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Technology sourcing: Are biotechnology firms different? An exploratory study of the Spanish case*

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Abstract:

In this paper, we study the pattern of technology sourcing, taking into account where firms' source technology and through which channels. We specifically, inquire whether biotechnology firms are different from other firms in their technology sourcing behaviour. Our results show some significant differences in the patterns of technology sourcing. Biotechnology firms show a greater propensity for external technology sourcing both with regard to the external purchasing of R&D services and with regard to cooperation for innovation. They also show a greater propensity for foreign R&D purchasing relations but they are, not more likely to establish foreign cooperation for innovation once we control for their firm-specific and industry characteristics as well as sample selection bias. Biotechnology firms do, however, show a more varied pattern of sourcing both concerning the types of agents and the geographic origin of technology.

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1. Introduction

Biotechnology is one of those emerging fields of innovation which may have the potential to radically transform other industries and economic activities, such as agriculture, the food and drink industry, or pharmaceuticals. In today's fast-paced, knowledge-intensive environment, however, innovation is rarely the outcome of firms own internal R&D efforts. Innovation is increasingly the outcome of interactions among multiple actors and both R&D outsourcing as well as networking for R&D have become significant features in current innovation management as ways to develop and gain access to new technologies. At the same time, the technology necessary for global competitiveness is often dispersed internationally. In this context, international R&D networks can provide firms with access to country-specific advantages and allow them to tap into the comparative advantages of foreign countries. While technology transfer is now recognized among economists and policymakers as key for economic growth, there is still relatively little knowledge at the firm level on the patterns of technology sourcing and the mechanisms underlying technology transfer.

In this paper we focus on the biotechnology sector in order to study the boundaries of innovative networks and the plurality of actors (e.g. firms, public administration, universities and research centres) involved in innovation. Biotechnology is faced with a complex knowledge base and rapid technological development. Powell et al. (1996) characterize the industry as one where innovations are therefore to a greater degree the outcome of networks of learning compared to other industries.

We study the sourcing of technology, taking into account where the firms source technology and through which channels. The paper contributes to the literature on technology sourcing first by assessing the relative importance of national versus international linkages of technology sourcing in general, and specifically in the biotechnology sector. Secondly, we explore whether technology sourcing through contracts or purchases may involve different spatial patterns than the sourcing of technology via cooperation, as well as its relation to the type of partner. Thirdly, we inquire whether biotechnology firms are different from other firms in their technology sourcing behaviour.

Our analysis is related to the literature on knowledge spillovers and technology transfer. This body of literature has shown its importance for innovative activity, productivity and competitiveness. Past studies have also underlined that knowledge spillovers are geographically localised. Not denying the role of space for knowledge flows, recent studies, nevertheless show that knowledge flows are not necessarily bounded by national borders (Malerba et al., 2007). In this sense, the micro-economic literature has highlighted different channels for the international transmission of technological knowledge: imports of new capital and differentiated intermediate goods, learning by exporting, foreign investment by multinationals (Zhu and Jeon, 2007), and the movements of workers (Markusen and Trofimenko, 2009) and specifically scientists. International networks of cooperation and international R&D purchasing are further catalysts for knowledge transfer across borders. A better understanding of the factors related to such international technology sourcing decisions will also contribute to the analysis of international knowledge spillovers.

Another related body of literature has focused on cross-border regional innovation systems (Tripple, 2010). An important question here is under which conditions regional innovation systems can transcend national borders. Our research can contribute to this strand of literature by providing insights into the patterns of different types of technology sourcing relations. Though the technology sourcing of some industries has deserved the interest of scholars, quantitative research on the possible specificity of industries which are at the forefront of sciences and techniques are rare.

Research cooperation is at the heart of EU innovation policy which aims to create a single European Research Area. A central objective is to make it easier for knowledge and technologies to circulate freely, especially in emerging high tech industries, such as biotechnology.

2. Literature review

Technology is becoming increasingly complex, multi-disciplinary and dynamic. For technology intensive firms such as biotechnology firms this means that developing all necessary technological know-how internally is increasingly costly (Powell et al. 1996; Cooke, 2005; Nilsson, 2001). Thus, to cope with this situation and stay competitive, firms rely on necessary knowledge from other firms (Hagedoorn, 1993). Herstad et al (2010) suggest that the importance of external knowledge sourcing may be increasing. More specifically, Hagedoorn and Narula (1996) and Hagedoorn (2002) provide evidence on the rise of technology sourcing cooperation over the past decades. Hopkins et al. (2007) argue that alliances and outsourcing linkages seem to be common since the end of the 1990s in the biotechnology sector. In the biotechnology industry, alliances may help to speed up R&D activities; and provide access to new knowledge and to R&D funding (Suárez-Villa and Walrod, 2003). By the same token, R&D outsourcing may be instrumental in cost savings (Suárez-Villa and Walrod, 2003). In pharma- biotechnology, the high cost of R&D, the decline of R&D productivity and the need to coordinate a complex knowledge base have stimulated the emergence of an increasingly networked industry (Powell et al 2005). Another study shows that a distributed innovation system is also the norm in the European agro-food biotech industry (Senker and Mangematin, 2008).

The external sourcing of technology (hereafter, the sourcing of technology) includes a wide range of arrangements such as: arms-length licensing arrangements, research contracts, joint development agreements, joint ventures, etc.

In this paper we study two alternative mechanisms that firms can use to acquire knowledge externally.

- R&D external acquisitions includes either the purchase of R&D services through arm-length contracts or through outsourcing relationships meaning that task and processes are contracted to a third party company.
- Cooperative arrangements. Two or more separate organisations join forces to share and develop knowledge in order to enhance their innovative performance.

