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*Cristina de Sousa**

Pedro Videira

Margarida Fontes

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Cristina de Sousa*

INETI, Estrada do Paço do Lumiar 22, 1649-038 Lisboa Portugal.
DINAMIA, Av. Forças Armadas, Ed ISCTE 1649-026 Lisboa Portugal.
E-mail: Cristina.sousa@ineti.pt

Pedro Videira

DINAMIA, Av. Forças Armadas, Ed ISCTE 1649-026 Lisboa Portugal.
E-mail: p_videira@yahoo.com

Margarida Fontes

INETI, Estrada do Paço do Lumiar 22, 1649-038 Lisboa Portugal.
DINAMIA, Av. Forças Armadas, Ed ISCTE 1649-026 Lisboa Portugal.
E-mail: margarida.fontes@ineti.pt

* Corresponding author

Abstract: The paper addresses innovation networks in a science-based sector, focusing on networks for scientific and technological knowledge access. It investigates the strategic choices made by new biotechnology firms regarding the type of actors and relations that prevail in accessing those networks. The results contribute to on-going debates in the area of innovation networks and knowledge management, both at the methodological and empirical levels. We develop a methodology to investigate the networking behaviour of science-based entrepreneurs in their search for scientific and technological knowledge for innovation. We apply it to the case of biotechnology entrepreneurs in a country that is peripheral to the major concentrations of biotechnology knowledge and business, which enables us to gain some insights on the strategies adopted by new entrepreneurial firms to access critical resources in these particular contexts.

Keywords: Innovation networks; Social networks; Knowledge access; Biotechnology.

1 Introduction

Research on innovation and knowledge management and on technological entrepreneurship testifies the systemic nature of innovation and the role of external knowledge sources and emphasizes the importance of "networking" for innovation success (see [1] for a survey).

However, developing and maintaining scientific and technological (S&T) knowledge access networks for innovation is a complex and costly process, requiring entrepreneurs to make some strategic choices. In this paper we investigate the decisions made by biotechnology entrepreneurs about the composition and structure of those networks.

The paper is structured as follows. The next section introduces the conceptual framework used in this research. The third section presents the research methodology, stressing in particular the empirical context, the (re)construction of networks and the collection of data. Section 4 highlights the main results obtained, namely in terms of the composition and structure of S&T knowledge access networks and the strategic choices made by firms in the formation of those networks. Section 5 concludes by summarising the main findings.

2 Innovation and Networks

The importance of networks to innovation processes is particularly evident in biotechnology, where innovation is vital, dedicated biotechnology firms tend to be relatively small, the knowledge base is characterised by complexity and multidisciplinary and the knowledge sources are dispersed, being critical to establish ties with different organisations [2, 3, 4]. In this sector, relationships with research organisations, namely those conducting frontier research, can be crucial for new firms [5, 6], not only for developing the first technologies/products, but also for maintaining their competitiveness through time [7]. Additionally, biotechnology is characterised by the proximity between scientific research and the market, creating opportunities for transforming the results from research into technologies, products and services [8].

Research on social networks has shown that to access the S&T knowledge required for innovation, entrepreneurs rely on their existing ties, while research on alliances has shown that young firms build new relationships with key actors. These two approaches usually look at two different types of relations: social networks tend to stress the importance of personal and informal relations and alliances literatures focuses on inter-organisational and formal relations. Since both formal and informal relations affect knowledge transfer and innovation in this research we consider these two types of relations.

Most alliances studies focus on the motivations underlying those alliances, on the effects of networking behaviour on innovation (either capacity or outcomes) or on the management of formal alliances or collaborations [9, 10, 11]; but few examine the strategies deployed by firms in the process of knowledge networks construction. We can find some insights in studies that investigate the influence of some characteristics of the actors on network evolution. Gulati and Gargiulo [12] analyse the emergence of new inter-organisational alliances and find that the probability of a new alliance between organizations increases with their interdependence and also with their prior mutual alliances, common third parties, and joint centrality in the alliance network. The role of past alliances is also mentioned by Milanov and Fernhaber [13] that, drawing on the imprinting literature, highlight the importance of early alliances in the evolution of new firms' networks arguing that network size and centrality of first partners influence the subsequent size of the firm network. Reuer and Zollo [14] focus on parent firms' prior experiences with alliances and on specific features of the alliances in influencing the likelihood and type of adjustments made in strategic alliances.

Additional insights come from the social network literature which stresses that the channels used and the strategies deployed to mobilise the actors that support the innovation process, can strongly differ and be influenced by the composition and also by the structure of those networks [15, 16]. Several authors stress the importance of personal-based relations, not only to access S&T knowledge, but also to formal partnerships/alliances formation [17, 18].

