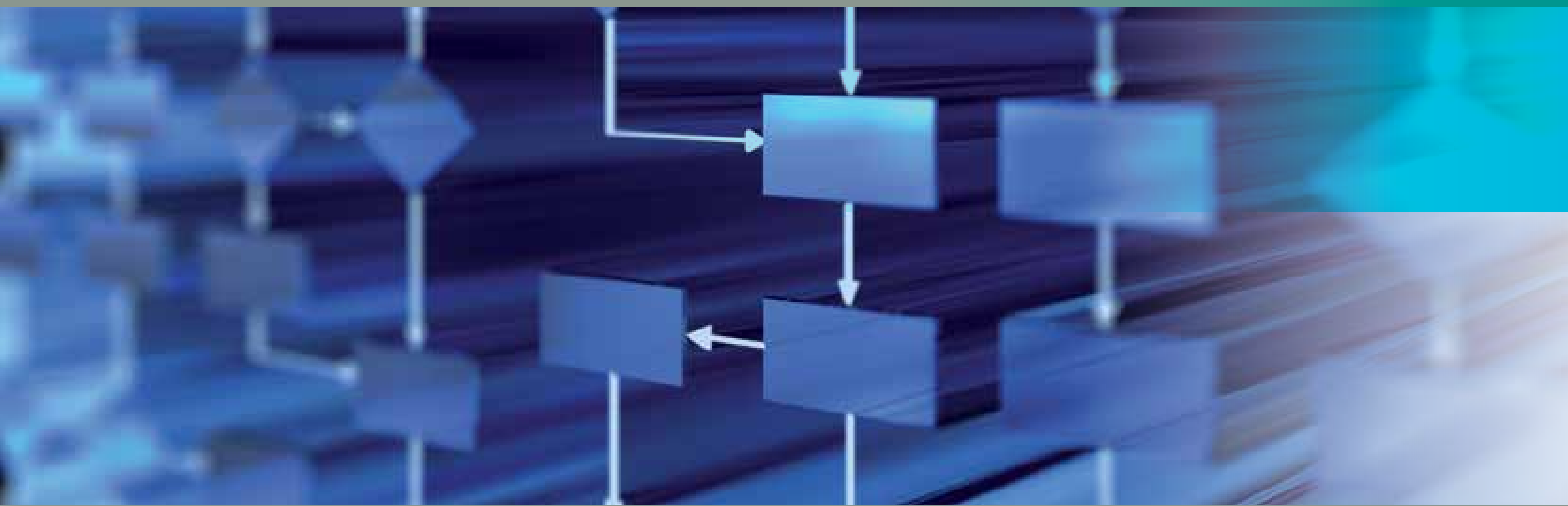

WIPO Economics & Statistics Series April

2013

Working Paper No. 6

What makes companies pursue an open science strategy?

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August 2012

Abstract

Whereas recent scholarly research has provided many insights about universities engaging in commercial activities, there is still little empirical evidence regarding the opposite phenomenon of companies disseminating scientific knowledge. Our paper aims to fill this gap and explores the motivations of firms that disclose research outcomes in a scientific format. Besides considering an internal firm dimension, we focus particularly on knowledge sourcing from academic institutions and the appropriability regime using a cost-benefit framework. We conduct an econometric analysis with firm-level data from the fourth edition of the French Community Innovation Survey (CIS4) and matched scientific publications for a sample of 2,512 R&D performing firms from all manufacturing sectors. The analysis provides evidence that the access to important scientific knowledge imposes the adoption of academic disclosure principles, whereas the mere existence of collaborative links with academic institutions is not a strong predictor. Furthermore, the results suggest that overall industry conditions are influential in shaping the cost-benefit rationale of firms with respect to scientific disclosure.

Keywords: R&D, Industrial Science, Knowledge Disclosure, University-Industry collaboration

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The views expressed in this paper are those of the authors, and do not necessarily reflect those of the World Intellectual Property Organization or its Member States. The usual disclaimer applies.

1 Introduction

The boundaries between the traditionally distinctive worlds of science and technology are becoming more and more porous. On the one hand, universities and public research institutions are not only contributing to the scientific discourse but also becoming involved in the commercialization of research results, leading to increasing numbers of university patents (Azoulay et al., 2007; Geuna and Nesta, 2006). The inventions originating from university research are used to generate additional funding via licensing and are regarded as an indicator of successful technology transfer. On the other hand, many profit-orientated companies are contributing to scientific literature via publications in peer-reviewed journals, and their contributions are often of a high standard (Hicks, 1995; Stephan, 1996; Godin, 1996; Lim, 2004). However, generic research and scientific publications by firms are counterintuitive since competitors might benefit from the disclosed knowledge. This raises the question as to which benefit expectations are relevant for firms in order to pursue a strategy of scientific disclosure. In practical terms, such an “Open Science” (OS) strategy implies that firms allow or even encourage their researchers to publish research outcomes in scientific journals or conference proceedings.

In her seminal work, Hicks (1995) identifies several potential reasons from a theoretical point of view. However, with a few notable exceptions (Stern, 2004; Ding, 2011; Polidoro and Theeke, 2011), there is still little empirical evidence concerning the motivations and drivers that actually lead firms to publish in a scientific format. Looking at the wider literature examining various aspects of science-based firms (e.g. Gittelman and Kogut, 2003; Cockburn and Henderson, 1998; Liebeskind et al., 1996; Zucker et al., 2002), studies also mainly focus on the pharmaceutical and biotechnology sectors while other R&D performing areas are much less covered. This paper intends to fill these gaps with an econometric analysis of the determinants of an OS strategy. We use firm-level information from the fourth edition of the French Community Innovation survey (CIS4) and matched scientific publication data from Elsevier’s Scopus database on a sample of 2,512 manufacturing firms. In our analysis, which is based on a simple cost-benefit framework, we examine the impact of three major dimensions on the scientific openness of firms. These concern not only internal research activities as the origins of an openness strategy but explicitly consider external drivers that shape the firm’s decision, namely interactions with academic institutions and the appropriability regime on the sector level.

One of the first findings of this paper is that scientific publications are not only originating from the pharmaceutical and biotech industries but from almost every sector. Particularly the communication equipment, medical instrument and transport equipment sectors have high proportions of publishing firms as well. In the econometric analysis, we find that firms with higher R&D intensities publish more frequently and larger quantities. Concerning links to academic institutions, firms publish more if interaction-based academic knowledge sources are regarded as important, whereas the mere existence of collaboration agreements has only little impact. Finally, our results concerning the sector appropriability conditions suggest that lower spillover levels and the higher use of legal protection instruments increase the frequency of scientific publications, while the use of strategic instruments has no apparent effect. We interpret these findings as indicative for the main drivers of scientific disclosure strategies and argue that the discovered relationships fit at least partially an open science paradigm. In particular, the sourcing of scientific knowledge does not only encourage firms to increase their absorptive capacity but promotes scientific disclosure practices in firms.

The remainder is organized as follows. Section 2 provides a literature review regarding scientific publications originating from companies. The framework of analysis and theoretical discussion is presented in Section 3. In Section 4, data sources, variables and descriptive statistics are presented while the econometric design is discussed in Section 5. In Section 6, regression results are displayed and discussed. Section 7 highlights robustness tests before conclusions, limitations and opportunities for future research are presented in Section 8.

2 Scientific Publications by Firms

As a matter of fact, companies need to generate sufficient financial returns from their R&D investments in order to secure their long-term survival in a market economy. This implies a more applied orientation for corporate research than for university research (Aghion et al., 2008; Nelson, 1959). Apart from the different scope of research activities in comparison to industry, "Open Science" (OS) is based on different reward mechanisms encouraging the rapid disclosure of new knowledge (Merton, 1973; Hagstrom, 1965; Dasgupta and David, 1994). Only those authors that provide new and original insights receive recognition from the scientific community and develop a good reputation. Based on their reputation, scientists can attain further career achievements like tenure or research grants (Dasgupta and David, 1994; Latour and Woolgar, 1979). Beyond the perspective of the individual scientist, disclosure also enables follow-on work to be done by other researchers in the field. Due to the importance of disclosure in the academic reward system, scientific publications represent a key component of OS. From a firm perspective however, voluntary disclosure is counterintuitive since competitors may access and utilize the knowledge as well (Arrow, 1962).

