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ALLIANCES AND THE INNOVATION PERFORMANCE OF CORPORATE AND PUBLIC RESEARCH SPIN-OFF FIRMS

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Abstract

We explore the benefits of alliances for the innovation performance of spin-off firms, in particular spin-offs from either other firms or from public research organizations. During the early years of the emerging combinatorial chemistry industry, spin-offs engaged in alliances with large and established partners, partners of similar type and size, or with public research organizations, often for different reasons. We seek to understand to what extent alliances of spin-offs with other firms (either large or small and medium sized firms) affected their innovation performance and how this performance may have been affected by their corporate or public research background. We find evidence that in general alliances of spin-offs with other firms, in particular alliances with large firms, increased their innovation performance. Corporate spin-offs that formed alliances with other firms outperformed public research spin-offs with such alliances. This suggests that, in terms of their innovation performance, corporate spin-offs that engaged in alliances with other firms seemed to have benefited from their prior corporate background. Interestingly, it turns out that the negative impact of alliances on the innovation performance of public research spin-offs was largely affected by their alliances with small and medium sized firms.
Jelcodes:L24,O32

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Spin-offs during the emergence of combinatorial chemistry (1990 – 2003)

Abstract

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(word count:193)

Key words: alliances, spin-offs, entrepreneurial firms, innovation performance

JEL codes: L24, L26, L65, M13, O32

INTRODUCTION

The observed substantial increase in the number of new firms as a result of completed spin-offs from existing firms and public research organizations throughout the 1990s, in particular in such sectors as biotechnology and information technology (Spin-Off Advisors, 2014), has provoked substantial academic and policy interest in this phenomenon. A large body of literature has been produced since the early work by Cooper (1971) and Garvin (1983) that documents important positive contributions of both corporate (CSOs) and public research spin-offs (PROs) to economic value and job creation (Shane 2004; Helm & Mauroner 2007; Klepper 2009 for an overview). Despite the growth of research on spin-offs and their economic consequences, the question whether there are significant differences in relative performance between different types of spin-offs remains a topic of debate (e.g., Wennberg et al. 2011; Zahra et al. 2007). While empirical results reveal superior growth of CSOs compared to other type of spin-offs in terms of employment and sales (e.g., Stankiewicz 1994; Callan 2001; Ensley & Hmieleski 2005; Yagüe-Perales & March-Chordà 2012; Zhang 2009), there are no significant differences found with respect to innovation performance between PROs and CSOs (e.g., Lindholm-Dahlstrand 1997a; Löfsten & Lindelöf 2005). These indiscriminate results are somewhat surprising, considering that new technology-based firms, such as spin-offs, have been shown to inherit the congenital knowledge of their entrepreneurial founders (Boeker 1989; Huber 1991). Also, founders of CSOs have been typically understood to possess a higher business acumen necessary for sensing and seizing innovative opportunities as manifested by their advantages through prior experience, their networks, and their connections to other firms and organizations (Colombo and Piva 2012; Zahra et al. 2007).

Despite a wide recognition of these networks and inter-organizational connections as a major vehicle for knowledge transfer and access to other firms' knowledge-based resources and capabilities (Mowery et al. 1996; Hagedoorn 1993), surprisingly, very few studies have examined whether and how inter-firm collaboration affects innovation performance of spin-offs. Over the last two decades, globalization and increased competition has reshaped the innovation strategies of many firms towards a greater focus on external sources of knowledge (e.g. Archibugi and Michie 1995; OECD 2007). Internal sources of technological development alone are often insufficient to cope with the increasing intensity of competition as well as with the complexity and uncertainty of modern technologies. The alliance literature has well established that in general firms are increasingly involved in various alliances simultaneously with heterogeneous partners, recognizing the crucial role of alliances in determining firms' performance (e.g., George et al. 2001; Lavie 2007).

The aim of the current paper is to fill these gaps in the extant literature on spin-off firms. In the following, we examine how inter-firm alliances affect the innovation performance of spin-offs by distinguishing between CSOs and PROs. Grounded in extant research on both new technology-based firms, such as spin-offs, and alliances, we derive a set of three hypotheses that guide our empirical investigation. We put forth that inter-firm alliances, with either large or small and medium-sized firms or larger firms, may contribute differently in improving innovation performance of spin-offs, in particular in the context of spin-offs from firms or from public research organizations.