In this context it is interesting to mention the distinction between strong and weak ties [19]. It is recognized that the balance between strong and weak ties affects the knowledge transfers [20], as well as the cost of accessing knowledge [21]. However there is an intense debate about the most favourable network configuration. According to some authors, densely embedded networks with many strong ties are more beneficial. They generate trust and cooperation between the actors [22], facilitate the exchange of high quality information [23, 24] and of complex [25] and tacit knowledge [26]. For other authors, however, more "open" networks with many weak ties [19] and structural holes [27] have more advantages, deriving from the fact that individuals can build relationships with multiple unconnected actors and explore brokerage opportunities. In this network configuration, actors use connections to obtain non redundant information, which can be particularly important in the identification of new opportunities [28, 29].

But what is not fully understood is how they choose which previous relationships to maintain and which new ones to build. A useful approach is the distinction between *non-intentional* and *intentional* networks: the former is a by-product of the entrepreneur activity/trajectory, its presence not being necessarily related with a particular goal – it is a "potential network" that may be activated or remain latent; the last is purposefully created to achieve a goal. This distinction was inspired on Lin's [30] and Hite and Hesterly's [31] work: the first distinguishes between "instrumental actions related with contact resources" and "expressive actions related with accessible resources"; the latter between "calculative networks" and "identity-based networks".

We draw on these contributions to address our main research question: what are the strategies adopted by firms in a science based sector, to build networks that enable access to S&T knowledge relevant for innovation? More specifically we want to understand:

1. To what extent "potential networks" are mobilised and to what extent new actors enter in those networks?
2. Which types of relations do entrepreneurs favour?

3 Research Methodology

In order to investigate the decisions made by biotechnology entrepreneurs about the composition and structure of their S&T knowledge access networks, we have developed a methodology that enables us to reconstruct the entrepreneurs/firms' social networks and to uncover the selection strategies adopted by entrepreneurs in the process of knowledge access at start-up. A central aspect of this methodology was the (re)construction of firms' social networks, encompassing both the entrepreneurs' personal networks built along their academic and professional trajectories, and the intentional networks specifically built for firm creation. This methodology was applied to a specific sub-set of the Portuguese dedicated biotechnology firms: the molecular biology companies, involving 23 firms and 61 entrepreneurs. The choice of this sub-group was based on the fact that

molecular biology firms configure the most science-based biotechnology subset, enabling us to focus on the specific start-up conditions, knowledge needs and knowledge access strategies of science-based firms.

3.1. Empirical context - The Portuguese biotechnology sector

The process of firm creation in biotechnology in Portugal is a relatively recent phenomenon. It started in the mid-80s, but only took-off around 2003. There are currently 79 firms formally in operation[1], of which, 80% were created from 2003 onwards. Thus several firms are still in an embryonic stage of development and only a small group of pioneers have developed their technologies/products and introduced them into the market.

This recent entrepreneurial upsurge was driven by a combination of favourable factors. We like to stress two. First, the growing quality and maturity of research in some public research organisations (PRO) combined with the presence of highly qualified and internationalised (but often under-employed) young scientists. Second, the changes in the institutional environment, namely the increase in the incentives and support to technology-based entrepreneurial initiatives, particularly those involving the commercial exploitation of knowledge from PROs. However, most of this support was directed towards the process of firm formation, and there are still several obstacles in the access to resources that are critical for the firms' subsequent development.

The conditions in which firm formation took place meant that the majority was a direct or indirect spin-off from research and involved the initiative of young scientists. Their location also reflects their origin, since it follows the main metropolitan areas where the main research organisations are located and where incubation and other support infrastructures and key services are increasingly available. The main areas of application include: health (human and animal) (45%), agriculture and food production (respectively 30% and 16%) and environment (9%).

The group of firms that are the focus of our research – the molecular biology firms - tends to follow the described pattern. But, given the nature of the technologies being exploited, their activities tend to be more concentrate in the health sector, with a greater predominance of clinical applications (as opposed to pharmaceuticals). All firms were created by at least one entrepreneur coming from universities or research organisations; even though in several cases non-academic individuals joined the team (e.g. graduates with managerial competences, entrepreneurs, and practitioners in the applications field). The teams are mostly composed of young entrepreneurs, although in some cases there is also a senior researcher in the team (who tends to retain the post in the university).

