World Journal of Management
Vol. 3. No. 2. September 2011 Pp. 70-93

Do Different Firm Activities and Characteristics Generate Different Attitudes Toward Research Collaboration and Publication? An Analysis of the Italian Biotech Sector

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An increasing attention is being devoted by many scholars to the phenomenon of the collaborations between university and other research institutions with industry. The new knowledge arising from such collaborations is often disclosed trough the scientific publications and the creation of new knowledge is rarely a solitary activity; knowledge creation and innovative activities usually take place within networks and come out from collaborations. Notwithstanding this increasing attention, some aspects of such collaborations remain probably not enough investigated. In particular there is need of a thorough analysis about the relationship between the activities and characteristics of the firms on one side and the frequency of the collaborations and the characteristics of the research networks on the other one. This paper tries to increase the knowledge in this direction, treating this issue with reference to the Italian biotech sector. A database identifies the existing Italian biotech firms at the end of 2005 and classify them according to the OECD criteria, which identify different typologies of firms according to the kind of activity mainly conducted. We crossed such data with data on publications (from ISI-Web of Science: number of publications; number, nature and localizations of co-authoring institutions) and data on firm size (from AIDA). Through an econometric analysis we try to verify if the different characteristics of the firms are related to different behaviour toward publication and collaboration. The results suggest that such relationships do exist: larger firms publish more and have larger networks of co-autorships. A more original result is that, even controlling for firm size, the belonging of a firm to an OECD typology has an effect on the number of publications done and on the number and quality of collaborations in publications activated by that firm. More precisely, consistently with their specific goals and attitudes, firms specifically devoted to R&D activity publish more than the other typologies of firms and targeted firms have more collaborators in their publications. These results have some consequences also in terms of policy: in fact the policies to adopt in relation to the collaboration in research and the dissemination of its results should be different according to the different typologies of firms. A complex and differentiated sector requires differently modulated policies.

JEL Codes: L2, O3.

1. Introduction

An increasing attention is being devoted by many scholars in the field of the economics of innovation to the phenomenon of the firms that publish papers in the "open" literature. Nevertheless, the relationship between the nature and characteristics of the firms, on one side, and their different attitudes and behaviour toward publication and research collaboration, on the other side, has not been probably enough investigated. This paper tries to increase the knowledge in this direction, treating this issue with reference to the Italian biotech sector.

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The choice of the this sector is not arbitrary: the biotech sector is characterized by an high level of knowledge intensity and by a pervasive nature of innovation. It has therefore an high production of new knowledge, that is often disclosed trough the scientific publications or by the introduction of innovations. Besides, new knowledge creation is rarely a solitary activity: knowledge creation and innovative activities take place within networks and come out from collaborations.

Furthermore, this sector is characterized by an high level of complexity because of its multidisciplinary nature and pervasiveness of innovation; boundaries of industries that can be included under the umbrella of "biotechnology" are blurring. This causes a great heterogeneity inside the sector, up to the point that it becomes difficult to give a definition and to precisely identify it. We considered the Italian situation: indeed, the Italian Statistical Office (ISTAT) does not identify a biotechnology sector, therefore it does not give a definition of it.

An attempt to manage such complexity has been done by the OECD, which on the contrary provides a definition of the whole sector and, on the basis of the kind of activity mainly conducted, tries to identify the different typologies of the firms.

We therefore face up a sector characterized by high heterogeneity and high propensity to publish. We try to investigate the relationship between these two aspects, analysing such heterogeneity in the light of the behaviour in publications. Basing on the work done by D'Amore and Vittoria (2006, 2008, 2009), who surveyed the Italian biotech firms and classified them according to the OECD criteria and crossing their data with data on publications and firms characteristics, we want to verify if the different characteristics of the firms (different activities that generate a different OECD categorization, together with other relevant aspects, like size and age) are relevant in explaining different attitudes to make publications in the "open" literature and to make publications in collaboration.

More precisely, through a bivariate and a multivariate analysis, we investigate the determinants of the number of publications of each firm and of the number of collaborations in each publication. Our hypothesis is that different typologies of firm, as defined by OECD, have a different behaviour under both profiles. Besides, we suppose that other relevant characteristics of the firms have an influence in both sense.

This analysis is particularly important in terms of policy implications: a highly knowledge based sector, as biotech is, requires fine tuned policy regarding the processes of creation, sharing and diffusion of knowledge. Therefore a deep knowledge of the sector is required, particularly regarding its internal differentiations toward such processes.

The paper is so articulated: the following section briefly describes the typologies of biotech firms identified by the OECD and their presence in the Italian biotech sector; the third section contains a literature review about the role and the main channels of knowledge disclosure, that are R&D collaboration and the production of scientific papers. In the fourth section we give a description of the data, methodology and variables used for the analysis; in the fifth section we report the results of bivariate and multivariate (negative binomial regression) analyses, firstly regarding the determinants of the number of publications (section 5.1), then

regarding the number of collaborations in each publication (section 5.2); then we synthesise the results (section 5.3). Some final considerations conclude the paper.

2. The OECD Classification of the Biotech Sector

As we said before, one of the main characteristics of the biotech sector is its multidisciplinary nature. Its definition comprises a broad range of knowledge fields; in fact in the existing literature we can find different definitions of the sector, like in the reports published by internationally influential bodies, such as OECD, OTA, BIO *et alia*, where the different points of view are based on the diversity in interpretation, measurement and policy ideas. The most frequently used definition is given by OECD: "biotechnology consists in the use of scientific and engineering principles (based on microbiology, genetic, biochemistry, chemical and biochemical engineering) to transform materials using biological agents (such as micro organism, enzyme, animal or vegetable cells) with the purpose to obtain good and service" (OECD, 1989).