Our historical, empirical setting is a panel of 135 publicly traded pin-offs in the nascent field of combinatorial chemistry (i.e. an automated synthesis method capable of creating dozens, if not hundreds and thousands, of different molecules simultaneously for the purpose of discovering drugs, new materials, pesticides and so forth) during the years 1990 – 2003. As such, our time frame largely covers the crucial period of the emergence and gradual maturing of that industry (Thomke and Kuemmerle 2002), a period also characterized by high growth and increasing alliance activity of spin-offs.

THEORETICAL BACKGROUND AND HYPOTHESES

The vast literature dealing with alliances appears unanimous in emphasising the importance of inter-firm collaboration in high-tech industries for a range of firms, including spin-offs (Hagedoorn 1996; Carayannis et al. 2000; Contractor and Lorange 2002; de Faria et al. 2010). The biopharmaceutical industry is a prime example of an industry where new firms, such as spin-offs, play an important role in inter-firm collaboration (Roijakkers and Hagedoorn 2006; Ernst & Young 2011). The continuing appeal of alliances in these industries may be understood from a number of perspectives, including achieving improved economies of scale and scope (Gomes-Casseres 1997), further specialization in newly discovered technology fields (Zidorn and Wagner 2012), obtaining external legitimation (Baum and Oliver 1991) and gaining access to international markets (Hamel and Prahalad 1989), financial resources (Roberts and Mizouchi 1989; Lerner and Merges 1998), and complementary assets necessary to commercialize end-products (Rothaermel 2001).

A more specific explanation resides in the observation that spin-offs operate in an environment characterized by strong technology and market uncertainties (Debresson and Amesse 1991; Santoro and McGill 2005). These characteristics are particularly relevant for the pharmaceutical and biotechnology industries (Senker and Sharp 1997), where many new chemical entities and proteins/peptides are developed but few are actually chosen. Recent data put the clinical success rate of pharmaceuticals and biopharmaceuticals at 13 and 32 percent, respectively (DiMasi et al. 2010, see also Bienz-Tadmor et al. 1992, for earlier data). Even so, only about 30 percent of the products that reach the marketplace eventually generate enough revenues so as to repay their R&D costs (DiMasi and Grabowski 2012). Given the prospect of such an uncertain future, the formation of inter-firm alliances may be seen as an important way for spin-offs and other new technology-based firms to hedge their R&D investments (Mowery 1989; Hagedoorn 1993).

In addition, few, if any, spin-offs initially possess the broad range of technological capabilities needed to stay innovative across a broad front of products and services (Forrest 1990). Insofar as innovations are the lifeblood of high-tech industries, allowing firms to increase market share and, ultimately, profits (Cooper 2001), it is not surprising that the lack of both skilled personal and information on new technologies is regarded as some of the most critical internal obstacles to innovation (Galia and Legros 2004; OECD 2005). In that context, new firms such as spin-offs are often prompted into inter-firm collaboration by the need to gain access to other firms' knowledge-based resources (Nohria and Garcia-Pont 1991; Das and Teng 2000). With the growth of these inter-firm alliances, the locus of innovation for firms, including spin-offs, is no longer located within a single firm but rather in the network in which that firm is located (Freeman 1991; Powell et al. 1996; Powell and Grodal 2005).[1]

The suggestion that the innovation performance of firms (both spin-offs and other categories of firms) owes very much to their network of alliances with other firms is even made more forcefully by the management literature. Some studies have thus shown that inter-firm alliances are positively associated with both innovativeness and innovation success of firms, as measured by their successful product development to the commercialization stage (Freel and Harrison 2006; Kim 2012), the percentage of new products ideas brought to market (Dowling and Helm 2006), and growth of new to the market sales per employee (Belderbos et al. 2004). Others have demonstrated that the more alliances a firm undertakes with other firms,