Given that firms may use legal intellectual property instruments for the same knowledge in parallel (see Murray, 2002), the question is if scientific publications by firms represent an equivalent openness as publications originating from academic institutions. Assuming a sufficient content overlap between the publication and the patent, which is likely to vary in practice, other firms cannot utilize the disclosed knowledge (see Murray and O'Mahony, 2007). The publication may still be informative, stimulate follow-up research beyond the particularly protected area or potentially even reveal additional knowledge due to comprehensive documentation requirements imposed by scientific journals, but direct benefits for other firms are typically limited. On the contrary, for the audience group of academic scientists, a parallel patent application should not impose serious restrictions for cumulative follow-on work unless the academic researchers are also "costumers" of the research outcomes that are protected by patents[3]. As Walsh et al. (2007) document in a survey that targeted academic researchers in biomedicine, patents are not regarded as an impediment for academic research in contrast to strategic behavior like withholding information or not sharing research inputs, which should apply to the domain of academic and commercial research in a similar manner (see also Vallas and Kleinman, 2008). However, if firms also seek patent protection, the scientific equivalent can be regarded as less open than described in the Mertonian ideal of scientific practice ("communalism"). On the other hand, the existence of a scientific contribution should still represent a greater openness than resorting to patent protection only. Moreover, this is also true for the interpretation of openness in the Open Innovation literature, which widely neglects the phenomenon of voluntary contributions to the public knowledge stock (see Dahlander and Gann, 2010).

In addition to potential spillover effects and costs of conducting generic research with its uncertain outcomes, there are further reasons that should make scientific openness a costly strategy for firms. The disclosure process itself contains opportunity costs since the researchers have to prepare their publications to meet the respective requirements of target journals, which may include, for instance, comprehensive documentation of experiments or responding to reviewer's queries (Penin, 2007; Kinney et al., 2004; Liu and Stuart, 2010). In this respect, the requirements should usually become more stringent the higher the journal quality. Regarding the firm's R&D incentive structures, an orientation of the firm towards OS with publication incentives for the firm scientists may lead to agency conflicts. The scientists might devote too much effort to generic research and corresponding disclosure activities but no longer commit themselves sufficiently to converting the results into applied outcomes if the internal reward systems are not balanced (Cockburn et al., 1999; Gittelman and Kogut, 2003). Finally, scientists who publish are more visible for competing firms, which may impose the necessity to establish costly retention policies to reduce outgoing job mobility (Liu and Stuart, 2010; Kim and Marschke, 2005).

[3] A well-known example is the "Oncomouse", where the firm DuPont patented an important input to biomedical research. Since academic scientists could not get these genetically manipulated mice without infringing the patent, Murray et al. (2009) argue that academic research was hampered by the monopolistic prices applied by DuPont.

The potential benefits of scientific disclosure are various and concern both knowledge creation and diffusion. The seminal paper of Hicks (1995) highlights several potential benefits and therefore serves as an important starting point for analyzing motivations. One reason lies in the possible desire of firms to be very closely connected to academic scientists and be part of the wider scientific community. By maintaining personal contacts with academic researchers, firms may be able to obtain the latest knowledge that has not even been published yet. Firms that publish can build up credibility thanks to their contributions and subsequently gain entrance to the respective scientific communities (Hicks, 1995; Rosenberg, 1990).

As regards socialization processes and firm cultures, Ding (2011) shows that strong scientific backgrounds of biotech start-up founders have a positive effect on the adoption of an OS strategy. Moreover, companies can use scientific publications as an instrument to hire and motivate researchers (Stern, 2004; Hicks, 1995). Even though the characteristics of academic scientists and their counterparts in firms vary in some ways, scientists in industry often share similar values and are concerned about their reputation (Sauermann and Stephan, 2012). Correspondingly, Stern (2004) and Sauermann and Roach (2011) reveal that many scientists on the job market are willing to accept lower salaries in order to receive the right to publish. This indicates that firms offering their researchers the concession to publish enjoy advantages in hiring, motivating and retaining those with an academic mind-set[4].

Moreover, signaling strategies can also target the audience groups of public funding authorities, regulatory bodies or professional customers. With disclosure in scientific journals, companies may gain access to public funding since firms signal their capability to use R&D funding effectively (Penin, 2007). The reverse logic may also apply since R&D subsidies are often bound to certain disclosure requirements although not necessarily in a scientific format (see EC, 2003). This may also apply to regulatory frameworks, which may require firms to provide scientific evidence that supports their claims, for instance, through clinical trials in the case of drug development (Hicks, 1995). In the pharmaceutical industry, scientific publications could also prove a useful instrument to encourage physicians to adopt a new drug. In this regard, Polidoro and Theeke (2011) show that pharmaceutical firms are more inclined to publish when more substitutes are available and other firms also publish about their drugs targeting the same therapeutic application. In addition, scientific articles and conference proceedings may be helpful to set standards when companies are competing for different alternatives in network industries (Penin, 2007).

With regard to the appropriation of inventions and intellectual property, publications in scientific or technical journals can be a means of maintaining the freedom to operate in very competitive environments where firms are engaging in patent races. Through disclosure in scientific journals, the patentability of the knowledge can be restricted for competitors since a new state of the art is created which increases the novelty requirements of subsequent inventions (De Fraja, 1993; Parchomovsky, 2000; Dell Malva and Hussinger, 2012).

[4] The authors Sauermann and Roach (2010, 2011) also emphasize that not all firm scientists have to desire to publish since PhD graduates with a particular strong developed academic mind-set and research abilities tend to select into academic jobs. This aspect is further discussed in section 3.1

3 Cost-benefit Considerations behind Scientific Disclosure

Given the variety of potential motivations for firms to publish in a scientific format, we propose a more specific framework. Scientific publications by firms can be seen as the outcome of a process evaluating the benefits and costs of this particular type of disclosure. Within our framework, the benefits concern the firm's own scientists and the access to academic knowledge whereas the costs lie in the appropriability regime since it may reduce or enhance the harmful spillover effects of disclosure.

3.1 Internal Research Activities

The production of relevant knowledge can be seen as a precondition for disclosing results in scientific journals and subsequently realizing benefits from this strategy. The more resources a firm commits to internal R&D and particularly to the research component, the more outcomes are likely to be eligible for scientific publishing (Adams and Clemmons, 2008). It should be borne in mind that R&D investment levels are not a purely exogenous choice but also depend on external knowledge flows that can be absorbed (Cohen and Levinthal, 1989). With regard to the composition of R&D, not only outcomes of pure basic research are suitable for publishing but also those deriving from more applied projects, which potentially provide fundamental insights as well (Stokes, 1997; Murray, 2002).

In addition, it can be argued that internal R&D implicitly captures the preferences of the R&D personnel. The production of internal knowledge is associated with the employment of a certain number of highly qualified scientists and engineers. As briefly mentioned in the previous section, scientists in firms often share norms and values that they have acquired thanks to their years of education and employment in academic institutions. Many industry scientists are concerned about academic values like reputation and autonomy and show similar motivations to those of their academic colleagues (Sauermann and Stephan, 2012; Stern, 2004; Ritti, 1968). In this sense, the relative importance of R&D in the firm may capture not only the eligible outputs but also a relative degree of scientific openness. As recent evidence shows, not all firm scientists have a "taste" for science. Sauermann and Roach (2011) found that around 20% of PhD students in the life sciences do not assign any amount to the right to publish when asked for a hypothetical wage in the private sector. This share increases to over 30% for those PhD students with a clear preference for an industrial career. While these numbers suggest that a majority of future firm scientists do value publication possibilities, it also shows that a notable minority does not. Additionally, it may be suspected that the share of those scientists is even larger in other (more applied) areas than life sciences.

However, from the perspective of our framework we would like to stress that it is not the ex-ante preferences of scientists that are tackled but the observed equilibrium within the firms, which is also a function of labor market conditions and the preferences of the companies. Concerning this specific labor market segment, Cyranoski et al. (2011) depict quite a pessimistic perspective for PhD graduates with an academic orientation.