The OECD Statistical Framework for technology also defined biotech activities, identifying six classes. The main distinction is between production and service activities. Among production activities it distinguishes active, innovative and dedicated biotech firms, in order to identify activities more or less focused on biotech. More in detail, a biotechnologically active firm (BAF) is defined as a firm engaged in key biotechnology activities, like the application of at least one biotech technique to produce goods or services and/or the performance of biotechnology R&D; a dedicated biotech firm (DBF) is a BAF whose *predominant* activity involves the application of biotech techniques to produce good or services and/or the performance of biotech R&D; an innovative biotech firm (IBF) is defined as a BAF that applies biotech techniques for the purpose of implementing new products or processes. Among service activities, the typologies are R&D, market and other service oriented firms: a biotechnology R&D firm with no product sales is classified by Italian national statistical offices into the R&D service industry category; targeted firms include firms classified as wholesalers, for instance local operators of large foreign pharmaceutical firms, whose local affiliate performs biotechnology research, but acts mainly by a wholesale distributor; other types of services firms are included if they are using biotech techniques for the purpose of providing a service (for example waste management and environmental remediation firms).
Table 1 synthesises the OECD classification:

Table 1: Biotech firm typologies in OECD taxonomy

• Biotechnology **active** firm (BAF) • **Innovative** biotechnology firm (IBF) • **Dedicated** biotechnology firm (DBF)	Production
• Biotechnology **R&D** firm • **Targeted** firm • **Other services** firm	Services

Source: OECD *Statistical Framework for Biotechnology* (2001)

As said in the Introduction, D'Amore and Vittoria (2006, 2008, 2009) identified the existing Italian biotech firms and classified them according to the OECD criteria. Table 2 shows the result of their work.

Table 2: Italian biotech firms distribution (OECD typologies), 2005

Firm typologies	Profit	No profit	Total
Active	50	1	
Innovative	139		
Dedicated	61		
Total Production Firms	250	1	251
R&D	58	278	
Targeted	83		
Other services	110	85	
Total Services Firms	251	363	614
Total Firms	501	364	865

3. Why Do Firms Make Research in Collaboration and Why They Publish the Results?

The biotech sector is characterized by an high degree of collaboration between innovative agents (firms, universities, research centres, hospitals) and an high propensity of firms to involve themselves in the practice of open knowledge: many firms publish scientific papers in the reviews read by the scientific community. The two phenomena go often together, in the sense that the papers are often the results of collaborative research.

A survey by *Science Watch* carried out in 2001 indicates that, between 1991 and 2001, many firms were among the most active institutions in terms of publications. Highly technological firms have adopted "open science" academic norms and routinely engage in basic scientific research and employ scientists who regularly publish in scientific journals (Adams, 1990). Contrary to conventional wisdom, in many industries firms often choose to openly disclose part of their knowledge. In doing so, industry scientists often collaborate with university researchers in solving particular scientific problems.

Clearly, writing publications for these peer-reviewed journals costs valuable time and corporate money, whereas the commercial benefits would seem uncertain or are sometimes marginally at best. Moreover firms have a natural propensity to secrecy and to the protection of intellectual property rights. Therefore the reason why industrial research labs act as quasi-academic research labs and publish large quantities of papers is still quite an open question.

Nelson (1990) argued that firms have many good reasons to publish (selected) results of their research endeavors of low competitive value: to maximize visibility and link up to the scientific community, but also to establish intellectual claims and legal rights. Hicks (1995) points out that the corporate research papers in the open literature may also signal R&D capabilities to (potential) partners and suppliers. Additional incentives of more recent data include R&D management objectives, such as: attracting private capital and public research funding and gaining a

reputation and enhanced credibility for doing high quality (basic) research, in order to attract first-rate researchers and technicians. As such, publications not only represent the firm's production of scientific and technical knowledge as a public good, but also act as PR vehicle and as a gateway in a two-directional knowledge diffusion pathway between the firm and the scientific communities in the outside world: in the case of low rivalry conditions, firms may expect reciprocity exchange effects where publications may induce further research by others. This "open science" mechanism produces a pool of knowledge that can be used freely by the international scientific community, from which corporate researchers draw very heavily (Jaffe, 1989).

Obviously companies will tend to publish only a fraction of their research findings that are of interest to the relevant scientific and engineering research communities. Firms will carefully balance their desire for secrecy and their willingness to share and disseminate information. Considering the strategic nature of industrial research and the importance of intellectual property rights, these publications should therefore mainly be seen in the light of corporate business strategies.

Zucker et al. (1998) asked how a firm's linkage to scientific networks affects its overall economic performance and more specifically its technological progress, particularly in instances when novel technologies are science-based. With respect to the role of research publications in these linkages, respondents indicated that, especially in the periods when there is a shift in technological paradigm to one closely linked to science, publications by the leading firms are crucial for mobilizing relevant in-house research and external research to make a successful transition.

If firms do decide to publish, many of these papers are likely to be co-authored with researchers in the public sector. In fact, with the shift itself of the technological paradigm and the increasing competition and shorter development cycles, companies innovation strategies include R&D collaboration with major sources of new knowledge creation around the world.

Traditionally, the creation of scientific knowledge and associated technical know-how has been viewed as a linear process in which firms endogenously seek out and apply these knowledge inputs, in the form of R&D efforts, to generate commercially valuable innovative output. This theoretical vision was consistent with the attitude of the firms, common prior to World War II, to keep discoveries highly secret and made no attempt to assimilate information from outside their own R&D labs. This was the "closed innovation" paradigm. Then the world has seen major advances in technology and society which have facilitated the diffusion of information. Not the least of these advances are electronic communication systems, including the Internet. Today information can be transferred so easily that it seems impossible to prevent. Thus, the "open innovation" paradigm arises. This calls for a more sensitive relation to external knowledge. The central idea behind open innovation is that in a world of widely distributed knowledge, companies cannot afford to rely entirely on their own research, but should instead buy or license processes or inventions (*e.g.* patents) from other companies. In addition, internal inventions not being used in a firm's business should be taken outside the company (*e.g.*, through licensing, joint-ventures, spin-offs).

In this framework it is easy to understand that the perspective of the university as a key contributor to wealth generation and economic development (Mansfield and

Lee, 1996) has increased in recent decades. De Backere and Sleuwaegen (2001) state that academic research has become "endogenised and integrated into the economic cycle of innovation and growth". Moreover, the literature on the "Triple Elix" depicts intensive scientific collaborations between universities, firms and government agencies and argue that university research may increasingly function as a locus of aggregation of national knowledge intensive networks (Etzkowitz and Leydesdorff, 2000). The rationale for collaborative knowledge production is straightforward: actors engage in collaborations to learn from each other and to make a stronger impact on the field than it could be achieved individually. The strength of interaction between any two actors, and any two regions, will be dependent on the learning opportunities involved in collaboration on the one hand, and the time and money required to participate on the other hand.