1. According to a number of innovation studies, knowledge contributing to the development of innovations from new technology-based firms such as spin-offs is also often obtained from or jointly developed with partner firms (Langrish et al. 1972; Gibbons and Johnston 1974; Von Hippel 1988; Arundel et al. 1995; Griffith et al. 2006; Eurostat 2008).

the more it generates new patents (Shan et al. 1994), new product awards (Soh 2003); new chemical entities in the market (Bierly and Chakrabarti 1996), new biotechnology products in the pipeline (Sorrentino and Garrafo 2010) or in the market (Rothaermel 2001), improved products (Knoben 2009), and technological innovations (Chen and Li 1999; De Propris 2000; Chang 2003; Faems et al. 2005; Neyens et al. 2010). Danzon et al. (2005) present evidence showing that a new drug is more likely to complete the crucial phases 2 and 3 of clinical trials if developed in an alliance rather than independently. This leads to the following baseline hypothesis:

H1 (baseline hypothesis): The number of inter-firm alliances of spin-off firms and their innovation performance are positively related.

Alliances involving partners of different size (i.e. large incumbents, small and medium sized firms (SMEs)) will unlikely be equally valuable. Haeussler et al (2012), for instance, investigate the link between network formation among SMEs and innovation performance and find that a new biotech firm's partnerships with other new firms offer no opportunities for new product development, although the effects of these alliances on innovation performance are mitigated by the degree to which the new firm has specialized technological capabilities. This finding is largely in consonance with those of Miotti and Sachwald (2003), Fritsch and Franke (2004) and Nieto and Santamaria (2007) who present different but compelling empirical evidence showing that alliances among SMEs have negative or no influence on their innovation performance.

A notable exception is the study of Luo and Deng (2009) set in the biotechnology industry. Investigating whether networking with other dedicated biotechnology firms promote innovation, Luo and Deng (2009) find an inverted U shaped relationship between this type of alliance formation and innovation output in terms of the number of patents issued to a biotech firm. This inverted U shaped relationship is explained in terms of both the cost of lack of information diversity and the competition between partners that take their toll on the innovation performance of the dedicated biotechnology firm. Rothaermel and Deeds (2006) also find an inverted U shaped relationship between a dedicated biotechnology firm's inter-firm alliances and new product development, regardless of the alliance type (i.e. other biotech firms and large pharmaceutical firms). The respective point of diminishing returns for alliances with large pharmaceutical firms, however, is reached later. Rothaermel and Deeds (2006) explain this as follows: inter-firm alliances with established firms achieve better results for a longer period because large pharmaceutical firms are endowed with superior alliance management capability enabling them and their smaller counterparts to get the most out of their collaborations.

A number of other studies have further highlighted the specific benefits of new, small firm - large firm alliances without such diminishing returns. These contributions suggest that alliances with large incumbent firms fortify a newly established firm's reputation and the perceived quality of its technology more than an alliance with a less prominent partner (Baum et al. 2000; Stuart 2000; Dacin et al. 2007; Rao et al. 2008). Most importantly, the endorsement of a technology's intrinsic value by large established firms has the potential of attracting other more high-quality partners which, in turn, can increase the access of a new technology-based firm, such as a spin-off, to critical resources and, in so doing, positively influence its innovation performance (Dacin et al. 2007). Stuart (2000), in his study on new technology-based firms in the semiconductor industry, reports that alliances with well-known and larger firms play a significant role in building confidence in the value of young and small firms' product and services, thereby facilitating their endeavors to attract other corporate partners and, ultimately, innovate. In another example, Baum et al. (2000) show that dedicated biotechnology firms, such as biotech spin-offs, using alliances with prominent pharmaceutical firms displayed better rates of patenting activity than those using alliances with other small biotech firms. Based on this understanding of the specific role of alliances with large established, incumbent firms, rather than with SMEs, we expect that:

H2a: In terms of their innovation performance, spin-off firms benefit more from alliances with large firms than from alliances with small and medium-sized firms.