While graduate numbers are increasing, there is a substantial scarcity of tenure-track positions. Consequently, even scientists with a preference for an academic career are often forced to search for industrial research positions. In the light of Sauermann and Roach's findings that the preference for publication is positively connected with a scientist's abilities, it appears likely that a further crowding out occurs where low-ability scientists may not even obtain industrial research positions but have to choose other private sector alternatives like consulting. From a firm-level perspective, the influence of firm scientists on scientific disclosure may either reflect that intrinsically motivated boundary spanners have been intentionally hired or simply that higher ability scientists (who tend to value publishing more) can be hired for comparatively lower wages (see Stern, 2004). In the end, no matter which mechanism applies: given the preferences for publication for a majority of scientists, more R&D intensive companies are endowed with higher shares of scientists in comparison to other employees and should therefore have a higher affinity for scientific practices.

Lastly, it should be stressed that the firm's benefits regarding disclosure are likely to go beyond the sustaining of motivation and the hiring opportunities, for instance marketing effects on professional customer groups (Polidoro and Theeke, 2011) or defensive publishing in order to maintain the freedom to operate. However, these motivations are also reflected to some extent in the firm's investments in internal knowledge creation since, for example, the potential use of defensive publishing is dependent on inventions (or at least intermediate research results) deriving from R&D activities.

3.2 Interactions with Academia

Many innovating firms rely not only on internal knowledge creation but also integrate external sources for their innovation process. Suppliers, consumers and also public science institutions can serve as important information sources for innovation projects (Chesbrough, 2003; Laursen and Salter, 2006). Particularly in some knowledge intensive industries, the academic sciences represent an important knowledge source for the generation of inventions (e.g. Cohen et al. 2002; Laursen and Salter, 2004; McMillan et al., 2000; Rosenberg and Nelson, 1994; Fleming and Sorensen, 2004). Here, different channels are available and considered important, ranging from passive sources like scientific literature to interaction-based links (Cohen et al., 2002; Arundel and Geuna, 2004).

To begin with, the exploitation of scientific journals requires no more than public library access or subscribing to some particularly relevant journals, and a certain knowledge base of the firm scientists to understand the content and methodology of the articles. As a matter of fact, passive sourcing does not per se impose any openness on the firm. Another mode of knowledge sourcing from academic institutions is interaction-based. Essentially,
interaction-based links with scientific partners can be beneficial for firms due to several reasons. Frequent motives are to gain access to complementary generic knowledge, to reduce costs (Veugelers and Cassiman, 2005; Cassiman et al., 2010), to stimulate firm R&D (Fleming and Sorensen, 2004; Rosenberg and Nelson, 1994; Hall et al. 2000) or to search for inventions in a more focused way (Cohen and Levinthal, 1989; Fabrizio, 2009; Cockburn and Henderson, 1998). We expect that these interactions influence the firm's scientific openness, as discussed below.

Academic laboratories may not have much interest in entering into relationships with firms if the opportunity costs of pursuing a common research project are too high (Carayol, 2003; Fontana et al., 2006). This is the case if collaborative research would deal with research topics that are distant from the "natural" agenda of a research group or ones that are not stimulating to the scientific community.

Consequently, firms that offer topics which are interesting from a scientific point of view and propose governance modes that are acceptable to universities should have an advantage in establishing interactive links. Own scientific contributions may signal here the capabilities of the firm that makes it appealing for universities to collaborate with it. Moreover, own scientific contributions by firms may also signal the compliance with the academic norm of disclosure, which can be a considerable source of controversy. Whereas the incentive systems of the academic sciences always favor disclosure, firms tend to keep project outcomes secret in order to avoid spillovers to competitors. In this connection, it is often argued that collaborations with industry may impose restrictions on the academic system where the norm of disclosure is threatened, i.e. through secrecy and delay of publication (Blumenthal et al., 1996; Czarnitzki et al., 2011). However, universities are not necessarily the weaker negotiating party and it can also be suspected that collaborations may impose greater openness on firms (see Lacetera, 2009; Tijssen, 2004). In other words, firms might concede the disclosure of subsequent project outcomes in order to convince the academic partner to enter into formal collaborations.

Besides interactions that are based on written contracts, firms can also maintain relationships that are of a more informal nature (Cohen et al., 2002). In practice, formal agreements and informal interactions often go hand in hand, but informal exchanges do not necessarily depend on contractual agreements (Powell et al., 1996). Specific benefits of informal relationships are the opportunities to access broadly distributed knowledge and to adapt more flexibly to changes since larger numbers of scientists can be leveraged without the costs of entering into new contractual agreements (Liebeskind et al., 1996; Liu and Stuart, 2010; Powell et al., 1996). In the absence of formal agreements which are typically based on some resource provision on the part of the firms, it may be even more challenging for companies to establish and maintain research links. Academic norms facilitate reciprocal knowledge exchanges which should exclude researchers from information networks if they are not contributing to the community (Hagstrom, 1965; Hicks, 1995; Cockburn and Henderson, 1998). In other words, there is little incentive for academic researchers to interact with firm scientists in an informal way if the latter do not provide interesting findings to the former. Correspondingly, Häussler (2010) suggests that academic researchers differentiate in their information-sharing behavior between inquirers from academia and industry, where industry researchers face a greater likelihood of having their request rejected. Accordingly to her findings, industry researchers are less interesting exchange partners for academic scientists. Therefore, we would also expect at the firm level that the disclosure of own research results is beneficial to successfully maintain informal contacts.

With respect to scientific publications as a means of openness, it is self-evident that these can be accessed by any particular interested party. However, firms and their researchers demonstrate credibility and signal their conformity with the normative rules of the scientific community (Hicks, 1995; Dasgupta and David, 1994). This appears particularly plausible if one considers that the academic community not only associates a firm publication with the company but also with the authoring firm scientists personally who in fact act as the interface to the academic community (see also Liu and Stuart, 2010).

3.3 Appropriability Regime

As the third major dimension, we examine the impact of sector conditions on firms' cost-benefit evaluation of scientific disclosure. More specifically, the appropriability regime concerning a firm's inventions may influence the costs of the firm's scientific openness. The execution of R&D produces knowledge as its main outcome, but due to the non-rivalry property of knowledge, its outflows may threat the ability of firms to generate sufficient returns from their private investments (Arrow, 1962).

As a consequence of spillover risks, voluntary scientific disclosure appears to be a costly firm strategy despite the potential benefits. This should be particularly the case if the firms in a sector compete for similar inventive outcomes and competitor knowledge is regarded as important information source. However, effective knowledge protection means or modest overall levels of spillovers and technological competition in an industry may positively affect the relative costs of disclosure in a scientific format (Gans et al., 2011; Cockburn and Henderson, 1994; Lacetera and Zirulia, 2011).

Basically, the available knowledge protection instruments can be classified into legal and strategic ones and their application depends both on firm-level strategies and sector characteristics. Concerning the firm-level dimension, firm size is an important determinant since the costs of legal protection are relatively higher for small firms due to the lack of specialized units that can handle the patent application, monitoring and enforcement tasks. For larger firms, these costs should be less critical since their financial resources are typically larger and scale effects can be exploited (Cohen et al. 2000; Lerner, 1995; Arundel, 2001; Leiponen and Byma, 2009). Apart from the firm-level dimension, the effectiveness of protection instruments is also strongly driven by industry characteristics like the "invent-around" possibilities for patented inventions (Levin et al., 1987; Cohen et al., 2000). Due to the particular nature of legal and strategic protection means, where in the case of patent protection some disclosure is imposed while secrecy relies explicitly on non-disclosure, there should be different costs of disclosure in a scientific format with respect to the spillover dimension.

On the one hand, patent applications lead to disclosure through the search report by the patent office after 18 months as from the application date. The search report contains relevant technical information which is potentially of interest for competitors. Since many R&D projects contain knowledge that is both of an applied and generic nature, the same knowledge can often be simultaneously patented and published, allowing for complementary strategies (Murray, 2002; Stokes, 1997). In such a case, the scientific publication does not necessarily contain much additional knowledge that is not yet revealed in the patent. Therefore, the marginal effect of scientific disclosure is lower than in the case where a patent is absent. Besides, patents also restrict the utilization of the disclosed knowledge, which prevents misappropriation by competitors and make knowledge outflows less harmful (Murray and O'Mahony, 2007; Gans et al., 2011). In this respect one has to remember that there are different degrees of content overlaps which may strengthen or weaken this assumed complementary relationship.