3.2. Network (re)construction methodology

To (re)construct the firms' networks we adopted an ego-centred perspective, where the ego is one firm from our sample, and alters are all actors mobilised to access S&T

[1] Firms identified up to December 2008. It includes the whole population of dedicated biotechnology firms, to the best of our knowledge, whose information is stored in an INETI proprietary database. There is also a growing number of firm projects, that will eventually be formally set-up in the near future.

knowledge during the process of firm creation[1]. Our networks encompass both formal (for example R&D projects) and informal (for example personal knowledge exchange) relations. We choose the organisation as the unit of analysis: in the case of informal relationships, a correspondence is made between the individuals and the organisation where these individuals are located. We consider seven types of organisations: biotechnology firms, firms from other sectors, venture capital organisations, universities and research centres, hospitals, S&T parks and other organisations (includes professional and trade associations, public support organisations, etc.).

The methodology for network (re)construction was build upon the distinction between potential networks and mobilised networks. Some authors stress the importance of founders' social networks for the firm's creation process [32,33], but we have also to consider that entrepreneurs will intentionally establish relations with new actors, in order to access resources that are relevant for firm creation and development and cannot be obtained through their existing network: they instrumentally search for new members [34]. So, it is useful to separate between two types of networks: *Potential networks* represent the latent set of ties resulting from entrepreneurs' previous trajectory that can be mobilised by the entrepreneur/ firm; *Mobilised networks* represent the set of ties that was effectively mobilised to access knowledge. This means that mobilised networks can have their origin in the potential networks or can have been intentionally built to access a specific knowledge. In the first case we call them *trajectory networks* and in the latter we call them *intentional networks*.

The (re)construction of those networks took several steps. The first consisted of the identification of networks at personal (entrepreneur) level, based on the reconstruction of the academic and professional paths of each member of the founding teams. The next step was the (re)construction of networks at firm level, translating personal networks into inter-organisational networks (based on the assumption that when firms are being created their social networks are basically the sum of the entrepreneurs') and combining, for each firm, the personal networks of all members of the founding team. The networks that result from this process are the *Potential Networks*. The next step entailed identifying and characterising the ties effectively mobilised by the entrepreneurs for knowledge access – both those deriving from the *trajectory networks* and those intentionally established having the new firm as a goal – during the formation process thus obtaining the *S&T Knowledge Access Networks*.

In this (re)construction process, following the social network literature, we considered that ties can have different strength. We measure the strength of the ties combining two criteria: the frequency of the contacts and the existence of more than one type of relation (formal or informal) between our firms and other actors. According to these criteria a *strong tie* is one where an informal (personal) relationship is sustained at least through one monthly contact or where there is more than one type of relationship (i.e. a formal and an informal relation, more than one formal relation, or more than one informal relation). Conversely, a tie will be considered *weak* when a sporadic informal relation supports it and when there is only one type of relation (e.g. when the two institutions only participate jointly in one project).

[1] Firm formation period is regarded as a process that includes the pre-start-up period, the year of formal creation and the two subsequent years of activity.

3.3. Data collection

Data collection on the 23 molecular biology firms[1] and on their 61 entrepreneurs was based on a combination of complementary methods, involving both search for documentary information and in-depth face-to-face interviews with the founders conducted during 2008. The former included: the Curriculum Vitae of the entrepreneurs, published data about formal collaborative projects, partnerships and patents, and a variety of documentary information about the entrepreneurs' personal trajectories and firm formation histories[2]. The interviews were based on a semi-structured questionnaire and had two parts. The first focused on the entrepreneurs' personal network and on the importance of that network to the firm's creation process, allowing the collection of more systematic and fine grained information about the people who were important during the process, including the origin of the relationships and the type, nature and relevance of their respective contributions. The second addressed the firm's activities, strategy and performance, with particular emphasis on innovation and technological development and on formal cooperation arrangements.

This combination of methods that are usually applied independently - career trajectory and CV analysis [35], project analysis [36], bibliometrics [37] and patent analysis [38] - represents a novel approach, which not only provides a richer set of data, but also offers the possibility of confronting different sources and perspectives, thus improving the robustness of the data. It also allows us to separate between the potential and the mobilised networks.

4 Results

In this section we present some results of the application of the methodology described above, that allowed us to map potential and knowledge access networks and to uncover several aspects of the strategies adopted by firms to build networks to access S&T knowledge relevant for innovation.

For each firm we've built two networks – the "potential network" and the S&T knowledge access network – and then computed some networks measures, that we report in several tables, showing average, maximum, minimum and standard deviation (SD) values.