However, despite all the attention paid to the potential benefits of alliances, it is also known that the failure rates of alliances are far from trivial, with failure rate estimates ranging anywhere between 46 percent (Kogut 1988) to 70 percent (Day 1995). Particularly interesting in the context of our paper, Alvarez and Barney (2001) estimate that the probability that a small firm - large firm alliance will be unsuccessful may be even as high as 80 percent, with many of the small firms involved having to declare bankruptcy following the alliance failure. Given this problematic track record of alliances between unequally-sized firms, it is not surprising that in an alternative view on such alliances, metaphors of 'dancing with elephants' (Perez et al. 2012), 'dancing with gorillas' (Prashantham and Birkinshaw 2008) and 'swimming with sharks' (Katila, et al. 2008) have been employed to also highlight risks that small firms face in partnering with larger companies. Rosenbusch et al. (2010), who conducted a meta-analysis to review 42 empirical studies, suggest that the internal innovation development projects of small firms are more productive than those projects that involve collaboration with larger firms. Similarly, a longitudinal study of alliances in the U.S. motion picture industry carried out by Vandaie and Zaheer (2014) indicates that large partners diminish the positive effect of internal capability on the growth of small, independent studios.

The literature suggests a range of explanations as to why alliances with large established partners do not always meet the expectations of new technology based firms such as spin-offs. Some studies state that convergence of purpose stemming from cultural distance and technological uncertainty stand in the way of successful asymmetric alliances between firms of very different size (Doz 1988; Tripsas et al. 1995). Others cite the poor communication between two very different 'species': whereas larger firms feature multiple 'layers' in their organizational structure and explicit processes for every task, small and newly established firms comprise generalists who generally use informal processes for getting things done (Botkin and Matthews 1992; Kelly et al. 2000; Prashantham and Birkinshaw 2008).

In general, the understanding of asymmetric alliances boils down to the basic idea that large firms might leverage their bargaining power and extract a disproportional share of the benefits (Khanna et al. 1998; Bessy and Brousseau 1998; Kishida 2002; Lavie 2007). Nowhere is this more evident than in exploratory alliances (i.e. alliances motivated by the desire to discover new opportunities (Koza and Lewin 1998)), where firms face constant value allocation renegotiations about the intellectual property rights of newly discovered technologies that were impossible to foresee at the outset (Rothaermel and Deeds 2004; Yang et al. 2014). In that context, new, small firms, such as spin-offs, that often lack the experience associated with managing external collaboration, are being disadvantaged vis-à-vis their large alliance partners (Rosenbusch et al. 2011; Yang et al. 2014).

To understand why the bargaining power of large partners often helps them capture the lion's share of the benefits of alliances requires not only looking closely at the type of alliance involved but also examining the options available to the small partner outside of the alliance (Khanna et al. 1998; Miles et al. 1999; Kishida 2002; Suen 2005; Lavie 2007). Indeed, as postulated by the resource dependence theory, cash-limited small new technology based firms, such as spin-offs, that have no alternatives for bringing their product to the market other than through alliances may find themselves in a relatively low power position for negotiating the terms of an alliance with large incumbents. Miles et al. (1999) tested this proposition more explicitly in the context of the Canadian high-tech sector and concluded that new technology-based firms, such as spin-offs, that heavily depend on alliances with large firms underperform compared to those that can consider a range of alternative options. In a more positive setting, Greve et al. (2013) stress that for innovative firms, also smaller innovative firms, these alternative options can also be found in alliances with small partners that generate valuable radically new innovative insights. Therefore, less asymmetric alliances with firms that are more equal in terms of size and bargaining power might therefore also provide an interesting option to spin-offs in securing benefits, such as innovative output, from their alliances. The above suggests an alternative hypothesis:

H2b In terms of their innovation performance, spin-off firms benefit more from alliances with small and medium-sized firms than from alliances with large firms.

The concept of spin-off has now been in existence for several decades (Cooper 1971; Garvin 1983) and much is known about the important and positive contributions of both corporate spin-offs (CSOs) and public research spin-offs (PROs) to economic value and job creation (for a literature overview, see Moncada et al. 1999; OECD 2001; Shane 2004; Helm and Mauroner 2007; Tübke 2005; Klepper 2009). Empirical studies that compare the relative performance of different types of spin-offs provide rather mixed results. On the one hand, the work of Lindholm-Dahlstrand (1997b), Löfsten and Lindelöf (2005), and Yagüe-Perales and March-Chordà (2012) find no significant evidence of differences in patenting activity among the different types of spin-offs. On the other hand, a range of other studies suggest that CSOs grow significantly faster than other types of spin-offs in terms of employment and sales or PROs perform less than other spin-offs (Stankiewicz 1994; Lindholm-Dahlstrand 1997a; Callan 2001; Tübke 2005; Ensley and Hmieleski 2005; Mustar et al. 2008; Yagüe-Perales and March-Chordà 2012; Zhang 2009; Zhara et al., 2007).