Secrecy, on the other hand, does not contain any disclosure by definition. Therefore, it can be seen diametrically opposed to any disclosure, including scientific publication. If secrecy is an effective protection mechanism, the disclosure of research results can be expected to be very costly. Indeed, many firms regard the obligatory disclosure of patents as problematic and rely more on secrecy (Horstmann et al., 1985; Harabi, 1995). In such a case, publishing in a scientific journal is likely to be perceived as harmful since the marginal disclosure levels are higher than in the case of a patent protection. In the absence of the specific protection mechanism offered by a patent, competitors have no formal access restrictions. Nevertheless, it is worth noting that knowledge contents might be partly separable at the project level and effective knowledge protection may include a diverse set of strategies, involving a parallel reliance on secrecy and patents (Arundel, 2001). Similarly, secrecy does not constitute the only strategic instrument since firms can also rely on lead-time or technological complexity.

4 Data and Variables

4.1 Data Sources

The empirical analysis relies on two main data sources referring to firms and their scientific publications, respectively. The firm-level information is extracted from the fourth edition of the French Community Innovation Survey (henceforth CIS4) that gathered data concerning the innovative behavior of firms during the period 2002-2004[5]. It is important to stress that the sampling procedure of the French CIS4 favors the inclusion of larger firms, which may limit the representativeness of our results with respect to small companies. The scientific publications of each firm were retrieved manually from Elsevier's Scopus online database. The Scopus database offers a very broad journal coverage that exceeds the also commonly used ISI Web of Science collection (Falagas et al., 2008) and therefore represents the best available data source[6].

For the sake of the analysis, both data sources have been limited in several respects. Regarding the CIS4 data, only R&D-performing firms from the manufacturing sectors have been included as we are interested in scientific publications as outcomes of scientific research and technology development. Moreover, non-innovative firms - as defined by not having introduced any product or process innovation in the survey period - have been disregarded since a considerable number of CIS4 questions have only been answered by innovative firms (see Mairesse and Mohnen, 2010). In order to avoid any potential bias arising from pure R&D service units that belong to business groups, we applied a conservative approach by removing those firms with a R&D expenditures/sales ratio higher than 50 per cent.

Regarding the scientific publication data, only articles and conference proceedings have been considered since only these document types represent original research outcomes. In addition, publications have

[5] For details concerning the European Innovation surveys, see Mairesse and Mohnen (2010).
[6] All firms in our sample are based in France and some firms could target French-orientated journals only. Since Scopus has an international scope, there could be an underrepresentation of French journals. In order to assess this potential bias, we cross-checked the coverage of Scopus with the PASCAL database from the French institute INIST. The results showed that Scopus fairly represents French-speaking journals since around 45% of the journals covered in PASCAL are included in Scopus. Given its quality standards and greater international coverage, Scopus still represents the best available source, although we cannot completely rule out the fact that our approach could miss some publications.

been classified by their publication date into three different time periods: before (1999-2001), during (2002-2004) and after (2005-2007) the CIS4 coverage period. The retrieval and cleaning procedures related to the scientific publications merit further explanation. While generally speaking the affiliation field in the Scopus database is of good quality since it is not sensitive to language-specific characters or name permutations, a broad text search was conducted aiming to minimize false negative matches. The search strategy consisted of using both truncation of the firms' names and their known acronyms together with wildcards. In order to minimize false positives, all retrieved publications were carefully checked both automatically and manually. As a general rule, we decided to apply a conservative approach whereby the risk of misattributing a scientific publication was minimized. First, automatic examination queries were executed to rule out any academic affiliation of the potential matches that refer, in fact, not to the firm but to institutions with a similar name.

This includes mixed affiliations between public research institutions and companies, which were also excluded[7]. The remaining matches were examined manually. Each potential match was cross-checked using the legal address of the company – including the addresses of all known subsidiaries – and the author's address in the scientific publication. In very few cases, firms with only common French or English terms in their names produced an extremely large amount of false positive matches. The impracticability of checking all the publications manually led us to fully exclude those firms.

4.2 Variables

For capturing scientific openness of firms, three different dependent variables are computed that require different estimation procedures and are therefore explained in section 5.

The internal research activities (R_i) can either be measured with the R&D intensity or the level of R&D as measures. This choice is influential with respect to the degree of representation of the scientific outcomes on the one hand and the cultural dimension on the other hand. Whereas the level of R&D should capture more the eligibility of outcomes for publication, the R&D intensity better reflects the relative importance (and potential influence) of scientists within the firm. Unfortunately, there is a high correlation between R&D intensity and expenditures in our data, which would make a separation in the analysis not very meaningful. Following related literature (Cohen and Levinthal, 1989; Crepon et al., 1998), the R&D intensity is used while we aim to capture the heterogeneity of R&D productivity and its orientation with two control variables explained further below in this section.

A core argument of our study is that the disclosure of scientific outcomes is influenced by the type of interactions the firm has established with the scientific community (C_i). We consider four interaction types that distinguish between the attributed importance and the formality of these interactions. The first reflects firms that (formally) cooperate with academic partners and simultaneously consider them as important information sources for innovation. The second type covers companies that regard universities as important sources for innovation but do not have any cooperation agreements, indicating informal links with academic scientists. As a further distinction, we explicitly separated firms claiming to collaborate with academia without considering it as an important source. This category comprises cases where universities might just provide technical services or where the collaborative project failed. Recent evidence suggests that cooperation failures are not a rare phenomenon in firm-university collaborations (Lhuillery and Pfister, 2009). The baseline category represents firms that have no link with scientific institutions, i.e. firms that do not collaborate and do not source information from academia. The underlying variables enabling these four distinctive types are the importance of universities as a source for innovation (measured on a four-point Likert scale, aggregated to dummy high/medium use) and the existence of cooperation with universities (dummy variable).

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[7] This refers to public research units that are attached to a private company facility. It should not be confused with co-authored scientific publications between firms and academia or authors with double affiliations. The most frequent case in our dataset consists of those known as *unités mixtes*, where a research unit is shared between the Centre National de la Recherche Scientifique (CNRS) and a private firm.

Moreover, we expect the appropriability regime to be influential in explaining scientific contributions by firms, which is represented in vector A_i. This set of variables covers the average use of protection means where we distinguish within each sector as to the share of legally and strategically protected firms. Besides the consideration of the effectiveness of legal and strategic protection instruments, we include also a measure that captures the sector spillover levels. More specifically, this measurement represents the average use of knowledge that comes from competitors.

The rationale for this variable is based on the possibility that detrimental knowledge outflows may occur despite the use of protection means, for instance, through the disclosure during the patent application process (see Horstmann et al. 1985). These sector variables are computed on the NACE2 level and additionally also by size strata since the effectiveness of certain protection means and the risk of outgoing spillovers have been found to vary with firm size (see Lerner, 1995) [8] [9].

Vector Z_i contains a set of control variables taking firm-level heterogeneity into account. First, we introduce a dummy variable that captures if firms regard scientific publications as highly important information source. This variable intends to represent the "basicness" of the corporate R&D activities, with the advantage that such a passive information sourcing does not require any signal of openness on the part of the firms. Since we cannot sharply distinguish between research productivity and relative openness on the dependent variable, we include a measure of past research productivity that aims to overcome this limitation. The variable is computed by the ratio of sales that are based on the firm's innovations over R&D expenditures. Given data limitations, this measure is constructed for the year 2004, which implicitly contains the assumption of a relationship between the research productivities in two subsequent periods. Moreover, as set out in our discussion in Section 3.3, we included also measures for the use of patents and secrecy at the firm level to capture any heterogeneous strategies not included in the sector component. Another control worth detailing concerns public R&D funding given that some institutions impose disclosure. For instance, the 6th European Framework Programme has a disclosure clause, although it does not specify a particular medium (see EC, 2003). Further controls are a dummy for firms aged 4 years or younger, if the firm is part of a national or foreign group, firm size and OECD technology intensity dummies.

4.3 Descriptive Statistics

The sample contains 2,512 R&D-performing firms. Within this sample, 346 firms (almost 14 per cent) have published at least one scientific article or conference proceeding paper during the nine-year period. The resulting data suggests that the population of publishing firms is increasing over time, although most of the increase occurred between the first and second periods.