Particularly in the biotechnology sector, characterized by an high level of innovation, one way to produce innovation is the collaboration in publications between firms and universities. Knowledge transfer becomes a crucial point in the sector. The inter-institutional co-authorship of research articles is a fundamental form of knowledge transfer and creation. Inter-institutional co-authorship, regardless of the type of the organizations involved, occurs when at least two different co-authors of a scientific paper have different affiliations. This type of interaction entails the tacit transfer of information and knowledge as a result of personal contacts between the authors, even where the process is scantly formalized.

4. Data, Methodology and Variables of the Empirical Analysis

Data

In order to build a database of scientific publications in the biotech sector we produced an intersection of three databases: *i*) RP Biotech data base; *ii*) ISI Web of Science; *iii*) "*Analisi Informatizzate delle Aziende*" (AIDA). They are briefly described in the following.

RP Biotech data base. It is a collection of Italian firms belonging to the biotech sector according to the OECD definition (see description and detail in the previous chapter). This database collects the firms in activity at the end of 2005, classified according to the OECD criteria; they are 865 firms, of which 501 are for profit firms, 364 are no profit firms. We focus our attention on the life-science for-profit firms, whose total number is 371.

ISI databases, especially the Science Citation Index®, and the web-based version Web of Science® (WoS), provide the best source of information to identify the basic research activity across all countries and fields of science. It is a detailed bibliometric database of journal articles and citations of worldwide research literature that contains 14000 international peer-reviewed scientific and technical journals. Each journal is attributed to one or more WoS-defined Journal Categories.

This source provides a comprehensive coverage of international "main stream" science presented in these research journals. These are primarily English-language journals and biased towards those presenting the findings of basic "academic" research. The coverage of the research literature is reasonable to be (very) good in the case of the industrially relevant fields of science, but limited in the case of the social and behavioural sciences, and very limited for arts & humanities fields.

The bibliographic record of each publication contains information on the author addresses and their institutional affiliations, which enables us to identify the institutional sector of co-authoring partners and their geographic location. The information on the institutional affiliations was cleaned and harmonized; the names of the main organizations were standardized and organizations classified according to their main institutional sector such as: universities, research institutes, hospitals and business enterprises.

We obtained information about publications of the selected firms, across the period 1990-2005. 149 of the considered firms made at least one publication during this period. 3859 is the total number of publications. We assumed that a publication refers to a firm when, among the addresses of the article, there was the address of the firm itself.

AIDA (*from Bureau van Dijk*). It contains balance sheets information of all firms operating in Italy. The data are used to get information, whenever possible, concerning the annual number of employees and the revenues, assumed as *proxies* for firm size, in the period 2001-2005. We collected information about 212 firms.

Methodology

The aim of our analysis is to verify if some characteristics of the firms, specifically their size and age, and the kind of activity mainly conducted (which determines their belonging to a specific OECD category), have an impact on their propensity to publish scientific papers and to collaborate with other partners to produce such publications.

We adopt both a bivariate and a multivariate statistical approach. The bivariate analysis is conducted only for size and OECD typology and it is based on a descriptive comparison of means, while the multivariate analysis is based on inferential procedures. In the latter case, our methodology of analysis consists of regressing the number of scientific publications and co-autorships of the firms against a number of explanatory variables described in the following.

More precisely, we created two different databases for the two different analyses we carried out: determinants of the number of publications; determinants of the number of collaborations in publications.

For the first analysis we used a panel database, whose dimensions are firms (individuals) and years (time); the dependent variable is the number of publications made by the firm *i* in year *t*; independent variables are the different characteristics (size and OECD category) of the firm *i* in year *t*.

For the second analysis we have a cross-section database, whose individuals are the single publications; the dependent variable is the number of institutions - different by the considered firms- whom the authors of the publication belong to (we called this number "collaborations"); the independent variables are the characteristics in year *t* (the year of the publication) of the firm that published the publication *i*[1]. Because the dependent variables are in both cases count variables, we utilised a negative binomial regression.

It must be underlined that data about firms publications and about firm size are collected for different time intervals (respectively: 1990-2005 and 2001-2005). This

is the reason why all the analyses involving firm size (both bivariate and multivariate) are conducted on the shorter interval (2001-2005); regarding the bivariate analyses not involving firm size, the analysis of the relationship between firm typology and number of publication is reported on both periods, while the analysis of the relationship between firm typology and the number of collaborations in publications, as it consists of different tables, is reported for the larger period only. The complete results may be obtained on request.

Variables
The variables included in the final models of our analysis are:

Numpub: it represents the number of scientific articles published by each Italian biotech firm in each year.

Ncoll**:** it represent the number of "collaborations" in each publications, that is the number of institutions with whom the Italian biotech firms co-authored the considered publication.

Employees: number of annual employees.

Then we have the *dummy variables* concerning the OECD class the firms included in our database belong to (they have value 1 if the firm belongs to that typology, 0 otherwise).

Active**:** this variable regards all firms defined active according to OECD taxonomy.

Dedicated**:** this variable regards all firms defined dedicated according to OECD taxonomy.

Innovative**:** this variable regards all firms defined innovative according to OECD taxonomy.

Targeted**:** this variable regards all firms defined targeted according to OECD taxonomy.
R&D: this variable regard all firms defined R&D according to OECD taxonomy.

Other services**:** this variable regards all firms that are defined "other type of services" according to OECD taxonomy.

Finally, we have built the class that includes the so-called "***out****"* firms. These are all the firms that it was not possible to include in any class of OECD taxonomy.

5. Results of the Analysis

5.1 Determinants of the Number of Publications

In analyzing what kind of relation exists between the propensity of a firm to publish a scientific article and its characteristics, we begin our analysis taking into consideration the dimension of the firms.

The classification by dimension has been done using the number of employees (*ne*), in line with the IPI Study[2]. In such a study four typologies of firms were introduced: micro firms (*ne* < 10), small firms (10 ≤ *ne* < 50), medium firms (50 ≤ *ne* < 250), large firms (*ne* ≥ 250).