The expected advantage of CSOs over PROs begs the question as to what factors cause these differences. The answer provided by most scholars refers to the imprinting argument set forward by Stinchcombe (1965): organizations carry the legacy of their founding conditions. In the context of spin-offs, the argument goes as follows: CSOs outperform non-CSOs because their founding team members exhibit different 'genetic' characteristics in the form of prior business experience (Dahl and Reichestein 2007; Zahra et al. 2007; Wennberg et al. 2011; Colombo and Piva 2012; Hirai et al. 2013; Andersson and Klepper 2013). In other words, spin-offs do not start their existence with clean slates; instead, they inherit the congenital knowledge of their entrepreneurial founders (Boeker 1989; Huber 1991). In this connection, it is argued that, if PROs are less successful, with fewer prospects for growth and survival than corporate spin-offs, it is largely because their founders often lack the social capital required to secure external financing (Shane and Stuart 2002) as well as the business acumen necessary to bring new products to markets (Lindholm-Dalhstrand 1997b). According to Colombo and Piva (2012) the founders of university spin-offs, that represent PROs, seldom held managerial positions in other firms. These authors also find that academic founders are less likely than their peers from other spin-offs to make adequate human capital based commercial investments. Interestingly, Geenhuizen and Soetanto (2009) reveal that the single most important obstacle to growth facing PROs, such as academic spin-offs, is their lack of marketing knowledge. In another telling study, Agarwal et al. (2004) also underscore the crucial role played by parental knowledge in linking the greater success of CSOs to better initial technological and market pioneering capabilities of their founders.

Extending the imprinting argument even further, Zahra et al. (2007) suggest that the superior performance of CSOs, compared to that of PROs such as university spin-offs, is also related to their founders' abilities to maintain and use various business relationships. According to the authors, the connections and networks of alliances that the founding team of a

CSO inherits at inception significantly enhance its ability to transform knowledge into valuable products. Given that the contacts and networks of PROs, such as university spin-offs, are not as varied and valuable as their corporate counterparts (Zahra et al. 2007), and taken into account the better technological and market pioneering capabilities of CSOs (Agarwal et al. 2004), we expect that, compared to PROs, CSOs are better able to benefit from their alliances. Hence:

H3. In terms of their innovation performance, corporate spin-offs benefit more from alliances with other firms than public research spin-offs.

METHODS

Technology and industry setting

The technology and industry setting for our study is found in the field of combinatorial chemistry, for which the period that we study in the context of alliance formation (1990-2003) marks the shift from its very early emerging state to a first stage of some maturity (Thomke and Kuemmerle 2002). In this context, it is important to note that over time, the term ‘combinatorial chemistry’ has taken different meanings, leading to some degree of misunderstanding and even confusion (Lebl 2002). For some, it refers solely to the split-mix method, arguably the first combinatorial synthesis technology developed by Arkad Furka at Eötvös University in Budapest in 1982. For others, including the International Union of Pure and Applied Chemistry (IUPAC), the term denotes any process used “ … to prepare large sets of organic compounds by combining sets of building blocks …” (Maclean et al., 1999: 2351). This broader definition encompasses over a dozen techniques, ranging from parallel synthesis to click chemistry, and it reflects the industry and technology setting that is subject to our study.