As shown in Table 1, there is considerable variation across industries. Not surprisingly, the sector category covering the pharmaceutical, biotechnology and chemical industries (NACE 24) is more frequent in the subsample of publishing firms, although it accounts for only 30 per cent of it. Indeed, with the exceptions of apparel (NACE 18), leather (19) and wood products (20), all other sectors contain at least one publishing firm in the nine-year period. Moreover, in eight sectors more than 10 per cent of firms published at least one scientific document. In particular, firms from the communication equipment (NACE 32), medical and optical instruments (33) and transport equipment (35) industries are almost as likely to publish as those from the pharmaceutical and chemical sector (24). Therefore, scientific publications are by no means only a phenomenon of the life sciences and chemical industries.

[8] It should be stressed that these sector variables reveal relatively high correlations (see Annex A.2). Nonetheless, the corresponding variables can be distinguished from a theoretical perspective and we performed robustness tests to ensure the validity of results. These are available upon request.

[9] We thank an anonymous referee for the suggestion to consider firm size explicitly.

Table 1 Publishing Firms by Period and Sector

Industry (NACE 2)	Total Firms	Publishing Firms per Period								
		1999-2007			1999-2001		2002-2004		2005-2007	
	Q	Q	%	% of total pub. firms	Q	%	Q	%	Q	%
Food & Beverages (15)	395	24	6.1%	6.9%	6	1.5%	13	3.3%	17	4.3%
Textiles (17)	113	6	5.3%	1.7%	2	1.8%	1	0.9%	5	4.4%
Apparel (18)	49	0	0.0%	0.0%	0	0.0%	0	0.0%	0	0.0%
Leather (19)	32	0	0.0%	0.0%	0	0.0%	0	0.0%	0	0.0%
Wood products (20)	53	0	0.0%	0.0%	0	0.0%	0	0.0%	0	0.0%
Pulp & Paper (21)	86	2	2.3%	0.6%	1	1.2%	0	0.0%	1	1.2%
Media (22)	55	2	3.6%	0.6%	0	0.0%	2	3.6%	1	1.8%
Petroleum (23)*	19	4	21.1%	1.2%	1	5.3%	1	5.3%	3	15.8%
Chem. & Pharmaceuticals (24)	269	99	36.8%	28.6%	54	20.1%	72	26.8%	81	30.1%
Rubber & Plastics (25)	167	13	7.8%	3.8%	8	4.8%	9	5.4%	6	3.6%
Mineral products (26)	122	14	11.5%	4.0%	6	4.9%	8	6.6%	8	6.6%
Basic metal (27)	70	15	21.4%	4.3%	7	10.0%	7	10.0%	9	12.9%
Metal products (28)	181	12	6.6%	3.5%	5	2.8%	7	3.9%	7	3.9%
Machinery & Equipment (29)	275	29	10.5%	8.4%	8	2.9%	19	6.9%	17	6.2%
Office Machines (30)**	13	2	15.4%	0.6%	1	7.7%	2	15.4%	0	0.0%
Electrical machinery (31)	137	26	19.0%	7.5%	13	9.5%	19	13.9%	17	12.4%
Communication Equipment (32)	99	32	32.3%	9.2%	17	17.2%	26	26.3%	30	30.3%
Medical & Optical instr. (33)	143	36	25.2%	10.4%	19	13.3%	22	15.4%	31	21.7%
Motor vehicles (34)	159	12	7.5%	3.5%	3	1.9%	10	6.3%	3	1.9%
Transport equipment (35)	75	18	24.0%	5.2%	9	12.0%	12	16.0%	14	18.7%
Total	2512	346	13.8%	100%	156	6.2%	230	9.2%	250	10.0%

* In the multivariate analysis, this category has been merged with Chemistry (NACE 24)

** In the multivariate analysis, this category has been merged with Communication equipment (NACE 32)

Summary statistics in Table 2 provide a general description of the sample and some particular characteristics of the subsample of publishing firms[10]. Even in our sample that contains only R&D active and innovative firms, the practice of publishing is highly skewed. Around one third of publishing firms have only one publication in the estimated three-year post-survey period, while two thirds have fewer than five publications.

[10] In the remaining discussion, we focus on the publishing behaviour of firms in the three-year period immediately after the CIS4 surveyed period. The main reason for this is our intention to explain this ex-post publishing behaviour by the ex-ante innovation strategies applied.

Table 2 Summary Statistics

	Full sample (2,512 Observations)				Publishing in 2005-2007		
					Yes (250)	No (2,262)	
Variables	Mean	Std.Dev.	Min	Max	Mean	Mean	diff p
PUByes: Publication	0.099	0.299	0.000	1.000	1.000	0.000	
PUBcount: Amount	1.464	21.21	0.000	902.0	14.71	0.000	
PUBint: Intensity	0.002	0.045	0.000	1.850	0.023	0.000	
R&D share of turnover	0.028	0.056	0.000	0.490	0.053	0.026	0.000
R&D intensity (per employee)	6.155	18.00	0.002	518.0	14.02	5.286	0.000
R&D productivity	967.5	9852.2	0.000	381050	6504.2	355.6	0.000
Academia: Only Source	0.073	0.259	0.000	1.000	0.108	0.069	0.024
Academia: Source & Coop	0.161	0.367	0.000	1.000	0.496	0.124	0.000
Academia: Only Coop	0.109	0.311	0.000	1.000	0.196	0.099	0.000
Coop: Academia	0.269	0.444	0.000	1.000	0.692	0.222	0.000
Source: Academia	0.234	0.423	0.000	1.000	0.604	0.193	0.000
Source: Competitors	0.430	0.500	0.000	1.000	0.540	0.420	0.000
Source: Journals	0.390	0.490	0.000	1.000	0.560	0.360	0.000
Legal Protection - sector	0.666	0.186	0.195	1.000	0.796	0.652	0.000
Strategic Protection - sector	0.578	0.141	0.189	0.797	0.704	0.564	0.000
Competitor spillovers - sector	0.399	0.100	0.110	0.684	0.443	0.394	0.000
Protec: Patent	0.499	0.500	0.000	1.000	0.864	0.458	0.000
Protec: Secrecy	0.424	0.494	0.000	1.000	0.708	0.393	0.000
EU/National funding	0.254	0.436	0.000	1.000	0.512	0.226	0.000
Employees	430.9	909.4	1.000	15025	1386.2	325.4	0.000
Foreign Group	0.300	0.458	0.000	1.000	0.412	0.287	0.000
National Group	0.457	0.498	0.000	1.000	0.536	0.449	0.009
Independent Firm	0.243	0.429	0.000	1.000	0.052	0.264	0.000
New firm	0.071	0.257	0.000	1.000	0.240	0.076	0.002
HT	0.147	0.354	0.000	1.000	0.460	0.112	0.000
MH	0.311	0.463	0.000	1.000	0.312	0.311	0.957
MF	0.231	0.421	0.000	1.000	0.132	0.242	0.001
FT	0.312	0.463	0.000	1.000	0.096	0.335	0.000

Without taking into account any multivariate interaction, firms publishing scientific outcomes are larger and belong more often to technologically intensive sectors. These firms are also more often part of a business group, which is more likely to be foreign. Publishing firms are on average more R&D-intense, being twice as intense in terms of turnover share and almost three times in terms of R&D expenditures per employee. Moreover, these firms are more closely connected to innovative institutional environments with respect to their information sourcing for innovation development. In particular, publishing firms tend to rely more on academic sources and collaborate more frequently with academic partners than non-publishing firms. Similarly, a higher proportion of publishing firms receive public support for R&D and innovative activities from French or European agencies. Interestingly, publishing firms are not only more likely to use patents but also secrecy for protecting their knowledge assets.

