order to identify the organisations that were involved in both.

The data shows that there were 49 RBSO active in both National and European projects (Table 9). We also identified the RBSOs that acted as project coordinators. The data shows that a substantial number of RBSOs active at both scales assumed coordinator

positions in at least one set of projects (38 in national and 10 in European) and that about 20% assumed coordination functions at both scales. Since this position indicates a higher responsibility in project definition and development, these firms were likely to have better conditions to play a conveyor role.

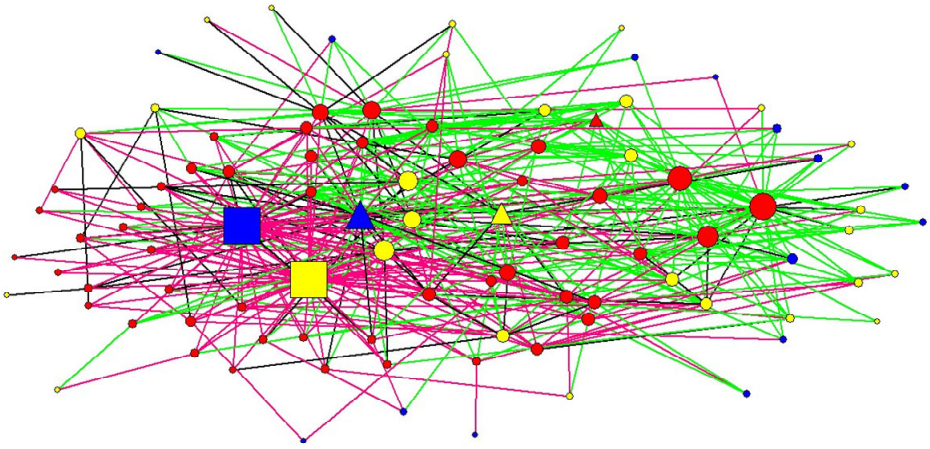
The data also suggests that, as already pointed out, the conveyor role may be shared with other organisations. In fact, there are 27 ROs and 18 downstream organisations that were equally active at the two levels.

Table 9 Descriptive of RBSO active in European and Portuguese projects

	Nº RBSO
RBSOs in EU and PT projects	49
of those Coordinating PT projects	39
of those Coordinating EU projects	10
of those Coordinating in both groups	09
Research organisations in EU and PT projects	27
Downstream organisations in EU and PT projects	18

Source: Own calculations

Figure 6 Linking European and Portuguese projects (see online version for colours)



Notes: Red – RBSO; blue – downstream organisations; yellow – research organisations. The size of the shape is proportional to the degree centrality. Green lines correspond to ties is Portuguese projects, pink lines correspond to ties in European projects and black lines correspond to ties in both projects.

Figure 6 illustrates this role. In this network all Portuguese organisations that are active in both European and Portuguese projects are represented by circles. It is therefore visible that although RBSOs (red circles) are the predominant type of organisation performing this role of opening the system, ROs (yellow circles) and downstream organisations (blue circles) are also acting as conveyors. In the latter case, we find some technology-intensive firms and some large Portuguese firms. Squares represent foreign

organisations, while triangles represent Portuguese organisations that are only present in one type of project (Portuguese or European). The circulation of knowledge from the different types of projects is also shown in the Figure, that considers different colours for the ties: in pink we have the dyads active in the context of EU funded projects, in green we have the dyads active in the context of Portuguese funded projects and in black we have the dyads active in both types of projects.

5 Conclusions

The goal of this paper was to contribute to a better understanding of the bridging roles played by RBSOs in the structuration and opening of innovation ecosystems, by acting as connectors, between the academia and the industry and as knowledge conveyors, between national and foreign actors. Previous research has empirically addressed the role of other types of actors (namely universities, technology transfer offices and large firms) in innovation ecosystems, but the role of RBSOs is still not well understood.

The paper conducted an analysis of the formal relationships established by Portuguese RBSOs in the context of collaborative RTD projects at National and European levels, with a view to explore the role played by these firms in the networks they establish in these different geographical and institutional contexts. This permitted to investigate, first of all, whether, in the context of RTD projects, RBSOs acted as bridges between upstream knowledge produced in ROs and downstream organisations, contributing to the structuration and strengthening of innovation ecosystems. It also permitted to investigate whether the participation in European projects enabled RBSOs to act as knowledge conveyors across different knowledge environments, contributing to open their innovation ecosystems.

The results show that RBSOs effectively played a bridging role, by partnering with organisations located downstream in the value chain or connecting between these and ROs. This role can be intensified in RTD projects involving a diverse set of actors, including both ROs and downstream organisations (namely other firms), in tripartite relationships. Therefore, the participation of RBSOs in national funded RTD projects would potentially facilitate the circulation of knowledge between academia and society contributing to the structuration of the country's innovation ecosystem, particularly when the networks formed in the context of these projects involve simultaneously upstream and downstream organisations.

Moreover, the results reveal the dynamics of the contribution of the participation RBSOs in RTD projects to the structuration and strengthening of the national innovation ecosystem. Over time, there was an expansion and complexification of the network, with a growing number of RBSOs establishing relationships with a wider range of partners, thus contributing to the densification of the country's innovation ecosystem. However, the results also show that socio-economic conditions can influence the performance of this role, given RBSOs vulnerability to external shocks.

The results also provide some insights on the role of RBSOs as knowledge conveyors across space. RBSOs were found to engage in a growing number of knowledge relationships with foreign organisations in the context of EU funded projects; and a substantial subset of these RBSOs combined them with relationships within their national ecosystem. Moreover, they were often project coordinators. This made them particularly well positioned for acting as connectors and translators between knowledge originating

from other – frequently more advanced - knowledge environments and their country's innovation ecosystems, contributing to open them and to strengthen the local knowledge networks. The results also show that this conveyor role is shared with other organisations - in particular ROs but also other technology intensive firms. This is not unexpected, since the role of these organisations had already been described in the extant literature. Further research may investigate whether RBSOs are particularly active in some areas or types of projects.

These results permit us to conclude that RBSOs have the conditions to play an intermediary role relatively to other Portuguese organisations, which can assume different forms in diverse contexts. In the networks formed by the national projects they are frequently in a position to bridge between ROs and firms, contributing to the dissemination of knowledge within their country's innovation ecosystem. In the international networks formed in the context of European projects, their most important role may be as connectors to and conveyors of advanced knowledge produced in these external knowledge environments and the Portuguese organisations with whom they collaborate in the national ecosystem.

This largely exploratory analysis provides some insights that need to be further investigated through more detailed research on the nature and contents of the partnerships. This can namely involve more qualitative research that addresses the RBSOs found to be in a position to act as knowledge conveyors (at various levels) in European networks. It can also be extended by conducting a more fine-grained analysis of the patterns of tripartite relations within the networks, namely by studying triads as building blocks in the networks.

One limitation of this research concerns the exclusive focus on formal relationships established in the context of funded RTD projects. In fact, interactions between RBSOs and other firms may go beyond these more formal relations, and such informal interactions can also be relevant channels to knowledge exchange between organisations that are not otherwise connected. However, those interactions tend to be hard to map, requiring more in-depth analyses using other methodologies. Further research could also address this question, starting from the RBSOs identified in this paper and attempting to uncover, through case studies, other channels through which these firms interact and exchange knowledge with their innovation ecosystem.

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