Firms data are available for the period 2001-2005; therefore we determined the dimension of the firms considering the average number of employees[3] in that period and we considered the total number of publications of the firms in the same years. Table 3 shows the distribution of the firms and their publications within the dimensional classes.

Table 3: Number and percentage of publications by firm size; years 2001-2005

	Firms		Publications		Mean of publications
Micro	40	18.9%	43	3.1%	1.07
Small	62	29.2%	277	20.1%	4.47
Medium	68	32.1%	309	22.4%	4.54
Large	42	19.8%	749	54.3%	17.83
Total	212	100%	1378	100%	6.5

As we can see, in the considered period there is a clear relation between size and number of publications; only between small and medium firm the increase in the number of publications is very small. The large firms have by far the greater propensity to publish (they are 19.8% of the total number of firms but publish 54.3% of the papers). This result may be easily explained: larger firms have more financial resources to devote to research activities, hence increasing the probability to achieve scientific or technological relevant results; allocating great financial means for research often implies large and well-equipped internal laboratories, advanced instrumentation, large researcher team, etc.; besides, larger financial resources, along with the fact that large firms often have seats and laboratories in several places, may be the reason why they are able to activate larger and more diversified research networks. Therefore we may distinguish between the "direct resource effect" (larger firms have greater internal researcher means and this increase the quantity and quality of research) and the "indirect resource effect" (larger firms activate larger networks and this generate more and better research) (Iorio, Labory and Paci, 2007)[4].

Now, in order to better explore this sector and the characteristics of the firms that publish, we can introduce the classification of the firms according to the OECD criteria (illustrated in the second section). In this way, we obtain a scenario about the production of publications by firms belonging to the different OECD categories. In Table 4 we report the average number of publications for each OECD category. Even though we have publications data for a longer period and for a larger number of firms, we restrict here our analysis to the same 212 firms considered before, in order to observe more clearly the relationship between publications, on one side, and different firm characteristics on the other. At the end of this section we replicate this analysis for a longer period.

Looking at the last column on the right of Table 4, we can observe that the firms belonging to the innovative category have the highest mean of publications (12.05), followed by R&D firms (11.31) and by firms belonging to the dedicated category (8.3). There is therefore a significant difference in the propensity to publish across the typologies of firms; the values let to think to a division of the firms, according to the OECD criteria, in two groups: the first one, composed by innovative, dedicated, and R&D firms, is the group that publishes frequently; for the other group, composed by active, targeted, other services and "out" firms, publication is, on average, a quite rare event.

Table 4: Number and percentage of publications by typology of firm; years 2001-2005

OECD classification	N° of firms	% of typology of firms on the total sample	N° of publications	% of publications by firm typology	Mean of publications by firm typology
Active	18	8.5%	93	6.7%	5.17
Dedicated	27	12.7%	224	16.2%	8.3
Innovative	62	29.2%	747	54.2%	12.05
R&D	19	9%	215	15.6%	11.31
Targeted	37	17.4%	50	3.6%	1.35
Other services	10	4.7%	14	4%	1.4
"Out"	39	18.4%	35	2.5%	0.9
Total	212	100%	1378	100%	6.5

It is now useful to cross all the information about the firms, their dimension and their OECD group, to have a complete framework about the biotech firms and their propensity to publish. In this way, we obtain 28 typologies of firms (7 OECD Categories X 4 Dimensional classes) and we calculated the mean of publications for each typology (Table 5; results for "out" firms are omitted).

It is interesting to observe that the typologies of firms having the highest number of publications belong to different dimensional classes and OECD categories: large innovative firms have an average of 29.4 publications, followed by large active firms (17.2), medium R&D firms (16.6), small R&D firms (13.6) and small dedicated firms (12). Therefore, while innovative firms are the most publishing OECD category of firms, this is true on average and for the dimensional class of the large firms, but not for the other dimensional classes. This confirms that dimension and OECD classification should be considered together when we desire to predict the propensity of a firm to publish.

Table 5: Number and percentage of publications by firm size and by typology of firm; years 2001-2005

	ACTIVE		DEDICATED		INNOVATIVE		R&D		TARGETED		OTHER SERV.	
	FIRMS and %	PUB. and mean	FIRMS and %	PUB. and mean	FIRMS and %	PUB. and mean	FIRMS and %	PUB. and mean	FIRMS and %	PUB. and mean	FIRMS and %	PUB. and mean
MICRO	2	0	8	20	5	6	5	4	4	11	5	2
	11%*	*0***	25%	*2.5*	10%	*1.2*	26%	*0.8*	11%	*2.75*	50%	*0.4*
SMALL	3	1	11	132	15	30	7	85	8	2	2	0
	17 %	*0.3*	34%	*12*	24%	*2*	37%	*13.6*	22%	*0.2*	20%	*0*
MEDIUM	8	6	6	50	21	94	7	116	16	26	3	12
	44%	*0.6*	19%	*8.3*	29%	*4.5*	37%	*16.6*	43%	*1.6*	30%	*4*
LARGE	5	86	2	22	21	617	0	0	9	11	0	0
	24%	*17.2*	6%	*11*	34%	*29.4*	0	*0*	24%	*1.2*	0	*0*
TOTAL	18	93	32	224	62	747	19	215	37	50	10	14

* This number represents the percentage of firms identified by dimensional class and OECD category on the number of firms belonging to that OECD category (e.g.: small active firms/ active firms).
** This number represents the mean of publications by each firm identified by dimensional class and OECD category (e.g.. publications of small active firms/number of small active firms).

In order to better understand the effect of both OECD characteristics and dimensions of the firms on the number of publications we introduce a regression analysis. Because the dependent variable, the number of publications, is a count data, the more suitable technique is the negative binomial regression. We run a panel regression with random effects: we cannot use fixed effect because we want to analyze the effects of the characteristics of OECD typologies, that are individual and constant in time.

We estimated the following model:

(1) $$y_{it} = \exp(\mathbf{X}_{it}\,\beta + v_i + \varepsilon_{it})$$

i represents the statistic units (firms)
t represents the years
y_{it} is a vector of observations on the dependent variables (number of publications);
$\mathbf{X}_{it}$ is a matrix of observations on k regressors (employees; OECD categories, inserted as dummy variables: we considered the innovative firms as our benchmark);
β is a vector of unknown parameters;
v_i is a vector of individual-specific errors;
ε_{it} is a vector of stochastic errors.