5 Econometric Design

We propose to model the firm's adoption of an OS strategy (OS_i) as function of the amount of produced outcomes for disclosing in a scientific format and factors affecting the firm's evaluation of the benefits and costs, namely interactions with academic partners and the appropriability regime at the sector level.

$$OS_i = f\left(R_i, C_i, E_i, Z_i\right) \tag{1}$$

In order to measure the scientific openness of firms, we rely on scientific publications since these represent the main dissemination instrument in OS. However, it has to be considered that as opposed to academic institutions, publication outputs of firms may represent both varying research productivities and relative degrees of openness. Unfortunately, the amount of publishable outcomes (R_i) is not observed directly and the created outputs per given R&D investments are likely not to be equal among firms. Even though it is reasonable to assume a direct and strong relationship between the internal R&D investments and scientific outcomes, we are unable to solve this problem entirely. In order to mitigate corresponding concerns, we estimate three models differing only in the choice of the dependent variable specification. First, we estimate a binary model that intends to capture the firm's decision to contribute to OS, which, in practical terms, means whether the firm has published or not. This specification implicitly assumes that the decision to disclose precedes the decision regarding the quantity of scientific contributions and that every firm attempting to publish succeeded at least once. Second, we model the firm's discrete amount of scientific publications, which can be regarded as the observed contribution to OS. Even though it reflects the total contribution best, it is also the most ambiguous with respect to the distinction between relative openness and research productivity. Third, we use the ratio of scientific contributions per internal R&D expenses. As this intensity measure relates the observed publications directly to the inputs, we expect it to be a good proxy for the relative degree of scientific openness. Additionally, as described in the variables section, we include in all models a control variable that aims to proxy for the research productivity effect.

In practical terms, we estimate Probit, Negative Binomial and Tobit regression models. It is worth mentioning that we preferred a Negative Binomial regression model over a Poisson model given the prevalence of over-dispersion in the data[11]. We also tested for this choice by comparing the fit between predicted and actual values which supported the superiority of the Negative binomial model. Furthermore, since one can expect time lags between firm-level decisions and the disclosure of research outcomes and also to rule out simultaneity problems, we estimate the scientific publications in the post-survey period (i.e. publications for the years 2005-2007) with the firm-level information for the years 2002-2004. Finally, all models are estimated with robust standard errors (clustered by two-digit NACE industries).

[11] The Wald test rejected the absence of overdispersion ($1/\theta=0$) at the p-value < 0.01. Following Cameron and Trivedi (1986), the variance is modeled as Var(OS_i) = $\lambda_i(1+\lambda_i/\theta)$ which corresponds to the NegBinII.

6 Results and Discussion

The results of the three estimation procedures are displayed in Table 3. Each model was estimated with two alternative specifications. One specification intends to control for the overall sector heterogeneity by including NACE2 sector dummies. The second specification contains the sector level variables which measure the appropriability regime while only controlling for the sector heterogeneity in terms of the technology intensity (using the four OECD classes). When discussing the marginal effects, we focus mainly on the latter specification.

To begin with, the internal scientific activities – captured by the R&D intensity – are associated with a higher likelihood and also larger total quantities of scientific contributions, whereas a negative effect is found in the intensity equation. With respect to the binary choice (column 1b), a ten per cent increase in the R&D intensity is found to increase the likelihood of publishing by five per cent. This is in line with the expectation that larger R&D activities generate more publishable outcomes. But the disambiguation between the amount of publishable outcomes and the firm's orientation ("scientific culture") is not straightforward. Given our controls for the research productivity and research orientation which are not significant in the Probit model (the former only at the 10% level in 1a), it seems that the relative weight of scientific activities is a relevant factor when it comes to the decision to engage in scientific disclosure or not. The results from the amount equation (2b) go in the same direction. The R&D intensity not only impacts positively the amount of publications, but its marginal effect doubles the effect of the R&D productivity control which is significant in this specification. Moreover, a one per cent increase of the R&D intensity is equivalent to the average increase in publications shown by firms with stronger science related R&D activities. Interestingly, the R&D intensity is not positively significant in the intensity model but shows a negative sign. Therefore, the assumption that greater shares of scientists in corporations enhance the relative openness does not find support in this model. However, there are further potential explanations: from a pure input perspective, this result would reflect decreasing marginal returns of R&D activities (see Griliches, 1990). Firms with high R&D intensities may perform in general more costly R&D which lowers the input-output ratio. Moreover, it is possible that R&D intensive firms publish more selectively and pursue signalling strategies only with their most promising outcomes. Unfortunately, due to the heterogeneity of our sample and the inclusion of publications from all scientific domains, we could not analyze the quality aspect within this study. Given the findings and the limitations of our R&D measurements, our results are not conclusive concerning the relative openness of firms based on greater scientists' shares and have to leave this aspect to further research.

A core interest of this paper concerns the firm's link to academia as a predictor for scientific disclosure. Following our discussion in Section 3.2, we use four variables in order to obtain a comprehensive picture of the firm's interactions with academia. Here, the baseline category is represented by firms not sourcing and not collaborating with academia. Consistently across models, all interaction types are positively and significantly associated with higher levels of scientific openness. When looking at the marginal effects, firms that regard interactions with academic partners as important reveal higher degrees of openness than those firms that have formal collaboration agreements, but do not regard them as crucial for their innovation development. Here, the interactions in the framework of a contractual agreement and those that are from an informal nature are not statistically different if the academic partner is considered a relevant innovation source[12]. Thus, interactions that are not based on financial resource provisions do not require a stronger openness than those where at least a partial resource provision of firms is involved. On the other hand, there is a significant difference in comparison to contractual agreements which are not regarded as important[13]. This result suggests that if a firm wants to source valuable information, regardless of the formality of the interaction, the incentive to show scientific openness is greater than in the case of a firm searching for "technical services" only. Given this finding, we believe that the scientific openness of firms is an expression of reciprocal behavior and the contractual conditions imposed by the academic collaboration partner. Even though we use an indirect strategy – as we predict publications in the post-survey period – the results suggest that companies have to provide scientific contributions to fully

[12] The *p*-values of the Wald tests are 0.73 (Probit), 0.72 (NBreg) and 0.51 (Tobit).
[13] Here, the *p*-values (H_0: *"All interaction modes have equal impact"*) are 0.03 (Probit), 0.00 (NBreg) & 0.07 (Tobit).

access academic knowledge sources. Therefore, the view that collaborations may impose restrictions on academic partners might be only part of the picture as firms are required to be more open in order to maintain close links to academia.

Concerning the influence of the appropriability regime, we obtain the following results: first, the spillover levels in a sector are negatively significant on the 1% level across all models and with strong marginal effects. If firms in a sector frequently use knowledge from competitors as a source for innovation activities, the firms are considerably more restrictive with publication activities. However, the spillover threats seem to be at least partially compensated by legal protection instruments since the sector use of legal instruments is positively significant in the binary and count models. On the other hand, strategic instruments are never significant but always have the expected negative sign. With respect to appropriability, it is also important to look at the two firm level controls. Surprisingly, the use of secrecy is always positively correlated with scientific disclosure. One possible explanation is that scientific openness is facilitated if knowledge contents are separable and critical parts can be kept secret. Moreover, one should take into account that effective protection instruments were found to stimulate R&D investments (Arora et al., 2008). In turn, this increase can be expected to lead to publishable outcomes and should be captured at least partially by the R&D intensity coefficient. As a result, appropriability conditions can be assumed as a relevant factor for influencing the cost-benefit evaluation behind firm's OS strategies.

With respect to our control variables, it is to be noted that the public funding variable is significant in all models. Since public funding is in practice often related to collaboration agreements with universities, we discuss this relationship more in-depth in the following robustness test section. Furthermore, as mentioned in the context of the R&D variable already, our control that captures the research productivity of the firm is only significant in the count data specification. This is plausible from the viewpoint that the count data specification is most sensitive towards the ambiguity between openness and research productivity, since the dependent variable does not directly account for the amount of R&D inputs like the Tobit model. Therefore, even though our data does not allow for a perfect disambiguation, the use of this control and different variations of the dependent variable strongly support our interpretations concerning the scientific openness of firms. In the light of the overall evidence of our analysis, the results provide support for the assumption that scientific publications are used as strategic instruments, with firms carefully balancing cost-benefit considerations[14].

[14] In order to avoid any misinterpretation, we carried out several interviews in large, research-intensive firms. In fact, interviewees mentioned that the decision to publish in scientific journals and its extent are dependent on several considerations where sector conditions, contacts with academics and the desire of firm scientists are all valid criteria.