Virtually all process innovations related to combinatorial chemistry originated in academic laboratories and other PROs, including the Central Veterinary Institute in the Netherlands (parallel synthesis), University of Cambridge (diversity-oriented synthesis), Torrey Pines Institute for Molecular Studies (the 'tea-bag' procedure), the German National Research Center for Biotechnology (SPOT synthesis), and Scripps Research Institute (click chemistry). Over time, dozens of university researchers, professors, and other public sector researchers coming from the chemistry discipline jumped on the combinatorial bandwagon, launching spin-offs in the United States (e.g. Richard Houghton at the Torrey Pines Institute for Molecular Studies formed Houghton Pharmaceuticals), Great Britain (e.g. Steve Davies from Oxford University launched Oxford Asymmetry), France (e.g. Thierry Jean resigned from the CNRS to establish Cerep) and Denmark (e.g. Glenn Tong from the Technical University of Denmark co-founded AudA Pharmaceuticals).

However, the field is not exclusively populated by PROs. Established in 1988, Affymax and Coselco Mimotopes were the first two new technology-based firms set up to engage in combinatorial chemistry research. Palo-Alto based independent start-up Affymax was the brainchild of Alejandro Zaffaroni – the quintessential Schumpeterian entrepreneur, legendary for having launched several successful firms (notably Syntex, Alza, and DNAX). Coselco Mimotope was established as a CSO from Commonwealth Serum Laboratories, Australia's largest biotech firm. This later case was not unique. Firms, both large and small and medium-sized, have spun off start-ups with a competence in combinatorial chemistry on their own (Ledbetter and Zipkin 2002). To name a few examples, GlaxoSmithKline spun out NiKem Research; Hoffman LaRoche, Basilea Pharmaceuticals; Scios, Guilford Pharmaceuticals; Affymax, Affymetrix and Maxygen; etc.

In addition, manufacturers of scientific instrumentation (e.g. Advanced ChemTech), computational chemistry suppliers (e.g. Tripos) and, most commonly, biotechnology firms (e.g. Oxford Glycosciences, Vertex Pharmaceuticals) that were seeking to diversify their technology portfolios, also entered into this field. The biotechnology industry embraced combinatorial chemistry for a simple, compelling reason. Genetic engineering is geared towards the production of biopharmaceuticals such as novel peptide and protein drugs. However, proteins and peptides cannot be taken orally and have to be administered by injection. Combinatorial chemistry, by contrast, may be used to generate small molecular weight compounds that may be taken orally, causing less discomfort and increasing patient compliance and thus wider use (Damms and Bains 1995).

New entrants in the field (and large pharmaceutical firms) may exhibit different origins and a variety of business models but they share similar experience regarding combinatorial chemistry: overall results in terms of productivity remained somewhat disappointing (Landers 2004). To understand why, it is important to note that the technology had been introduced with the promise to revolutionize the way medicinal chemists contemplate drug discovery. The premise of the promise - the more compounds screened, the better the chances of finding a good lead for optimization - proved incorrect. Several reasons may be cited – the foremost being the vastness of chemistry space, in terms of the almost limitless quantity of molecular shape that can potentially be created (Lipinski 2000)[2]. However, there is no question that combinatorial chemistry has evolved into a mainstream research tool, not so much for randomly synthesizing huge numbers of compounds but rather to rationally make, in conjunction with structural genomics and computational capabilities, smaller focused collections of molecules with drug-like characteristics (Kennedy et al. 2008). The technology even started to show signs of success, with dozens of compounds with a combinatorial chemistry background entering clinical testing (Golebiowski et al. 2001, 2003). Sorafenib, a de

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2. The chemistry space is estimated to contain from 10^{40} to 10^{100} molecules (Lipinski 2000).

novo combinatorial drug discovered by Bayer for the treatment of advanced renal cancer, was approved by the Food and Drug Agency (FDA) in 2005 (Wilhelm et al. 2006). Equally encouraging is the fact that new materials (Rajan 2008) and pesticides (Lindell et al. 2009) discovered by combinatorial means have made their appearance in the marketplace.

Data and sample

We test our hypotheses on a longitudinal data set composed of 135 spin-offs operating in the field of combinatorial chemistry. Technology class information was used to make an initial identification of spin-offs. Each firm had to be endowed with at least one 'Class 506' patent (which is a special subclass created by the USPTO for inventions in the domain of combinatorial chemistry technology) or have a scientific publication in that field [3]. We then applied the following three criteria to the initial selection: the firm had to be 1) publicly traded so as to allow the collection of R&D expenditures data, 2) established as either a PRO or a CSO, and 3) commercially active between 1990 and 2003. Following Thomke and Kuemmerle (2002), this timeframe represents a particularly interesting period to examine as it largely captures the rapid emergence of combinatorial chemistry and its most dynamic phase of industrial technological development.