We start with network size. According to Burt [39], other things being equal, bigger networks indicate that an actor can receive a more diverse and complete set of resources from his network. Since networks are made of actors and relations, network size can be analysed at those two levels. Here we consider three measures: i) total number of actors in a network; ii) total number of ties in a network; iii) mean (nodal) degree, that is the mean of the number of nodes adjacent to each ego, that gives the mean "activity" of the network [40].

Observing table 1, we can conclude that the potential average network of those firms has 15 actors and 52 ties. However there is big amplitude on network size values, reflecting differences in the dimension of the entrepreneurial team and also difference in the academic and professional paths of entrepreneurs.

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[1] We have identified 25 firms in this area, but 2 of them did not collaborate in the research.
[2] Publication data were also collected and will be included in a final version of the study.

Table 1 Network size

Network	*Statistic*	*No Actors*	*No Ties*	*Nodal Degree*
Potential	Average	15	52	1,77
	Maximum	61	664	12,13
	Minimum	2	2	0,19
	SD	14	138	2,53
S&T Knowledge Access	Average	5	12	0,57
	Maximum	25	145	3,95
	Minimum	0	0	0
	SD	6	30	0,80

Regarding the size of S&T knowledge access networks, we found that they are substantially smaller than potential networks, indicating that to access knowledge during firm creation processes, the entrepreneurs do not mobilise all relations in their potential network. It is interesting to note that some firms (3 out of 23) do not mobilise any actor to access S&T knowledge. Those firms are very young (all created in 2008) and their entrepreneurs retain their post in the university. They are involved in research activities in the academy and do not perceive any of the links established as integrating new firms' knowledge access networks.

But, if entrepreneurs do not mobilise all the ties of their potential networks, they also look for new sources of S&T knowledge. So, to deeply understand the strategies of S&T knowledge access we turn our attention to intentional networks, that is, to the set of ties that were intentionally built to access a specific knowledge. In table 2, we consider the proportion of new actors (intentionally mobilised) in the total number of actors. There we can see that on average 37% of these firms' S&T knowledge access networks are purposefully built.

Table 2 Proportion of new actors in the S&T Knowledge Access Network

Statistic	*Proportion of new actors*
Average	37%
Maximum	100%
Minimum	0%
SD	39%

If we take individual data into consideration, we can depict three different strategies to access S&T knowledge: some firms (10) only mobilised trajectory ties; some firms (2) only mobilised intentional ties, and some firms (11) mobilised a mix of trajectory and intentional ties. Hence we can assume that, for the majority of these firms, the S&T knowledge that the entrepreneurs can mobilize through their networks is not sufficient for the formation of the new firm's knowledge base leading them to purposefully establish contacts with institutions which are not already present in those networks.

W can detect a negative correlation between the size of potential networks and the size of intentional networks, indicating that firms with smaller potential networks tend to have a higher proportion of new actors in their S&T knowledge access networks (when compared to companies with larger potential networks).

To characterise the strategies related to network composition we've analysed: i) the importance of each type of actor, measured through the respective proportion in the total number of actors; ii) the weight of national and international relations, measured through the share of actors in each location. Data presented in table 3 show that universities account for an important share of the analysed networks. As we've mentioned above, all firms have entrepreneurs who have been associated with universities or research centres as young or senior scientists, and this academic path is well visible in the potential network.

Table 3 Network composition

Network	*Statistic*	*Biotech Firms*	*Other Firms*	*VC*	*Univ.*	*Hosp.*	*S&T Parks*	*Other*	*National* actors
Potential	Average	4%	12%	0%	68%	3%	0%	14%	66%
	Maximum	20%	75%	0%	100%	45%	0%	50%	100%
	Minimum	0%	0%	0%	20%	0%	0%	0%	20%
	SD	6%	18%	0%	27%	10%	0%	17%	26%
S&T Knowledge Access	Average	11%	7%	0%	60%	7%	1%	2%	62%
	Maximum	100%	50%	0%	100%	75%	25%	33%	100%
	Minimum	0%	0%	0%	0%	0%	0%	0%	0%
	SD	24%	14%	0%	38%	19%	5%	8%	38%

The importance of academia in S&T knowledge access is in line with the nature of knowledge that is critical to biotechnology firms' innovation processes. But, it is also interesting to notice a tendency towards a different structure of actors in these networks, when compared to potential ones, associated with the integration of other biotech firms, hospitals and S&T parks and with the decay of universities, firms from other sectors and other organisations.