The results are shown in Table 6.

Table 6: Determinants of the number of collaborations. Results of the negative binomial regression on panel data; years 2001-2005

COVARIATES	Coefficients (p-values P>|z|)
Employees	0.00041*** (0.001)
Targeted	-1.35404*** (0.009)
R&D	0.92437* (0,080)
Active	-0.61875 (0,273)
Dedicated	0.02831 (0.950)
Other services	-1.07445 (0.142)
"Out"	-1.81635*** (0.000)
_constant	0.992535*** (0.003)

STATISTICS	
Number of observations	797 (groups: 212)
Wald Chi2(7)hood	43.22 (prob>chi2: 0.0000)
Log Likelihood	-778.37268
R	1.325976 (st.err.0.239)
S	0.2908933 (st.err.0.053)
Likelihood-ratio test vs. Pooled	chibar2(1) = 279.26 (Prob>=chibar 2=0.0000)

Notes: Dependent variable: number of papers published by each firm each year (*Npub*)
Benchmark category for OECD class: Innovative
*Significant at 90 % level; **Significant at 95 % level; ***Significant at 99 % level;

These results show that firms belonging to targeted and "out" categories publish less then the innovative firms (these result are significant at 99% level of significance), while R&D firms publish more (at 90% level of significance). The employees variable is positive and significant.

Therefore we can confirm what we saw in the previous statistic analysis, but in this case we can conclude that it is true also *ceteris paribus* (equal employees): the belonging of a firm to an OECD category is a determinant of the propensity to

publish and the firm size also has a positive effect on publications. It has to be underlined that the ranking of typologies of firms is not the same in the bivariate and multivariate analysis: the innovative firms on average publish more, but R&D firms show a stronger propensity to publish if we "control" for the firm dimension. This is consistent with the nature of the R&D firms, particularly interested in basic research.

We also considered firm revenue as a proxy of dimension. The previous results are substantially confirmed, even though some parameters for dummy variables become not significant. Then we also tried to test the effects of other variables on the number of publications, such age of the firm and the number of past publications.

The variable age has a positive but not significant effect. This is due to the high correlation of this variable with the number of employees (0.47), that may be obvious if we consider that a firm tends to grow time by time. Considering, instead, the number of past publications (the number of publications of the year before and the number of total past publications) we observe that it has a positive and significant effect, but the introduction of this variable causes the lost of significance of the OECD categories dummy variables.

The previous analysis is based on data about publications and firm characteristics from 2001 to 2005. Indeed we have collected data on publications of a larger period, from 1990 to 2005 and regarding a larger number of firms, 306 instead of 266. Therefore it is possible to conduct an analysis similar to the previous one, without considering the firm characteristics but on a much longer period of time[5].

As we can see comparing Table 4 with the following Table 7, the previous results are substantially confirmed: there are relevant differences in the propensity to publish between different kind of firms, with the prominence of the innovative firms.

Table 7: Number and mean of publications by typology of firm; years 1990-2005

OECD classification	Number of firms	Percentage of typology of firm on the total sample	Number of publications	Mean of publication for each firm typology
Active	24	8	300	12.5
Dedicated	44	14,3	430	9.77
Innovative	76	25	2466	32.45
R&D	42	13,7	370	8.81
Targeted	51	16,6	91	1.78
Other services	18	5,8	31	1.72
"Out"	51	16,6	172	3.37
Total	306	1	3860	12.61

5.2 Determinants of the Number of Collaborations

Our data on firm publications confirm the results of other studies, reported in the third section: collaborations are frequent in the biotech sector. In fact about 83% of publications are made in collaboration with other partners, such as universities, researcher centres, hospitals and other firms. Because of the relevance of the phenomenon, we want to explore in which way the belonging to different classes of OECD influences the propensity to collaborate in publications. This analysis makes it possible to analyze an aspect of the complexity of the biotech sector. In fact, as a first consideration, we observe some differences in the propensity to collaborate. The percentage of collaborations goes from 78% for the R&D firms, to 96% for the targeted firms (Table 8).

Table 8: Collaboration in publications by typology of firm; years 1990-2005

Tipology of firms	N° publications	Publications in collaboration	Percentage of publications in collaboration
Active	300	273	91%
Dedicated	430	349	81%
Innovative	2466	2034	82%
R&D	370	287	78%
Targeted	91	87	96%
Other services	31	28	90%
"Out"	172	153	89%
Tot	3860	3211	83%

Now we conduct this analysis more in depth, exploring not only the number of collaborations of each typology of firms, but also who are the actors of these collaborations. On a geographic point of view, we conducted our analysis at an "aggregate" and "disaggregate" level: at the aggregate level we consider the institutions without specifying their location, while at the disaggregate level we specify if they are regional (the collaborator is located in the same region of the considered firm), Italian (the collaborator is located in Italy, but in a different region from the considered firm) or abroad (the collaborator is located abroad).

In Table 9 we show for each OECD class the number of collaborations in publications with the different actors (aggregate level). We observe that all typologies of OECD classes collaborate frequently with all actors. Overall the Italian biotech firms collaborate more frequently with universities, then with hospitals, research centres and other firms. Considering the single typologies of firms there are some exceptions, that emerge with evidence from Table 10, where we show the percentage, for each OECD class, of collaborations with each actor on the total number of collaborations[6]. We observe that the targeted and the active firms collaborate more frequently with hospitals then with universities: this is consistent with their nature and their goals, more directed to the commercialization of products than to pure research. The opposite holds for R&D firms: we observe that they have more collaborations with research centres than with hospitals; as the kind of research done in research centres is much more basic then in hospitals, even this result is consistent with the nature and goals of such firms.