The second dimension that we study in this paper is the spatial extent of these relations. Herstad et al. (2010) observe the rise of "globally distributed knowledge networks" (p. 116). Since the second half of the nineties, the growing phenomenon of globally distributed work organization has brought with it also a rise in international R&D sourcing and international collaboration for innovation. For instance, while in 1990 10% of all patent applications filed at the European Patent Office listed at least one inventor located in a different country than the applicant, this figure had risen to 18% by 2004 (Abramovsky et al., 2008). Robles et al. (2009) provide evidence on the general rise of international partnerships during the 1990's among Spanish firms. Our research compares national and international technology sourcing relations.

Powell et al. (1996) argue that different forms of R&D cooperation are particularly relevant for innovation in the biotechnology sector, given that the sector is characterized by a complex knowledge base and rapid technological development. New industries based on emerging fields of innovation have been argued to adopt specific forms of organisation (Hopkins et al., 2007). For instance, such emerging fields often rely initially on contributions made by universities and government labs, while private companies may play a limited role in innovation (Miyazaki and Islam, 2007). This circumstance, in our view, can make contacts with academic laboratories particularly important for these firms. Sectoral studies of innovation indicate that aspects related to R&D network structure and composition are insufficiently explored in the literature (Malerba, 2005). A special concern is, in our view, whether new science-based industries promote new types of arrangements in R&D networks. Are these emerging networks different from those prevailing in other industries? There is not much quantitative research on this topic. However, the available evidence seems to support the idea that they are fundamentally different. Analysing French firms, Miotti and Sachwald (2003) note, for instance, that companies conducting research at the technological frontier are more likely to cooperate; and they are more prone to engage in transatlantic collaboration. Using Community Innovation Survey (CIS) data for a pooled sample of manufacturing and service firms from France, Germany, Ireland and Spain, Mohnen and Hoareau (2002) also find that R&D collaborations are more frequent among firms belonging to the scientific sectors. These analyses provide important insights at the sector level. However, emerging industries are based on radically new products or ideas. Usually there is not yet a specific industrial classification containing these economic activities and, therefore, information is disseminated in a variety of sectors (we come back to this question below). This situation poses a statistical difficulty to researchers conducting quantitative analyses of such industries (see, for instance, Benneworth, 2003). Fine grained studies focusing on the specificity of linkages developed by firms active in emergent industries (e.g. biotechnology) are, therefore, still rarer. Nevertheless, case studies need to be complemented by statistical analyses which may help to understand the technology sourcing of these emerging industries.

In this paper, we compare the different modes for technology sourcing between biotechnology firms and firms with no biotechnology activity in order to test whether biotechnology firms are really different in their technology sourcing behaviour.

3. Data

Our data comes from a survey of Spanish firms (Panel de Innovación Tecnológica, PITEC) collected by the Spanish National Statistics Institute (INE). The PITEC survey includes information on the technological innovation activities of all the main sectors in the Spanish economy, including services and manufacturing. Firms are specifically asked if they carry out some type of activity (involving production, distribution, sales, services and R&D) related to biotechnology, where biotechnology is defined as the application of science and technology to live organism or parts of live organism in order produce knowledge, goods and services. This feature of the questionnaire enables us to identify, across a variety of sectors, the firms which are active in biotechnology. Some of the previous studies use samples of convenience owing to the difficulty to identify firms with biotechnology activity; such samples, however, are not likely to be statistically representative of the whole biotechnology industry.

We use data for the year 2007 which provides information on nearly 12,000 firms.[2] In this sample, 407 firms carry out some type of bio-technological activity. Table 1 shows the distribution of these firms by type of company. We can observe that biotechnology firms are more frequently public sector companies, multinational firms and research associations compared to non-bio technology firms.

Table 2 shows the distribution of the firms in the sample by main activity. The sector categories are those of CNAE (the Spanish acronym for National Classification of Economic Activities), similar to NACE rev 1, the classification of economic activities used in EU statistics. Other studies which analyse R&D alliances and R&D outsourcing in biotechnology also survey establishments in a variety of sectors(Benneworth, 2003; Suárez-Villa and Walrod, 2003). As stated, biotechnology is an emerging industry spanning over several sectors. The sample biotechnology firms operate mainly in the following sectors: Research and Development; Agriculture and Food and Drinks; and Pharmaceutical and Chemical products. The importance of R&D firms in the sample is in line with previous studies that note the pronounced rise of specialist research firms in biotechnology (Cooke, 2004). Companies involved in production of medical instruments, software and testing are providers of diagnostic kits, bioinformatics (e.g. data processing for genetics experiments) and other materials and services necessary for biotech research. Biosciences and healthcare are strongly intertwined (Cooke, 2004); hence, the substantial presence of health care companies in our sample. Our data corroborate the interest in biotechnology shown by a large range of companies from different sectors (Alfranca et al., 2004; Powell and Grodal, 2005). Also, country-specific factors shape the characteristics of this Spanish industry. The relative importance of the various sectors displayed on Table 2 is in line with results of a European survey which includes 49 Spanish firms active in biotechnology (Senker and Mangematin, 2008). The evidence supports these authors' findings in that agro-food firms are over-represented in the Spanish biotechnology industry, in accordance with the importance of the agro-food sector in Spanish production and exports (Senker and Mangematin, 2008).