In order to remove the ambiguity involved with identifying different types of spin-offs, we adopted the OECD definition of PRO. Accordingly, the term is defined as any new firm 1) of which the key technology is licensed from a university or another PRO, 2) which includes a university or public sector employee as a founder, and/or 3) in which a PRO has made an equity investment (Callan 2001). A CSO, by contrast, refers to any independent entity founded

3. For an examination of the process of creating a new patent category for combinatorial chemistry within the International Patent Classification (IPC), see Kang (2012).

on the basis of a technology and human capital originating from a parent firm (Lindholm-Dalhstrand1997b). Guided by these considerations, we were able to identify 98 public research-based spin-offs (PROs) and 37 corporate spin-offs (CSOs) among our sample firms. Some 104 firms are located in the United States, while the remaining firms are established in eleven EU countries, primarily in Sweden, Great Britain, and Germany, as well as in Canada.

We collected data from a variety of sources. Alliance records were compiled from the Recombinant Capital, a health care data warehousing company, owned by Deloitte Consulting and from the websites of the sample spin-offs. In the present study, we consider all alliances that were established between 1990 and 2003 and include licensing agreements, R&D contracts, minority holdings, distribution or manufacturing agreements, asset trading, joint ventures, and consortia. From the two data sources we were able to identify some 3048 alliances undertaken by the sample firms in the period during which we calculate (lagged) alliance portfolio measures using a 3-year window. Alliances are differentiated into those between spin-offs and large firms (1284 alliances in total), those between spin-offs and SMEs (1184 alliances in total), alliances between spin-offs and PROs (524 in total) and alliances between spin-offs and their parent firms (56 in total). We retrieved information on patents, to construct our measure of innovation performance, from the Technology Profile Report maintained by the U.S. Patent and Trademark Office (USPTO). Our measure is based on granted patents, an indication of successful patent applications that we subsequently assigned to a particular application year. Data on firm-level variables, such as R&D expenditures and the number of employees of US firms were obtained from SEC data at sec.gov., similar data for non-US firms were obtained from annual reports and firm websites.

Measures

Dependent variable. We use an invention (patent) count as our measure of spin-off's innovation output. Insofar as firms were engaged in a broad spectrum of research activities, patent data not only include patents in ‘Class 506’, but also those related to technologies other than combinatorial chemistry, as for example ‘Class 435’ (molecular biology and microbiology). Patents are typically regarded as among the most effective source of information for research on innovation and have been widely used as an indication of firm innovation (Sampson, 2007). One of their key advantages is reliability and objectivity because new inventions are cross-examined whether they satisfy criteria of novelty by patent officers at the U.S. Department of Commerce. The caveats of using patent data as a proxy for innovativeness are well known: not all innovations are patented, and those that are do display a great deal of variability in terms of value or importance (Pavitt 1985; Griliches 1990). The dependent variable is measured in year t+1 with respect to the right-hand-side variables.

Focal independent variables. In line with previous research, alliances are defined as inter-firm cooperative agreements that are intended to affect the long-term product market positioning of at least one partner (Hagedoorn, 1993). Alliances are measured as the number of alliances established by the firm in the years t-2 through t (i.e. cumulative sum over three years prior to the measurement of the dependent variable). Alliance data precede patent data for two reasons. First, learning from collaborators is not automatic; it requires commitment, resources and, not least, time (Bierly and Chakrabarty 1996). Second, a gestation lag naturally separates the start of collaboration and the output of innovative activity (Stuart 2000; Katila and Ahuja 2002). For the purpose of this study, a large firm alliance is defined as an alliance with a partner firm of more than 500 employees (more than twice the average size of a spin-off) whereas a SME partner has fewer than 500 employees.