Table 9: Distribution of collaborations by typology of firms; years 1990-2005

	Active	Dedicated	Innovative	R&D	Targeted	Other services	"Out"	Total
Univ	327	444	2537	387	94	37	171	3997
CR	43	192	695	140	18	1	48	1137
Hosp	401	222	1073	120	140	24	147	2127
Firm	44	93	545	84	14	7	20	807
Tot n° of collab	815	951	4850	731	266	69	386	8068

Table 10: Percentage of collaborations by typology of firms; **years 1990-2005**

	Active	Dedicated	Innovative	R&D	Targeted	Other services	"Out"	Total
Univ	40%	47%	52%	53%	35%	54%	44%	50%
CR	5%	20%	14%	19%	7%	1%	12%	14%
Hosp	49%	23%	22%	16%	53%	35%	38%	26%
Firm	5%	10%	11%	11%	5%	10%	5%	10%

As a further step of our analysis, in Table 11 we report, for each OECD class, the mean of collaborations for each publication (that is: the average number of actors with whom the firms have collaborated to produce each article). We observe that targeted firms on average collaborate with the highest number of actors (2.92), followed by active, "out", other services, dedicated, R&D and innovative firms (1.97).
If we look from the side of each actor, we observe that the highest mean value is registered by universities (1.04) following by hospitals (0.55), research centres (0.29) and firms (0.21).

Besides, observing the different propensity of each OECD kind of firm to collaborate with the four kind of actors, we observe the high number of collaborations with research centres for dedicated and R&D firms and the high number of collaborations with hospitals for targeted and active firms: this is consistent with the previous analysis (results of Tables 9 and 10). There are not relevant differences in the number of collaborations with universities and firms.

Table11: Mean of collaborations for each publication by typology of firm; years 1990-2005

	Active	Dedicated	Innovative	R&D	Targeted	Other services	Out	Total
Univ	1,09	1,03	1,03	1,05	1,03	1,19	0,99	1,04
CR	0,14	0,45	0,28	0,38	0,20	0,03	0,28	0,29
Hosp	1,34	0,52	0,44	0,32	1,54	0,77	0,85	0,55
Firm	0,15	0,22	0,22	0,23	0,15	0,23	0,12	0,21
Total	2,72	2,21	1,97	1,98	2,92	2,23	2,24	2,09

Repeating the same analysis at the disaggregate level, in Table 12 we show, for each OECD class, the number of the total collaborations in publications with the different actors, in this case divided according to their location.

As we can see, the highest number of collaborations with the universities is with the Italian universities (2040), followed by foreign universities (1003) and regional (located in the same region of the firm) universities (954). Regarding the hospitals, the highest number of collaborations is with the Italian hospitals (1140), then with the foreign hospitals (551) and finally with the regional hospitals (430). The number of collaborations with the Italian research centres is greater respect to the collaborations with the regional and foreign research centres, (477, 425 and 235, respectively). Finally the highest number of collaborations with other firms is with the foreign firms (481), then with the Italian and regional firms (189 and 137).

Looking at the single OECD categories, we observe some peculiarities (results are shown in Table 12): the active, targeted and "out" firms collaborate more frequently with the Italian hospitals then with the Italian universities; regarding the R&D firms, we observe that they have more collaborations with the Italian research centres than with Italian hospitals.

Table 12: Number of collaborations at a disaggregate level by typology of firm; years 1990-2005

	Active	Dedicated	Innovative	R&D	Targeted	OS	Out	Tot
Univ Reg	81	99	**599**	89	9	30	47	954
Univ ITA	193	237	**1272**	170	82	5	81	2040
Univ Abr	53	108	**666**	128	3	2	43	1003
CR reg	6	58	**263**	84	10	0	4	425
CR ita	26	79	**296**	31	5	1	39	477
CR abr	11	55	**136**	25	3	0	5	235
Hosp Reg	59	39	**239**	33	26	3	37	436
Hosp ITA	292	93	**514**	37	112	7	85	1140
Hosp Abr	50	90	**320**	50	2	14	25	551
Firm Reg	7	21	**80**	18	8	1	2	137
Firm ITA	13	22	**127**	16	1	2	8	189
Firm Abr	24	50	**338**	50	5	4	10	481
Tot n° collab	815	951	4850	731	266	69	386	8068

Pursuing the analysis, Table 13 shows, for each OECD class of firm, the percentage of collaborations with each actor on the total number of collaborations. We notice that the dedicated, innovative and R&D firms collaborate mainly with the Italian universities, while the active, targeted and "out" firms collaborate more frequently with the Italian hospitals; the other services firms with regional universities.

Other observations seem interesting: the relatively high propensity of the R&D firms to collaborate both with foreign universities and local research centres; the low percentage of collaborations with Italian hospitals of dedicated, innovative and targeted firms; the almost constant percentage of collaborations with Italian universities across almost all groups (other services being the only exception); the

high concentration of collaborations with universities of the targeted firms in the extra-regional dimension, with very low percentages of collaborations both with regional and foreign universities.

Table 13: Percentage of collaborations at a disaggregate level by typology of firm; years 1990-2005

	Active	Dedicated	Innovative	R&D	Targeted	Other Services	Out	Total
Univ Reg	10%	10%	12%	12%	3%	43%	12%	12%
Univ ITA	24%	25%	26%	23%	31%	7%	21%	25%
Univ Abr	7%	11%	14%	18%	1%	3%	11%	12%
CR reg	1%	6%	5%	11%	4%	0%	1%	5%
CR ITA	3%	8%	6%	4%	2%	1%	10%	6%
CR Abr	1%	6%	3%	3%	1%	0%	1%	3%
Hosp Reg	7%	4%	5%	5%	10%	4%	10%	5%
Hosp ITA	36%	10%	11%	5%	42%	10%	22%	14%
HospAbr	6%	9%	7%	7%	1%	20%	6%	7%
FirmReg	1%	2%	2%	2%	3%	1%	1%	2%
Firm ITA	2%	2%	3%	2%	0%	3%	2%	2%
Firm Abr	3%	5%	7%	7%	2%	6%	3%	6%

Even for the mean of collaborations for each publication, we replicate the analysis at a disaggregate level. We calculate, for each OECD class, the mean of collaborations for each publication (that is: the average number of actors, divided into regional, Italian and abroad categories, with whom the firms collaborated to produce each publication). The results, reported in Table 14, show that the targeted firms are the category with the highest mean of collaborations, while the R&D and the innovative firms have the lower mean.