As stated, in this paper we focus on R&D purchasing and cooperation for innovation patterns among firms with biotechnology activity and compare those firms to firms without biotechnology activity. As for cooperation activities, only innovation active firms[3] were asked questions related to their cooperation. For the biotechnology firms, these means that for cooperation activities we have responses for 393 firms as only 14 companies (3.4 %) reported no type of innovative activity. These are 3 public sector companies, 7 private domestic companies and 4 multinational companies. These companies operate mainly in the wholesale trade (6) and the health and social sector (5). As will be seen below, the low percentage of non innovators reflects the enormous importance of innovation for firms active in biotechnology. There are, however, no significant size differences between the innovative and non-innovative biotechnology firms. Note that for non-biotechnology companies approximately 33% in the sample report no innovative activity and thus were not asked the questions regarding cooperation for innovations. For this reason, one has to be careful in comparing the two groups. We, therefore, check all results presented in the next Section for their robustness when we restrict the comparison to innovative active firms.

Appendix 1 displays the variables used in the analysis.

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[2] We use the anonymized data set that is freely available. López (2010) compares regression results based on the anonymized and original data and shows that using the anonymized data from PITEC produces reliable results.

[3] Firms that have at least introduced new products or new processes or that have innovative activities ongoing or abandoned during the two years prior to the survey date.

4. Empirical results

We start our analysis with R&D sourcing relations through the external purchasing of R&D services before we present our results for R&D cooperation.

In Table 3, we can see that among non biotechnology firms 76 percent of firms do not report any external purchasing of R&D services. In contrast, biotechnology firms purchase to a greater extent R&D services from other firms. The percentage of firms that report no purchases of R&D is much lower with 43.7 percent. From the remaining firms that do report purchasing of R&D services, we see that R&D purchasing is still dominantly domestic. Nevertheless, among biotechnology firms a greater percentage engages in international R&D sourcing. About 12 percent of these firms report to purchase R&D services in the international markets. Repeating the comparison for only innovative active firms reduces the differences between biotechnology firms and others only slightly and in all cases the significances of t-tests reported remain unchanged.

As stated, Table 3 shows that most firms that purchases R&D do so in the domestic market. In Table 4 we compare domestic and foreign sourcing relations in biotechnology firms and non-biotechnology firms according to the type of supplier of the technology. Do biotechnology firms source from different technology suppliers? Panel A compares the location of the technology supplier (domestic or foreign) for different types of suppliers. Relations with other companies and universities involve more frequently a foreign supplier in the case of biotechnology firms compared to non-biotechnology firms. Again, the results remain qualitatively unchanged when we restrict the sample to innovative active firms only. In Panel B we compare the type of technology supplier in domestic and foreign relations. Foreign relations in non-biotechnology firms are to a much greater extent within the same company group. In contrast, biotechnology firms show a greater propensity to source technology from foreign public administrations and universities. In domestic relations, non-biotechnology firms source technology above all from other companies while biotechnology firms source technology more frequently from universities and public administrations than non-biotechnology firms also in domestic relations. Again, repeating the comparison for innovative active firms only changes percentages marginally in the case of domestic sourcing, but does not change significances of t-tests reported. All firms with foreign purchases of R&D are at the same time innovative active firms, thus comparisons between biotechnology firms and non-biotechnology firms remain unchanged.

So far we have shown that there are some significant differences in the patterns of R&D sourcing between biotechnology and non-biotechnology firms. We have also shown that these differences persist even when we restrict the sample to innovative active firms. Nevertheless, differences in the pattern of R&D sourcing could also be due to other differences in the characteristics of biotechnology firms and non-biotechnology firms.

In Table 5 we present some controlled associations between R&D sourcing and a number of firm and industry characteristics for innovative active firms. We carry out probit estimations where the dependent variables are binary indicating, respectively, whether or not the firm purchases R&D services (column 1 to 3) and if yes whether or not it does so in the international market (column 4 to 7). We present different specifications for each dependent variable. Our variable of interest is a dummy indicating whether or not the firm carries out bio-technological activities. As for other firm characteristics, in all columns we control for the size of the firm by including the number of employees. We also include the number of R&D employees as internal R&D activity and external R&D purchases could be substitutes or complements in the innovation process. Other firm characteristics that we include are a dummy whether or not the firm belongs to a group, a dummy whether or not the firm belongs to a multinational company, a dummy whether or not the company has its headquarters in Spain and four regional dummies respectively for location of R&D activities in the main industrial agglomerations in Spain (Madrid, Cataluña, Pais Vasco or Valencia). Location in those regions could induce a different sourcing behaviour compared to peripheral locations. Also, proximity to the border may facilitate R&D collaboration with foreign partners (Okubo and Zitt, 2004). In column (2), (3) and (5) to (7) we have added the export status of the firm. In column (3) and (6) we have also added two variables which attempt to measure obstacles to innovating: high innovation costs and lack of cooperation partners. These obstacles to innovation are likely to affect the decision to purchase R&D services but as we argue below should not influence the decision on the location of supplier (domestic versus abroad). All estimations control for industry fixed effects.

The results in column (1) to (3) in Table 5 show that biotechnology firms indeed show a greater propensity to purchase R&D externally even if we control for other firm and industry characteristics. However biotechnology firms show no statistically significant greater propensity to purchase R&D services from foreign suppliers once we control for other firm and industry characteristics (column (4) to (6)). Here, however, we face a classical selection problem in so far that our dependent variable is only observed for a non-random sample of firms that engages in R&D purchasing. This could result in biased estimations. Heckman (1979) provides a two-stage method to correct for such selection bias. The first stage estimates the probability that firms engage in R&D purchasing. In the second stage, estimates are corrected for self-selection by incorporating a transformation of the predicted probabilities as an additional explanatory variable.[4] We include the two obstacles to innovation as additional variables in the selection equation. The results in column (3) and (6) show that these factors relate significantly to the decision to purchase R&D services but not to the decision of where to source the services. The corresponding results from the Heckman probit model are shown in column 7 and confirm that biotechnology firms do show a greater propensity to purchase R&D services from abroad once we control for firm and industry characteristics as well as selection bias.