Table 3 Regression Outputs

	(1a)		(1b)		(2a)		(2b)		(3a)	(3b)
Scientific openness	PUByes		PUByes		PUBcount		PUBcount		PUBint	PUBint
	Coeff. (se)	Marg.eff	Coeff. (se)[#]	Marg.eff	Coeff. (se)	Marg.eff	Coeff. (se)[#]	Marg.eff	Coeff. (se)	Coeff. (se)[#]
R_i (R&D)										
R&D intensity (in logs)	0.087***	*0.005*	0.085***	*0.005*	0.156***	*0.003*	0.202***	*0.010*	-0.014	-0.014*
	(0.031)		(0.020)		(0.054)		(0.064)		(0.009)	(0.008)
C_i (Collaboration)										
Academia: Only Source	0.715***	*0.076*	0.748***	*0.077*	1.483***	*0.053*	1.680***	*0.169*	0.071***	0.074***
	(0.155)		(0.119)		(0.234)		(0.428)		(0.023)	(0.026)
Academia: Source & Coop	0.732***	*0.071*	0.785***	*0.092*	1.062***	*0.034*	1.545***	*0.167*	0.070***	0.083***
	(0.119)		(0.155)		(0.295)		(0.257)		(0.026)	(0.029)
Academia: Only Coop	0.398***	*0.032*	0.411***	*0.035*	0.479*	*0.011*	0.699**	*0.048*	0.035**	0.039***
	(0.132)		(0.087)		(0.257)		(0.272)		(0.016)	(0.014)
A_i (Appropriability)										
Legal Protection - sector			1.296**	*0.081*			2.014*	*0.102*		0.109
			(0.651)				(1.166)			(0.070)
Strategic Protection - sector			-0.623	*-0.039*			0.075	*0.004*		-0.069
			(0.655)				(1.207)			(0.078)
Competitor spillovers - sector			-2.876***	*-0.181*			-5.722***	*-0.291*		-0.314***
			(0.635)				(1.513)			(0.104)
Z_i (Controls)										
Source: Journals	-0.074	*-0.004*	0.052	*0.003*	0.044	*0.001*	0.202*	*0.011*	-0.010	0.005
	(0.145)		(0.111)		(0.259)		(0.115)		(0.016)	(0.011)
R&D productivity (in logs)	0.039*	*0.002*	0.031	*0.002*	0.123***	*0.002*	0.107**	*0.005*	0.004	0.004
	(0.021)		(0.022)		(0.035)		(0.045)		(0.003)	(0.003)
EU/National funding	0.385***	*0.028*	0.361***	*0.027*	0.699***	*0.017*	0.814***	*0.052*	0.041**	0.039***
	(0.102)		(0.075)		(0.209)		(0.244)		(0.016)	(0.008)
Employees (in logs)	0.312***	*0.018*	0.311***	*0.020*	0.787***	*0.015*	0.783***	*0.040*	0.035*	0.038*
	(0.044)		(0.072)		(0.076)		(0.080)		(0.018)	(0.021)
Foreign Group	0.029	*0.002*	-0.030	*-0.002*	-0.163	*-0.003*	-0.249	*-0.012*	-0.006	-0.015
	(0.097)		(0.081)		(0.192)		(0.268)		(0.013)	(0.014)
Independent Firm	-0.518***	*-0.024*	-0.573***	*-0.028*	-0.769**	*-0.013*	-0.851	*-0.036*	-0.065*	-0.073*
	(0.197)		(0.210)		(0.390)		(0.517)		(0.035)	(0.038)
New Firm	0.533*	*0.049*	0.531**	*0.052*	1.353***	*0.051*	1.273***	*0.119*	0.083	0.081
	(0.286)		(0.266)		(0.523)		(0.487)		(0.054)	(0.058)
Protec: Patent	0.345***	*0.021*	0.335***	*0.021*	0.327	*0.006*	0.200	*0.010*	0.047**	0.042***
	(0.116)		(0.092)		(0.248)		(0.215)		(0.019)	(0.012)
Protec: Secrecy	0.250***	*0.015*	0.264***	*0.017*	0.716***	*0.015*	0.523**	*0.028*	0.044*	0.044*
	(0.094)		(0.083)		(0.190)		(0.212)		(0.024)	(0.025)
OECD tech. Intensity	no		yes		no		yes		no	yes
Sector dummies (Nace2)	yes		no		yes		no		yes	no
Constant	-4.099***		-3.642***		-7.504***		-7.689***		-0.448***	-0.473***
	(0.324)		(0.286)		(0.593)		(0.472)		(0.132)	(0.178)
Observations (Clusters)	2,512 (-)		2,512 (18)		2,512 (-)		2,512 (18)		2,512 (-)	2,512 (18)
Log-Likelihood	-487.6***		-495.0***		-1,162.2***		-1,178.8***		-126.1***	-129.6***

*Note: *** p<0.01, ** p<0.05, * p<0.1; [#] Standard errors clustered by NACE2 code*

7 Robustness Tests

We performed several robustness checks to ensure the validity of our results. All output tables are available upon request. We describe the most relevant tests as follows.

First, it can be assumed that adoption incentives derive from other firms in the sector that published in the past (see Ding 2011; Polidoro and Theeke, 2011). Therefore, we tested the inclusion of the sector's share of publishing firms in the pre-survey period. We found the corresponding coefficients to be significantly positive in the Probit and Negative Binomial estimations, but not significant in the Tobit one. With the exception of legal protection means at the sector level, all other results remained stable. However, since it is reasonable to assume that this sector openness depends on the appropriability regime, we preferred to keep it out of the models, as discussed in the previous section.

A second concern arises from the skewness of our dependent variables. In particular, the data presents an excess of zeros which may advocate for the use of a Zero-inflation model. However, from a theoretical point of view, there is not much justification to assume that there is a different data generation process for a subset of the zeros, i.e. incidental and structural zeros. In our framework, the structural zeros account for firms that do not produce any knowledge that could be publishable, while the incidental ones refer to those firms that are expected to produce some scientific output but they do not. As the sample does not contain firms without any R&D expenditures, it is likely that all structural zeros have been removed already. Nevertheless, acknowledging the relevance of a zero-inflation from an empirical viewpoint, we estimated a Zero-inflated negative binomial (ZINB) regression model as a robustness check where we use the level of R&D and firm size as predictors for the excess of zeros. Moreover, NACE2 sector dummies are used in the first stage, whereas the continuous part of the model is completely identical as in the other performed models. The results of the ZINB model are in line with the findings of the standard Negative Binomial model.

A more relevant concern lies in the possibility that some factors affect not only the scientific openness (OS_i) but also the firm's commitment to R&D (R_i).

For instance, academic knowledge sources may not only influence the scientific openness of firms based on reciprocal behavior, but may also simultaneously encourage firm internal investments into R&D which allows to absorb external knowledge, and this internal R&D in turn increases also the amount of publishable outcomes. To account for this endogeneity and given that we are using non-linear models, we adopted a "control-function" approach where the estimated residuals of a first-stage R&D equation are plugged into the equations of interest (see Cameron and Trivedi, 2010; Wooldridge, 2008). We follow the existing literature for the concrete specification of the first equation (Cohen and Levinthal, 1989; Crepon et al., 1998). Given that the estimated residuals are not statistically significant and the results remain stable, we found little support for such estimation strategy.

Lastly, a bias may derive from the fact that scientific publications by firms are partly imposed by institutional rules, particularly disclosure clauses in public funding agreements. For the regression models which we have reported in the previous section, we therefore included a dummy variable that captures if firms received public R&D funding. However, public R&D funding, for instance through the community framework programs, also encourages collaboration with academic partners. As a result, the coefficients of academic collaboration may be biased due to an interaction with public funding. In order to analyze the impact of public R&D funding more properly, we interacted the public funding variable with the different links of the firm to academic partners. However, the regression results and strength of the marginal effects remain fully consistent with the outputs of our main models.

8 Conclusion

This article discusses the position of firms' regarding the adoption of scientific disclosure practices, enhancing the view that companies only source knowledge from academia by also regarding them as active contributors. We distinguish between three major dimensions that influence the firms' cost-benefit calculations concerning disclosure. These dimensions comprise an isolated firm perspective, interactions with academic institutions and the appropriability regime. For the empirical analysis, a unique and rich dataset is built from firm-level data and scientific publications. From a purely descriptive viewpoint, it is interesting that almost every sector shows an increasing ratio of firms contributing to scientific literature over time. This underlines the relevance of academic studies concerning the scientific activities and disclosure of companies.