Looking at the partners with whom each OECD class of firm collaborate, we observe that the highest mean value of collaborations for the active firms is with the Italian hospitals and the same happens for the targeted firms and the "out" firms. For the dedicated firms the highest mean value of collaborations is with the foreign universities, like for the innovative and R&D firms; the other services firms have the highest mean value of collaborations with the regional universities.

Table 14: Mean of collaborations at a disaggregate level for each publication by typology of firm; years 1990-2005

	Active	Dedicated	Innovative	R&D	Targeted	Other Services	Out	Tot
Univ Reg	0,27	0,23	0,24	0,24	0,10	0,97	0,27	0,25
Univ ITA	0,64	0,55	0,52	0,46	0,90	0,16	0,47	0,53
Univ Abr	0,18	0,25	0,27	0,35	0,03	0,06	0,25	0,26
CR reg	0,02	0,13	0,11	0,23	0,11	0,00	0,02	0,11
CR ita	0,09	0,18	0,12	0,08	0,05	0,03	0,23	0,12
CR abr	0,04	0,13	0,06	0,07	0,03	0,00	0,03	0,06
HospReg	0,20	0,09	0,10	0,09	0,29	0,10	0,22	0,11
Hosp ITA	0,97	0,22	0,21	0,10	1,23	0,23	0,49	0,30
Hosp Abr	0,17	0,21	0,13	0,14	0,02	0,45	0,15	0,14
Firm Reg	0,02	0,05	0,03	0,05	0,09	0,03	0,01	0,04
Firm ITA	0,04	0,05	0,05	0,04	0,01	0,06	0,05	0,05
Firm Abr	0,08	0,12	0,14	0,14	0,05	0,13	0,06	0,12
Tot	2,72	2,21	1,97	1,98	2,92	2,23	2,24	2,09

Now we want to analyze if this framework holds also *ceteris paribus.* In other words, trough a regression analysis on the cross section data, we explore if the belonging to an OECD class rather then to another is relevant for the propensity to collaborate, even "controlling" for the dimension of the firms, measured, like in the previous analysis, with the number of employees. Also in this case the dependent variable (the number of collaborations for each publication) is a count variable, then the negative binomial regression is the best technique to adopt.

The estimated model is:

(2) $$y_i = \exp(\mathbf{X}_i \beta + \varepsilon_i) \qquad i : 1, 2, \ldots n$$

Where:
i represents the statistic unity (the publication);
y is a vector of observations on the dependent variables (number of collaborations);
X is a matrix (n x k) of observations on k regressors (employees; OECD categories, inserted as dummy variables: we considered the targeted firms as our benchmark);
β is a vector (k x 1) of unknown parameters;
ε is a vector (n x 1) of stochastic errors.

The results of the estimation are shown in Table15.

Table 15: Determinants of the number of collaborations. Results of the negative binomial regression on cross-sectional data; years 2001-2005

COVARIATES	Coefficients (p-values P>|z|)
Employees	0.00010*** (0.002)
Innovative	-0.28112** (0.036)
R&D	-0.41678*** (0.004)
Active	-0.01208 (0.489)
Dedicated	-0.25596* (0.068)
Other Services	-0.54484* (0.055)
"Out"	-0.25319 (0.200)
_constant	1.10171*** (0.000)

STATISTICS	
Number of observations	1150
Pseudo R^2 (McFadden)	0.0059
LR Chi2(7)	27.05 (prob>chi2: 0.0003)
Log Likelihood	-2263.1215
Alpha	Coeff.= 0.27247°
Likelihood-ratio test of alpha=0	chibar2(1) = 279.26 (Prob>=chibar2=0.0000)

Notes: Dependent variable: number of collaborating institutions for each publication (*Ncoll)***.**

Benchmark category for OECD class: Targeted

P-values (P>|z|) for coefficients in brackets, except where differently specified.

*Significant at 90 % level; **Significant at 95 % level; ***Significant at 99 % level;

These results show that the targeted firms (the benchmark category) have more collaborations than the other OECD classes also *ceteris paribus*, considering the dimensional variable. This result is significant (at least at 90% level of significance) for 4 OECD classes: R&D, innovative, dedicated, other services; in the other cases the coefficients are not significant.

These results are consistent with the goals of each typologies of firms. In fact, if we look to the targeted firms, as said in the second section, their main goal is to find firms engaged in key biotechnology activities, wherever they are currently classified; therefore it is obvious that this is the typology of firm with the highest number of collaborations.

We can conclude that the dimensional variable is significant, such as the number of collaborations grows with the dimension of the firms, but the difference in the number of collaborations among the OECD classes does not depend exclusively by the dimension of the firms.

5.3 Synthesis of the Results

In this section we have underlined the importance of introducing the OECD classification of the firms belonging to the Italian biotech sector to explain an aspect of its complexity. In particular we have shown the different behaviour of the firms in relation to the knowledge disclosure and the production of new knowledge, through the analysis of the propensity to publish scientific articles and the propensity to collaborate to make them.

The descriptive analysis regarding the propensity to publish let us to obtain two main groups: the first one, composed by innovative, dedicated and R&D firms, has an high mean of publications; the second one, composed by targeted, active, other services and "out" firms, has a considerably lower mean of publications.

This result helps to understand that the propensity to publish depends on the different goals and characteristics of each firm belonging to the biotech sector. In fact the firms belonging to the first group are strictly connected to basic research and this kind of research is more oriented to publication then applied research (Grinnel, 1992): the innovative firms have specific dedicated laboratories of research; the R&D firms are based on the research and the dedicated firms were born mainly with the goal to make a research, due to the fact that they frequently are spin offs from university.

The typologies of the second group are quite far from basic research; in fact, the active firms are based more on the application of biotech, the targeted firms have as their main core business the sale of products; the other services, although biotech firms, have a core business different from the other ones.

We also considered the dimension of the firms as a determinant of the number of publications and we found a clear correlation between size and the number of publications. This correlation holds even when we consider the number of employees as a *proxy* for firm size.

As the innovative firms, the most publishing category, are on average the largest typology of firms, we could think that the typology is not itself a determinant variable of the propensity to publish. But, conducting a regression analysis using a panel data with information on the characteristics of the firms in the period 2001-2005, we obtained a similar result to the descriptive analysis. Therefore we may conclude that both typology and size are *ceteris paribus* determinant on the propensity to publish.