We now turn to cooperation for innovation. Note, that the survey only asked innovative active firms questions regarding their cooperation behaviour. Thus, results regarding cooperation are only based on those firms. In Table 6 we can see that biotechnology firms engage more frequently in cooperation for innovation than non-biotechnology firms.[5] As for the percentage of firms with only domestic cooperation for innovation we do not find a significant difference among the two. However, when we look at firms which report foreign cooperation we see that a significantly higher percentage of biotechnology firms is engaged in international cooperation for innovation. While about 55% of the biotechnology firms in the sample report having either only foreign or foreign and domestic relations of cooperation for innovation this percentage is nearly half (28%) in the case of firms with no-biotechnology activity.

In Tables 7 we present information regarding the type of cooperation partner and the location of the partner (in the domestic market, in Europe, in the USA or in other countries). Table 7a presents the raw numbers and column and row percentages. In Table 7b we present test results for statistical significance of differences between biotechnology firms and non-biotechnology firms. In Panel A we test for differences in

[4] We estimate this model by using the heckprob command in STATA.
[5] To put these figures into perspective, note that 59% of Spanish biotechnology firms collaborate versus 66% of US biotechnology firms (Súarez-Villa and Walrod, 2003)

the spatial pattern of cooperation between biotechnology firms and non-biotechnology firms in each type of cooperation. A significantly higher percentage of biotechnology firms shows more long-distance cooperation with partners outside Spain and Europe. This holds for each type of cooperation partner, except for cooperation for innovation with competitors and other firms in the same sector. In Panel B we present significance test for differences in the type of partner in each of the four geographical cooperation markets. The main differences exist again in the more distant cooperation markets. In Europe, patterns are similar with the only exception that biotechnology firms tend to operate to a greater degree with European universities. Specifically for the USA we see that biotechnology firms show a more varied pattern of cooperation partners, whereas cooperation of non-biotechnology firms with the USA are mostly within the same company group or with private R&D labs.

In Table 8 we present again some controlled associations between cooperation for innovation and the set of firm and industry characteristics we analysed in Table 5. We run again probit estimations. Now the dependent variables are, respectively, whether or not the firm cooperates for innovation (column 1 to 3) and if yes whether or not it does so in the international market (column 4 to 7). In columns (1), (2), (4) and (5) we use the same set of explanatory variables as in Table 5 in the corresponding columns. In column (3) and (5) we have again added two variables which attempt to measure obstacles to innovating: lack of qualified personnel and lack of information about technology and we expect to influence the cooperation decision but not the decision of the location of cooperation partner. The results in Table 8 show that biotechnology firms show a greater propensity to carry out cooperation for innovation even if we control for other firm and industry characteristics (column (1) to (3)). The results in column (4) to (6) also indicate that biotechnology firms show a greater propensity to cooperate with foreign partners. However, once we control for sample selection, the results in column (7) show no higher propensity of biotechnology firms to cooperate with foreign partners. Again, we have included the two variables capturing obstacles to innovation in the selection equation.[6] Note, that in all the estimations results reported are based on estimations that include detailed sector dummies. Thus, results show that within the same sector, those firms that report biotechnology activities are not more prone to cooperate with foreign partners. Repeating these estimations without sector control, does, however show a slightly significant positive coefficient for the biotechnology dummy. This reflects, that as a whole biotechnology firms cooperate more with foreign partners, however not more than firms in the same sectors without biotechnology activity.

5. Discussion

Compared to other firms, biotechnology firms display a greater propensity to purchase external R&D and to engage in cooperation for innovation, even when other characteristics of companies are controlled for. This finding supports, with a large sample at the national level, results of previous studies which are mostly based on case-studies of world's leaders in the biotechnology industry (Hopkins et al., 2007; Powell and Grodal, 2005).

There are also differences concerning the firms' partners in R&D cooperation and their suppliers of technology. Biotechnology firms are more likely to source technology from

[6] Note that results remain qualitatively unchanged when only the lack of qualified personnel dummy is included as additional variable in the selection equation. Results are also unchanged, if for example, the high innovation cost dummy variable used in Table 5 together with the lack of qualified personnel dummy is included.

public institutions (as opposed to companies) both by engaging in R&D cooperation with them or by purchasing R&D services from them. This finding is in line with the idea that the rise in the commercialisation of university knowledge is associated, among other causes, with the emergence of the biotechnology industry (Rasmussen et al., 2006). On the other hand, our finding on the importance of institutional partners in R&D cooperation is in accordance with findings for the US biotechnology industry (Bagchi-Sen, 2004). It is true that, compared with other European universities, Spanish universities are much more oriented towards teaching as opposed to research (Bonaccorsi and Daraio, 2009). Nevertheless, our results are coherent with another study. Out of 47 Spanish universities, Gómez et al. (2009) find four universities specialising in Agriculture-Biology-Environment-Biomedicine; these universities displayed high levels of cooperation with private companies, as measured by co-authored ISI publications. On the other hand, as noted by a study on this industry in North East England, biotechnology firms may also have links with non life science university departments, such as engineering departments (Benneworth, 2003). In spite of the importance of R&D private labs in current fundamental research in biotechnology (Cooke, 2004), the sample biotechnology firms are significantly less likely than other sample firms to collaborate with such labs in Spain or in "other countries" (differences between both types of Spanish firms concerning R&D partners located in the rest of Europe and the USA are statistically not significant).