In terms of location, we find that all firms have potential ties with international actors, reflecting the international mobility of their founders. However, it is evident that international actors have different roles for the various firms analysed. Many firms (11 out 9 of 23) do not mobilise international relations (either from the trajectory or intentionally built); others mobilise existing international relations to obtain knowledge for innovation process, but do not intentionally add new international actors; finally, others integrate international actors in intentional knowledge mobilisation networks. Not building intentional international networks may be related with the difficulties associated with this process when balanced with the availability of resources nearby.

To uncover the strategies of S&T knowledge access, it is interesting to observe the composition of intentional networks, which is presented in table 4. We find that universities also have a critical role in intentional ties, suggesting that those new actors may grant access to other kinds of knowledge. The addition of non academic actors may reveal the need to access knowledge whose nature makes it more difficult to access on the basis of entrepreneur's previous (largely scientific) trajectory. It is also interesting to

note that these intentional networks are dominated, on average terms, by international actors, exposing the strategy of establishing ties with "the best" knowledge source, no matter where it is located. Sometimes, firms use ties established with trajectory actors to reach these leading knowledge centres.

Table 4 Intentional S&T knowledge access network composition

Statistic	*Biotech Firms*	*Other Firms*	*VC*	*Univ.*	*Hosp.*	*S&T Parks*	*Other*	*National* actors
Average	15%	16%	0%	49%	8%	8%	4%	45%
Maximum	100%	100%	0%	100%	100%	100%	33%	100%
Minimum	0%	0%	0%	0%	0%	0%	0%	0%
SD	29%	28%	0%	40%	28%	28%	10%	43%

As mentioned above, in a network, relations can have different strengths: strong and weak ties take different amounts of time, energy and money to develop and maintain. Networks with a bigger proportion of strong ties are denser. So, to characterise network density we have considered the average strength of connection between actors [39], which is the ratio between the sum of all ties considering the respective strength and the total number of ties[1]. Results are reported in table 5. There we can see that mobilised networks have a higher average strength of ties, fact that can be related with the trust needed to access S&T knowledge. At this level it is interesting to note that trajectory S&T knowledge access networks appear to be built around some key organisations, mainly universities, with whom firms maintain strong relations in the process of knowledge mobilisation. However, it is also possible to conclude that, on average, S&T knowledge access networks do not have a high level of density.

Table 5 Average strength of ties

Network	*Statistic*	*Average Strength of Ties*
Potential	Average	1,57
	Maximum	3
	Minimum	1
	SD	0,50
S&T Knowledge Access	Average	1,93
	Maximum	3
	Minimum	1
	SD	1,06

However, if we consider individual data, we can observe that some firms have very dense S&T knowledge access networks (9 firms present an average strength of ties equal to 3). All these firms have small S&T knowledge access networks (with up to 4 actors, when the mean size is 5). This indicates that it is not possible to develop and maintain strong ties with many actors and that firms that interact with a diverse set of organisations to

[1] As we consider that strong ties have intensity equal to 3 and weak ties have intensity equal to 1, the average strength of ties will vary between 1 and 3.

obtain diverse pieces of S&T knowledge needed for innovation process will have sparser networks.

5 Final Remarks

This paper addresses S&T knowledge access networks in a science-based sector, investigating the strategic choices made by new biotechnology firms regarding the type of actors and relations that prevail in those networks. We've developed a methodology to (re)construct the networks mobilised by entrepreneurs in their search for S&T knowledge for innovation and applied it to the case of biotechnology.

In terms of network *composition*, not surprisingly, results show that, both potential and S&T knowledge access networks are dominated by universities. However, those networks have different composition structures.

Results also demonstrate that to access S&T knowledge entrepreneurs select only some members of their potential network, but, at the same time, they usually add new members to that network. In fact the predominant strategy used by these firms consists in using a mixture of trajectory and intentional ties to access S&T knowledge during the process of firm formation.

Regarding addition of new members different strategies were found: i) they may be of a different type granting access to knowledge whose nature makes it more difficult to access on the basis of entrepreneurs previous trajectory; ii) they may be of the same type but provide different kinds of knowledge resources.

Regarding actor *location*, we find that potential networks usually have international ties, but entrepreneurs may not choose to mobilise them or to add intentional international ties. The latter option may be explained by expected difficulties of access to S&T knowledge at distance, when balanced with the availability of resources nearby.

Finally, in terms of network *structure* there are two possible strategies: some firms choose to extend the number of actors, with whom they develop less intense relations; other firms choose to have smaller networks, with more intense relations.

This research globally contributes to a more in-depth understanding of entrepreneurs´ choices in terms of the S&T knowledge network composition and configuration, providing some important insights both at the methodological and empirical levels. This contribution is particularly relevant, since previous research has rarely addressed the strategic choices underlying the development of knowledge networks for innovation.

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