The results of the multivariate analysis provide evidence that the decision to participate in OS is not only an internal decision of the firm, but is dependent on interactions with academic partners. Firms that draw from the public science base show a greater openness, indicating that access to these academic scientists and institutions requires an adoption of the academic norm of disclosure. Furthermore, there is considerable support for the impact of the appropriability regime. Whereas higher levels of spillovers reduce the willingness of firms to contribute in a scientific format, legal protection instruments can reduce the "damage" of knowledge spillovers and facilitate scientific openness strategies. Based on these results it can be concluded that firms do not show naïve openness, but are adapting to academic disclosure practices in exchange for valuable knowledge links, while trying to minimize negative side effects with respect to competitors.

The findings have some important implications for both scholarly research and practitioners in firms. First, our results indicate that the concerns of scholars regarding threatened academic disclosure in collaborations may be only one aspect since interactions with academia also induce greater openness on the part of the firms. Moreover, the results are also important for the discussion concerning Open Innovation since they suggest that the provision of financial incentives for accessing academic knowledge is not necessarily sufficient.

This also implies for managers in companies that it can be counterproductive to minimize outflows, i.e. to apply "non-publication" policies where the scientists are not allowed to publish.

Like every study, this article is not without limitations that simultaneously offer avenues for further investigation. The firm-level data set is of a cross-sectional nature and it would be desirable to consider information for more than just one CIS wave, yet the sampling procedure of the CIS surveys leads to a relatively low overlap between the different versions. Furthermore, we have not differentiated the scientific contributions in terms of academic quality. Since our sample includes a wide range of sectors, as well as both articles and conference proceedings, where some sectors focus more on the latter, taking into account scientific quality would have been a source of potential bias. Future work might focus on particular sectors or scientific subject areas in order to include quality indicators such as impact factors or citation counts. Despite these limitations, our paper provides novel empirical evidence concerning the drivers of scientific openness by firms with our study supporting the view that firms use publications as strategic tools while carefully considering the costs.

Acknowledgements:

We would like to thank Carsten Fink, Dominique Foray, Stéphane Lhuillery, Paula Stephan, Michele Cincera, David Mowery, Priit Vahter, Paul Windrum, Keld Laursen and two anonymous referees for their comments.

Markus Simeth gratefully acknowledges the financial support provided by the Swiss National Science Foundation, grant no. 100014-125513.

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Annex A.1 Variables

Variable	Description	Type
OS_i	*Scientific disclosure*	
PUByes	Published a scientific article or conference proceeding in the period 05-07.	Dummy
PUBcount	Discrete number of publications in the period 05-07.	Discrete
PUBint	Number of publications (05-07) relative to amount of internal R&D expenditures (R&D in thousand EUR).	Continuous
R_i	*Scientific outcomes and firm culture*	
R&D intensity	Internal R&D expenditures per employee (in log).	Continuous
C_i	*Interactions with academia*	
Academia: Source & Coop	Collaborated with an academic partner and considered it as important source.	Dummy
Academia: Only Coop	Collaborated with an academic partner without considering it as an important source.	Dummy
Academia: Only Source	Considered academia as an important source without collaborating with it.	Dummy
A_i	*Appropriability regime*	
Legal protection - sector	Industry average (NACE2) of firms using legal appropriation means (i.e. patents, utility models, designs, trademarks or copyrights).	Continuous
Strategic protection - sector	Industry average (NACE2) of firms using strategic protection means (i.e. secrecy, complexity or technological lead).	Continuous
Competitor spillovers - sector	Industry average (NACE2) of firms considering their competitors as a medium or highly important source of information for innovation.	Continuous
Z_i	*Controls*	
Source: Journals	Scientific journals are of a high importance as information source for innovation activities	Dummy
R&D productivity	Ratio of firm's innovative sales (i.e. sales based on radical & incremental innovations) / R&D expenditures in the year 2004; in log	Continuous
EU/National funding	Company received public support for its innovation activities from the EU or national government institutions or agencies.	Dummy
Employees (in log)	Number of employees in 2002 (in log).	Continuous
Independent Firm	Firm is independent and does not belong to a group.	Dummy
Foreign Group	Firm belongs to group based abroad.	Dummy
New Firm	Firm age < 4 years.	Dummy
Protec: Patent	Firm regards patents as effective protection mechanism	Dummy
Protec: Secrecy	Firm regards secrecy as effective protection mechanism	Dummy
OECD tech intensity: HT; MH; ML; LT	4 industry dummies according to OECD technology intensity definition. Include High Tech (HT), Medium High Tech (MH), Medium Low Tech (ML),	Dummies
	Low Tech (LT).	Dummies
Sector dummies (Nace2)	18 dummy variables based on Nace2 sector classification	Dummies

Annex A.2 Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
(1) PUByes	1																						
(2) PUBcount	0.21	1																					
(3) PUBint	0.15	0.10	1																				
(4) R&D intensity (in logs)	0.22	0.06	-0.12	1																			
(5) Academia Source & Coop	0.30	0.12	0.02	0.16	1																		
(6) Academia Only Coop	0.05	-0.01	-0.01	0.01	-0.12	1																	
(7) Academia Only Source	0.09	-0.01	-0.01	0.06	-0.15	-0.10	1																
(8) Legal protection - sector	0.23	0.05	0.01	0.06	0.17	0.01	0.16	1															
(9) Strategic protection - sector	0.30	0.09	0.04	0.19	0.18	0.01	0.16	0.64	1														
(10) Competitor spillovers - sector	0.15	0.07	0.02	0.10	0.12	-0.01	0.10	0.66	0.46	1													
(11) Source: journals	0.10	0.01	0.00	0.08	0.18	0.07	0.03	0.06	0.10	0.02	1												
(12) R&D productivity (in logs)	0.27	0.13	0.07	-0.01	0.23	0.01	0.15	0.30	0.31	0.16	0.06	1											
(13) EU/National funding	0.20	0.08	0.03	0.15	0.28	0.00	0.10	0.02	0.09	0.07	0.11	0.12	1										
(14) Employees (in logs)	0.30	0.13	0.05	0.01	0.21	-0.01	0.17	0.79	0.62	0.50	0.04	0.39	0.01	1									
(15) Foreign group	0.08	0.03	-0.01	0.02	-0.01	0.00	0.09	0.34	0.30	0.22	-0.01	0.11	-0.12	0.34	1								
(16) Independent	-0.15	-0.04	-0.01	-0.04	-0.07	-0.01	-0.12	-0.44	-0.34	-0.26	-0.03	-0.22	0.09	-0.48	-0.37	1							
(17) New firm	-0.06	-0.02	0.00	0.05	-0.01	-0.04	-0.07	-0.35	-0.21	-0.19	0.02	-0.13	0.10	-0.40	-0.18	0.49	1						
(18) Protec: Patent	0.24	0.06	0.01	0.21	0.19	0.00	0.14	0.35	0.34	0.22	0.07	0.23	0.14	0.35	0.20	-0.23	-0.10	1					
(19) Protec: Secrecy	0.19	0.07	0.03	0.20	0.17	0.02	0.13	0.16	0.18	0.09	0.12	0.16	0.10	0.18	0.07	-0.10	-0.04	0.19	1				
(20) OECD: HT	0.29	0.12	0.11	0.24	0.15	0.00	0.03	0.03	0.30	0.20	0.06	0.12	0.18	0.01	0.02	0.01	0.07	0.10	0.08	1			
(21) OECD: MH	0.00	-0.02	-0.03	0.17	0.00	0.02	0.06	0.21	0.29	0.31	0.02	0.04	0.04	0.05	0.09	-0.05	0.02	0.17	0.03	-0.28	1		
(22) OECD: MF	-0.08	-0.03	-0.03	-0.18	-0.02	0.01	-0.01	0.01	-0.09	-0.29	-0.05	0.00	-0.04	0.07	0.04	-0.06	-0.03	0.09	-0.01	-0.23	-0.37	1	
(23) OECD: FT	-0.15	-0.04	-0.03	-0.19	-0.09	-0.03	-0.07	-0.25	-0.44	-0.20	-0.02	-0.13	-0.14	-0.13	-0.15	0.10	-0.05	-0.32	-0.08	-0.28	-0.45	-0.37	1