Previous research has shown that biotechnology firms display a relatively high proportion of R&D alliances with foreign firms (Suárez-Villa and Walrod, 2003). However, our results suggest that biotechnology firms' high rates of foreign R&D collaboration may actually reflect general patterns of collaborative behaviour in the respective sectors of such companies. Spanish biotechnology firms are not more involved in foreign R&D alliances than firms of the same sector with no biotechnology activities. It may well be that, following international trends in the biotechnology industry (Cooke, 2004), the sample firms rather participate in regional R&D networks. This trend could favour domestic linkages. However, this hypothesis could not be tested with the available evidence.

By contrast, the nature of the respective foreign partners and the geographic scope of collaboration differ. When they cooperate with European partners, biotechnology firms are more likely to interact with universities. In spite of the strengthening of Spanish research in agro-food biotechnology (Senker and Mangematin, 2008), a possible reason is that these companies are not able to find in Spanish universities all the scientific resources they may need. As noted by Powell (2005), in biotechnology, linkages to universities and research centres which are at the forefront of basic science are highly necessary. Analysing co-authored ISI production, Okubo and Zitt (2004) note that Spain's scientific collaborations display a high level of Europeanization (as measured by the share of scientific collaboration with 15 Member States). As a consequence, a special high level of European collaborations could have been expected on the part of Spanish biotechnology firms -- given that biotechnology is a science-based industry. Nevertheless, with the exception of universities, the level of R&D collaboration displayed by Spanish biotechnology firms with European partners seems comparable to that shown by the rest of the sample companies. This situation may be an indirect indication that, as claimed by some authors, Europe is weak in science and technology related to biotechnology and other fast growing fields (Lundvall and Borrás, 2005). As will be seen below, the situation is quite different concerning the R&D collaboration of the sample biotechnology firms with US partners.

We find that biotechnology firms are more likely than other companies to engage in transatlantic partnerships. Our results are similar to Miotti and Sachwald's (2003) who note that French firms which research at the technological frontier are more inclined to engage in transatlantic collaborations. In specific fields of the life sciences, the resources put to the disposal of research are greater in the USA than in any other country; and public stimulus to university- firms networking is substantial in the USA (Cooke, 2004; Salter and Salter, 2010). Previous research shows that many European leading pharmaceutical companies are tapping into US biotechnology research through R&D alliances and other methods (Lazonick and Tulum, 2009). Our results suggest that this strategy may be more extended than believed. According to our findings, Spanish biotechnology firms of all sizes, even those coming from sectors other than pharmaceuticals, are tapping into such US resources mainly through R&D collaborations with US universities and, especially, R&D private labs.

6. Conclusions

In this paper we have studied the technology sourcing behaviour of biotechnology firms and firms that are not engaged in biotechnological activities We find some significant differences between their respective patterns of technology sourcing. Compared to other firms, even to those operating in their same sector, biotechnology firms are more inclined to engage in open innovation and in network- based governance of R&D. Their preferences for a heterogeneity of interfaces with different types of partners and suppliers suggests a substantial search investment.

Biotechnology firms are also more likely than other firms in their respective sector to purchase R&D from abroad but not to establish cooperation for innovation with foreign partners. However, their sources of foreign technology are more varied both concerning the types of agents and the geographic origin of technology. This finding confirms that biotechnology firms organize innovation differently from other companies, including firms with no biotechnology activities pertaining to their own origin sector.

Our results show the need to specifically focus on emerging industries in order to formulate policies concerning innovation. Processes of learning display a collective dimension (Lazonick, 2005; Teece and Pisano, 1994). Therefore, a systemic approach (Malerba, 2005) to innovation policy is needed, especially in industries highly inclined to source technology externally as the one studied in this paper. As stated, the constellations of actors involved in such learning processes differ in biotechnology firms. Universities, both at home and abroad, seem to play a very important role; hence, the need to create stimuli for scientists and universities active in this field both at the national and the supra-national levels. Linkages of these institutions with the biotechnology industry should be facilitated. At the national level, bureaucratic difficulties and insufficient stimuli to university-industry linkages are likely to be especially harmful for biotechnology firms. Also, the managerial burden often involved in EU projects (Lundvall and Borrás, 2005) may put breaks to European R&D integration in this strategic field, with especially harmful consequences for catching-up countries such as Spain.

Finally, it is important to emphasise that the results indicate associations, but should not be taken to prove causal relations. Firms make decisions regarding their technology sourcing strategy together with decisions concerning their size, internal R&D and a series of other company and plant-level characteristics that our cross-sectional data cannot easily control for. Moreover, international R&D purchasing as well international cooperation for innovation can not be viewed in isolation. These decisions are part of a firm’s internationalisation strategy that goes hand in hand with the exporting decision.

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Table 1. Biotechnology firms by type of company

	Biotech firms		*Non biotech firms*		*Total*	
	No	*%*	*No*	*%*	*No*	*%*
Public sector	16	3.9	236	2.1	252	2.2
private national	314	77.2	9690	86.6	10004	86.3
private multinational	55	13.5	1137	10.2	1192	10.3
research association	22	5.4	124	1.1	146	1.3
Total	407	100	11187	100	11594	100
Pearson chi2(3) = 71.9435 Pr = 0.000						