Another important aspect to consider in order to evaluate the position of the firms regarding the knowledge disclosure is the propensity to collaborate in the production of scientific articles. We obtained that, as for the propensity to publish, different kinds of biotech firms have a different behaviour, but with a turnaround respect to the previous analysis. In other words, the targeted firms, although they have a low number of publications, have the highest propensity to collaborate with other actors and in particular with the hospitals. This behaviour is justified by the core business of this typology of firm, that is the sale of the biotech products and, considering that the main customers are the hospitals, it is obvious to expect that they have many collaborations with them.

We can conclude this synthesis with a brief framework of the firms, considering all their characteristics. The innovative firms are larger then the others, have more publications but less collaborations respect to all the other categories of firms. Universities are the actors with whom they collaborate more frequently.

The R&D firms are mainly small firms but the medium firms publish more. The propensity to publish is high, second only to the targeted firms (but they are first if we control for firm size). Universities are the actors they collaborate more frequently with and it is worth noting the propensity to collaborate with foreign universities; they also collaborate much with research centres, particularly local ones.

The dedicated firms are mainly micro firms but small firms publish more. They also publish more frequently with the universities. The targeted firms have the highest propensity to collaborate, especially with hospital, but they have a low propensity to publish; among them, the medium firms have the highest propensity to publish. The active firms have an high propensity to collaborate, second only to the targeted firms. Among active firms, large firms are particularly productive in terms of publications.

6. Conclusions

This work is focused on the analysis of a sector that is unanimously considered as leading in the contemporary knowledge driven economy. More specifically, this paper aims to explore the complexity of the biotech sector, characterized by an high level of knowledge intensity, an high degree of heterogeneity and an high level of dynamism. We tried to manage this complexity trough the analysis of the propensity to disclose knowledge by the different typologies of firms belonging to this sector.

In order to realize this kind of analysis we based on a previous work (D'Amore and Vittoria, 2006, 2008 and 2009) that, moving from the problems of definition and classification of the Italian biotech sector, ends up with the creation of an original database, including all the Italian biotech firms, classified according to some typologies, defined by the OECD, that should underline different characteristics of the biotech firms, mainly their fundamental activity. We wanted to know if and how such characteristics influence the behaviour of the biotech firms. In order to give an answer to this question we analyzed a relevant theme in a knowledge intensive and science based sector, that is the propensity of firms to publish a scientific article and to collaborate with research institutions or with other firms to make it; we also took into account size and age of the firms, being characteristics typically considered important in determining the behaviour of a firm. We crossed

information coming from different sources: an original database including all the Italian biotech firms active in 2005 classified according OECD criteria; data on publications (period 1990-2005); data on firm size and age (period 2001-2005).

Our first analysis on the propensity to disclose knowledge, based on the number of publications made by each firm, showed that the firms, although all defined as biotech firms, have a different behaviour, because their specific goals are different. Indeed, the propensity to publish is different according to the different OECD typologies. In particular, we may identify two groups: the first one is composed by biotech firms that are interested in the basic research (innovative, dedicated and R&D) and that show an high propensity to publish; the second one is composed by firms that are more far from basic research and so have a low propensity to publish (active, targeted, other services). Thanks to the econometric analysis, we can observe this behaviour also *ceteris paribus*, considering the dimensional variables, that is also very important in determining the propensity to publish.

We also analyzed the propensity to collaborate, considering the number of collaborations in publications. Also this analysis shows that the firms have a different behaviour according to their typology; indeed this analysis shows a different behaviour of the firms respect to the previous analysis. In particular, we observe that the targeted firms have a low propensity to publish but have the highest propensity to collaborate, in particular with the hospitals. This fact can be justified by the core business of this typology of firm, that is the sale of the biotech products and, considering that the main costumers are the hospitals, it sounds as obvious that they have many collaborations with them. Also the regression analysis confirms this result, again controlling for the firm size.

These results have some consequences also in terms of policy. A knowledge based economy and particularly a knowledge based sector, like biotechnology, requires fine tuned policies to implement innovative capacity. A key topic of a modern innovation policy is surely the increase of the incentives to collaborate in research and to diffuse the knowledge achievement. Our analysis about the different approach inside the biotech sector to these issues induces us to think that the policies to adopt in relation to the collaboration in research and to the dissemination of its results should be different in relation to the different typologies of firms. A complex and differentiated sector requires differently modulated policies.

Acknowledgements

This paper is the result of a strict collaboration between the authors. Nevertheless, sections 2, 3 and 5.1 may be mainly attributed to Rosamaria D'Amore; sections 4, 5.2 and 5.3 may be mainly attributed to Roberto Iorio; the Introduction and the Conclusions have been jointly written. We are very grateful to prof. Pasquale Persico, who gave the initial input to this research.

Endnotes

[1] It would have been possible to make the two analyses homogeneous, creating a panel data for collaborations too, calculating the number of total or average collaborations for each firm each year; but, in studying the propensity to collaborate, our opinion is that the relevant variable is the average number of

collaborations for each publication: using the other variable (number of collaboration for each firm each year) there is a bias against those firms that publish less frequently (e.g. they have many years without publications), but, when they publish, they collaborate with a lot of partners.

[2] IPI is the firm's institute of promotion.

[3] More precisely, because of several and not uniforms lacks of data, we calculated a central value of the number of the employees, given, for each firm, by the mean between the minimum and maximum value in the five year period.

[4] The same study by Iorio, Labory and Paci (2007) refers of an high quality (measured by the received citations) of the publications done by the small (but not micro) firms: it is possible that they decide to publish a scientific article only when the article has a high scientific value (Penin, 2007). In other words, it could be reasonable to think that small firms, especially in a very dynamic and innovative sector like biotechnology, can be more efficient in the production of scientific and basic knowledge than large firm: this may be called the "efficiency effect". This leads therefore such firms to publish a low number of scientific articles, even of high quality.

[5] For this kind of analysis, we worked on a database including only the firms that, in the period 1990-2005, have at least one publication or have at least one annual data about employees or revenue.

[6] For instance, considering the active firms, 40% of actors they collaborate with are universities, 5% are research centres, 49% hospitals, 5% other firms.

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