Table 2. Biotechnology firms by type of main activity

	Biotech firms		*Non biotech firms*		*Total*	
	No	*%*	*No*	*%*	*No*	*%*
Agriculture	42	10.3	129	1.2	171	1.5
Food and drinks	57	14.0	697	6.23	754	6.5
Paper	4	1.0	109	1.0	113	1.0
Chemical products	38	9.3	566	5.1	604	5.2
Pharmaceutical products	40	9.8	124	1.1	164	1.4
Rubber and plastic materials	2	0.5	370	3.3	372	3.2
Non-metallic mineral products	2	0.5	290	2.6	292	2.5
Machinery and mechanical equipment	3	0.7	807	7.2	810	7.0
Machinery and electrical equipment	1	0.3	283	2.5	284	2.5
Medical instruments, optical and precision equipment	8	2.0	240	2.1	248	2.1
Recycling	1	0.3	41	0.4	42	0.4
Production and distribution of energy	6	1.5	73	0.7	79	0.7
Construction	4	1.0	463	4.1	467	4.0
Wholesale trade	20	4.9	544	4.9	564	4.9
Retail trade	1	0.3	202	1.8	203	1.8
Accommodation	2	0.5	186	1.7	188	1.6
Finance	1	0.3	216	1.9	217	1.9
Software	2	0.5	637	5.7	639	5.5
Other computer programming activities	1	0.3	183	1.6	184	1.6
Research and development	91	22.4	215	1.9	306	2.6
Architecture and engineering activities	11	2.7	435	3.9	446	3.9
Testing and technical analysis	23	5.7	123	1.1	146	1.3
Other business activities	5	1.2	688	6.2	693	6.0
Education	1	0.3	55	0.5	56	0.2
Other health and social activities	41	10.1	437	3.9	478	4.1
Other sectors with no biotechnology firms			3074	27,5		
Total	407	100	11187	100	11594	100
Pearson chi2(55) = 1.4e+03 Pr = 0.000						

Table 3. External R&D sourcing

	Biotech firms		Non biotech firms		t-test of means difference	sig.
	No	%	No	%		
No external R&D sourcing	178	43.7	8.505	76.0	14.896	***
Only domestic external R&D sourcing	181	44.5	2.265	20.2	-11.836	***
Only foreign external R&D sourcing	6	1.5	127	1.1	-0.630	
Domestic and foreign external R&D sourcing	42	10.3	290	2.6	-9.214	***
Total	407	100.0	11.187	100.0		

Note: *** significant at the 1% level; ** significant at the 5% level; *significant at the 10% level

Table 4. Domestic versus international R&D sourcing relations by type of technology supplier

Panel A: significance test for differences between domestic and international technology suppliers

	Biotech firms					***Non biotech firms***						
	Domestic		***foreign***		**total**	***domestic***		***foreign***		**total**	**t-test**	**sig.**
Type of R&D partner	*No*	*%*	*No*	*%*		*No*	*%*	*No*	*%*			
intra-group	21	77.8	6	22.2	27	248	65.4	131	34.6	379	-1.310	
other companies	127	77.4	37	22.6	164	1.587	86.0	259	14.0	1846	2.959	***
public administration	62	92.5	5	7.5	67	170	93.4	12	6.6	182	0.240	
Universities	115	89.1	14	10.9	129	800	95.6	37	4.4	837	3.052	***
private non-profit organisations	18	81.8	4	18.2	22	186	92.1	16	7.9	202	1.605	
other research organisations	47	95.9	2	4.1	49	552	97.5	14	2.5	566	0.678	
Total	390	85.2	68	14.8	458	3543	84.4	469	15.6	4012		

Panel B: significance test for differences between the type of technology supplier

	Biotech firms		***Non biotech firms***		**domestic**		**foreign**	
	domestic	***foreign***	***domestic***	***foreign***	**t-test**	**sig.**	**t-test**	**sig.**
Type of R&D partner	*%*	*%*	*%*	*%*				
intra-group	5,4	8,8	7,0	27,9	1.199		3.408	***
other companies	32,6	54,4	44,8	55,2	4.634	***	0.125	
public administration	15,9	7,4	4,8	2,6	-8.917	***	-2.115	**
Universities	29,5	20,6	22,6	7,9	-3.067	***	-3.367	***
private non-profit organisations	4,6	5,9	5,2	3,4	0.536		-1.005	
other research organisations	12,1	2,9	15,6	3,0	1.841	*	0.020	
Total	100,0	100,0	100,0	100,0				

Note: multiple responses; categories are not exclusive.*** significant at the 1% level; ** significant at the 5% level; *significant at the 10% level

Table 5. Controlled associations for R&D purchases

	R&D purchases			R&D foreign purchases			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Biotechnology	0.474*** (0.071)	0.458*** (0.071)	0.448*** (0.072)	0.070 (0.117)	0.047 (0.118)	0.050 (0.118)	0.242*** (0.100)
number of employees (in 1000)	0.004 (0.011)	0.004 (0.011)	0.005 (0.011)	-0.030 (0.030)	-0.030 (0.031)	-0.030 (0.031)	-0.015 (0.024)
number of R&D employees	0.003*** (0.0005)	0.003*** (0.0005)	0.003*** (0.0005)	0.006*** (0.001)	0.005*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
firm belongs to a group	0.089 (0.070)	0.068 (0.070)	0.106 (0.070)	0.832*** (0.129)	0.807*** (0.130)	0.784*** (0.131)	0.637*** (0.099)
multinational company	0.017 (0.074)	0.002 (0.074)	-0.001 (0.074)	0.185 (0.131)	0.165 (0.131)	0.171 (0.132)	0.093 (0.099)
headquarter in Spain	0.201*** (0.072)	0.208*** (0.072)	0.179** (0.072)	-0.562*** (0.128)	-0.556*** (0.129)	-0.536*** (0.130)	-0.309*** (0.099)
firm is exporting		0.198*** (0.035)	0.196*** (0.036)		0.408*** (0.088)	0.410*** (0.088)	0.421*** (0.071)
Madrid	0.366*** (0.048)	0.345*** (0.048)	0.341*** (0.048)	-0.017 (0.092)	-0.036 (0.093)	-0.024 (0.093)	0.142** (0.074)
Cataluña	0.270*** (0.038)	0.243*** (0.039)	0.247*** (0.039)	0.110 (0.075)	0.086 (0.076)	0.085 (0.076)	0.173*** (0.058)
Pais Vasco	0.613*** (0.048)	0.607*** (0.048)	0.598*** (0.048)	-0.250*** (0.097)	-0.249*** (0.097)	-0.244** (0.097)	0.074 (0.082)
Valencia	0.537*** (0.054)	0.522*** (0.054)	0.518*** (0.054)	-0.137 (0.105)	-0.155 (0.105)	-0.140 (0.105)	0.116 (0.087)
Obstacle to innovating: high innovation cost			0.064** (0.032)			-0.086 (0.067)	
Obstacle to innovating: lack of cooperation partners			0.156*** (0.031)			-0.019 (0.066)	
No of observations	8709	8709	8709	2885	2885	2885	8709
Log likelihood	-5137.1	-5121.3	-5103.2	-1081.7	-1070.5	-1069.5	-6165.45
Pseudo R2	0.071	0.074	0.077	0.151	0.160	0.161	
Rho							-0.986***

Note: .*** significant at the 1% level; ** significant at the 5% level; *significant at the 10% level; all estimations include 26 sector dummies. Column (7) presents results from the Heckman selection model using STATA command heckprob where the selection equation includes the two dummies for innovation hindering factors: high innovation cost and lack of cooperation partners.

Table 6. Cooperation for innovation among innovation active firms

	Biotech firms		***Non biotech firms***		**t-test of means difference**	**sig.**
	No	***%***	***No***	***%***		
No cooperation for innovation	161	41.0	5.555	66.8	10.603	***
Only domestic cooperation for innovation	14	3.6	453	5.4	1.621	
Only foreign cooperation for innovation	120	30.5	1.238	14.9	-8.388	***
Domestic and foreign cooperation for innovation	98	24.9	1.070	12.9	-6.879	***
Total	393	100.0	8.316	100.0		

Note: *** significant at the 1% level; ** significant at the 5% level; *significant at the 10% level

Table 7a. Domestic versus international cooperation for innovation. Location of partners

Biotechnology	domestic	C%	R%	Europe	C%	R%	USA	C%	R%	other	C%	R%	Total
intra-group	46	26,0	14,6	68	33,3	21,6	89	24,7	28,3	112	42,6	35,6	315
Supplier	19	10,7	18,1	27	13,2	25,7	33	9,2	31,4	26	9,9	24,8	105
Client	9	5,1	30,0	4	2,0	13,3	12	3,3	40,0	5	1,9	16,7	30
competitor or other firms in the sector	1	0,6	4,0	11	5,4	44,0	7	1,9	28,0	6	2,3	24,0	25
private R&D labs	56	31,6	16,2	52	25,5	15,1	150	41,7	43,5	87	33,1	25,2	345
Universities	29	16,4	22,7	33	16,2	25,8	44	12,2	34,4	22	8,4	17,2	128
public research organisations	12	6,8	37,5	6	2,9	18,8	13	3,6	40,6	1	0,4	3,1	32
technology centres	5	2,8	20,8	3	1,5	12,5	12	3,3	50,0	4	1,5	16,7	24
Total	177	100	17,6	204	100	20,3	360	100	35,9	263	100	26,2	1004
non-biotechnology													
intra-group	535	22,7	20,6	745	39,9	28,7	763	32,2	29,4	550	30,1	21,2	2593
Supplier	242	10,3	32,7	251	13,5	34,0	152	6,4	20,6	94	5,2	12,7	739
Client	57	2,4	42,2	50	2,7	37,0	19	0,8	14,1	9	0,5	6,7	135
competitor or other firms in the sector	49	2,1	34,8	57	3,1	40,4	16	0,7	11,3	19	1,0	13,5	141
private R&D labs	1011	42,9	27,4	490	26,3	13,3	1176	49,7	31,8	1017	55,7	27,5	3694
Universities	352	14,9	40,6	206	11,0	23,8	192	8,1	22,2	116	6,4	13,4	866
public research organisations	66	2,8	53,2	28	1,5	22,6	23	1,0	18,5	7	0,4	5,6	124
technology centres	44	1,9	35,8	39	2,1	31,7	27	1,1	22,0	13	0,7	10,6	123
Total	2356	100	28,0	1866	100	22,2	2368	100	28,1	1825	100	21,7	8415

Note: multiple responses; categories are not exclusive.

Table 7b. Comparing location and type of cooperation partner

Panel A: significance tests for differences in location								
	domestic	**sig.**	Europe	**sig.**	USA	**sig.**	other	**sig.**
intra-group	0.528		0.658		0.649		**0.000**	***
Supplier	0.097		1.000		**0.000**	***	**0.000**	***
Client	1.000		**0.096**	*	**0.001**	***	0.163	
competitor or other companies in the sector	**0.003**	***	1.000		0.116		0.765	
private R&D labs	**0.000**	***	0.564		**0.000**	***	1.000	
Universities	**0.001**	***	0.727		**0.000**	***	0.293	
public research organisations	1.000		1.000		**0.006**	***	1.000	
technology centres	0.315		0.109		**0.022**	**	1.000	

Panel B: significance tests for differences in type of partner								
	domestic	**sig.**	Europe	**sig.**	USA	**sig.**	other	**sig.**
intra-group	1.000		1.000		1.000		**0.000**	***
Supplier	1.000		1.000		**0.003**	***	**0.000**	***
Client	0.207		1.000		**0.000**	***	**0.017**	**
competitor or other companies in the sector	1.000		0.164		**0.011**	**	0.221	
private R&D labs	**0.004**	***	1.000		0.122		**0.000**	***
Universities	1.000		**0.010**	***	**0.000**	***	0.247	
public research organisations	**0.018**	**	0.431		**0.000**	***	1.000	
technology centres	1.000		1.000		**0.000**	***	0.644	

Note: multiple responses; categories are not exclusive. Significance is based on Pearson chi2 p-value: *** significant at the 1% level; ** significant at the 5% level; *significant at the 10% level

Table 8. Controlled associations for cooperation for innovation

	Cooperation for innovation			Foreign cooperation for innovation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Biotechnology	0.418***	0.408***	0.410***	0.351**	0.331**	0.332**	0.100
	(0.071)	(0.072)	(0.072)	(0.153)	(0.153)	(0.153)	(0.133)
number of employees (in 1000)	0.013	0.013	0.014	-0.024	-0.023	-0.023	-0.029**
	(0.011)	(0.011)	(0.011)	(0.016)	(0.016)	(0.016)	(0.013)
number of R&D employees	0.006***	0.006***	0.006***	0.004***	0.004***	0.004***	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
firm belongs to a group	0.216***	0.198***	0.221***	-0.784***	-0.808***	-0.803***	-0.716***
	(0.069)	(0.069)	(0.069)	(0.130)	(0.130)	(0.130)	(0.097)
multinational company	-0.032	-0.043	-0.036	0.041	0.035	0.039	0.101
	(0.073)	(0.073)	(0.073)	(0.135)	(0.135)	(0.135)	(0.099)
headquarter in Spain	0.106	0.113	0.100	0.479***	0.489***	0.486***	0.317***
	(0.070)	(0.070)	(0.071)	(0.129)	(0.129)	(0.129)	(0.096)
firm is exporting		0.160***	0.155***		0.213***	0.212***	0.055
		(0.035)	(0.035)		(0.076)	(0.076)	(0.056)
Madrid	0.227***	0.209**	0.213***	0.208**	0.183*	0.183*	0.040
	(0.048)	(0.048)	(0.048)	(0.098)	(0.099)	(0.099)	(0.080)
Cataluña	0.076**	0.054	0.055	0.055	0.038	0.036	0.001
	(0.039)	(0.039)	(0.039)	(0.079)	(0.079)	(0.079)	(0.061)
Pais Vasco	0.561***	0.557***	0.548***	0.360**	0.352***	0.353***	0.001
	(0.048)	(0.048)	(0.048)	(0.099)	(0.099)	(0.099)	(0.083)
Valencia	0.210***	0.197***	0.199***	0.068	0.053	0.053	-0.055
	(0.055)	(0.055)	(0.055)	(0.113)	(0.113)	(0.113)	(0.091)
Obstacle to innovating: lack of qualified personnel			0.141***			0.058	
			(0.034)			(0.071)	
Obstacle to innovating: lack of information about technology			0.031			-0.012	
			(0.035)			(0.073)	
No of observations	8709	8709	8709	2993	2993	2993	8709
Log likelihood	-5214.5	-5204.0	-5189.0	-1148.4	-1144.5	-1144.1	-6324.0
Pseudo R2	0.070	0.071	0.074	0.114	0.117	0.117	
Rho							-0.999***

Note: .*** significant at the 1% level; ** significant at the 5% level; *significant at the 10% level; all estimations include 26 sector dummies. Column (7) presents results from the Heckman selection model using STATA command heckprob where the selection equation includes the two dummies for innovation hindering factors: lack of qualified personnel and lack of information technology.

Appendix 1. Description of variables

Name of variable	Survey question, responses, and measurement :		
External sourcing of R&D	Purchase of R&D services external to the firm through contracts or other arrangements (in € before taxes)	From: 1. Enterprises of the same group 2. Other companies 3. Public Administration 4. Universities 5. Private non-profit organisation 5. Other research organisation	For each response, the surveyed company was asked to indicate the location of seller : 1. Spain 2. Foreign country
Cooperation for innovative activities	In 2005-2006, has your firm cooperated with other firms or with institutions to carry out innovative activities? (subcontracting excluded)		1 =Yes 0 = No
Type of partner	Indicate the type of partners with whom you cooperated and the countries where they are located	1. Other companies of your group 2. Suppliers of equipment, components or software 3. Clients 4. Competitors or other sector companies 5. Consultants, commercial labs or private R&D centres 6. Universities or other high education institutions 7. Public research centres 8. Technological centres	For each response, the surveyed company was asked to indicate the location of partner: 1.Spain 2.Other European countries (1) 3.USA 4. Other countries
No. of employees	No. of employees of the company		
No. of R&D employees	No. of R&D employees of the company		
Group	Does your firm belong to a business group?		1 =Yes 0 = No
Multinational company	Type of company	Private company with at least 50% foreign ownership	1 =Yes 0 = No
Headquarters in Spain	Where are the headquarters of your business group?		1= Spain 0= other countries
Firm is exporting	In what geographic markets have you sold production in 2005-2007?	1. Local or regional 2. National 3. International market	1= if the firm reports sales in the international market 0=otherwise
Location of main laboratory	No. of R&D employees by region: 17 Autonomous regions	Dummies for Madrid, Cataluña, País Vasco, and Valencia =1 if R&D employment >0, and zero otherwise. (2)	
Obstacles to innovation	Indicate the importance of factors that make innovation difficult.	1. High innovation cost 2. Lack of qualified personnel 3. Lack of information about technology	Ratings of importance: high, intermediate, reduced, not relevant. Dummies for values of high and intermediate =1 and zero otherwise.

Notes: (1) Includes EU-27, Switzerland and Turkey. (2) Alternatively the regional dummies have been based on the location of the main R&D centre (R&D employment >50%). Results are qualitatively unchanged.