Control variables. We control for alliances that spin-off firms formed with PROs and with their own parent firms. These two variables are constructed in the similar way as the focal variables. Research on industry-science collaboration shows that alliances between industry and universities intensified in the 1990’s (e.g. Hall et al., 2003). Public science is attractive for firms because it provides low cost access to new knowledge and recent scientific developments. Alliances with parent firm may serve the purpose of strengthening a newly established firm's reputation and the perceived quality of its technology and provide a newly establish venture with resources.

The value of R&D expenditures accounts for variation in inputs into the innovation process (Griliches, 1990). R&D activities are expected to be a vital instrument in the innovation process and these activities are also expected to eventually be transformed into patents, certainly in a high-tech and patent-driven sector such combinatorial chemistry. In addition, higher levels of internal R&D activities of firms can also be seen as a signal of valuable R&D capabilities to potential alliance partners.

Firm size (the logarithm of firm employees) is a standard control variable in innovation studies and refers to the classical Schumpeterian understanding of the impact of firm size, through economies of scale and scope, on innovative performance in general and patenting activity, in particular (see also Belderbos, et al., 2006).

We also control for the technological diversification of spin-offs that can affect both innovation output and alliance activities of firms due their technological flexibility (Bierly and Chakrabarty, 1996). Technological diversification refers to the distribution of patents in a firm's patent portfolio over technology classes. Technology class information comes from the patent classes into which patents are assigned. To construct the diversification measure we distinguished between 243 unique 3-digit patent classes. We use a standard Shannon-Wiener diversity index to measure technological diversification, i.e. $Tx = \sum_i p_i \log 1/p_i$ where i stands for any patent class. Obviously, a firm that has been granted patents in different patent classes will have a greater diversification index than a firm with patents in a single patent class. In addition, all models include unreported year dummies.

RESULTS

Some descriptive statistics and correlations are presented in table 1. We have predominantly small firms in our sample of spin-offs with a mean of about 180 employees. Average alliance portfolio size is about seven alliances, based on a 3-year cumulative sum, including alliances with PROs and own parent firms. The latter two types are not very frequent in our data, with sample average of 1.07 and 0.16, respectively. Pairwise correlations among the variables used in the estimation are moderate in most cases, with two exceptions. This includes the correlation between firm size and R&D and between portfolio of alliances with large firms and SMEs. We show that any estimated effect of these two alliance variables is not due to potential (spurious) correlation, by also estimating models with only one of these variables included. The mean variance inflation factor (VIF) for the variables used in our models is about 2.6, which is below the commonly used threshold of 10 (Cohen et al. 2003).

Insert Table 1 about here

From the early till late 1990s we observe among the sample firms a strong upward trend in the alliance formation that flattens in 1998-1999 (see figure 1). This in turn is followed by a strong recovery around the turn of the century and a further dip after the technology crisis. The upward trend is more pronounced among the PROs than CSOs (see figure 2). Overall, these trends are consistent with those documented in Hagedoorn (2002) and Schilling (2009).

The composition of these alliances is largely similar in the two types of spin-offs, suggesting that variation of innovation performance across spin-offs cannot be linked to variation in the number of, for instance, R&D contracts (see figures 3a and b).

Insert Figures 1, 2, 3a and b about here

In the estimation of our models we seek to control for unobserved heterogeneity and potential endogeneity of the focal variables. Regarding the former we are inclined to argue that a core part of unobserved firm heterogeneity will be fixed, given the relatively short time span of our analysis. A number of traits such as firm corporate or public-research background, founding team's demographic traits and human capital will not change or change little over time. In our empirical models we control for such influences by including the firm fixed effects.

A second potential source of endogeneity is the formation of alliance portfolios (over time). Portfolios may be not be completely exogenous if their configuration is driven by other endogenous concerns such as the search for technological variety or if their composition is dictated by the relative ease or difficulty of attracting partners. The latter may play a role if the relatively more successful firms in terms of their patenting become systematically more attractive to incumbent firms for alliance formation.

We sought to address the above concerns by conducting estimation of our model via instrumental variables (IV) and fixed-effects Poisson regression methods.[4] In the IV GMM approach, we instrument alliances with other firms, alliances with large firms and SMEs, with

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4. Estimation of our models with the fixed-effects Poisson regression method implies that we cannot include any time-invariant variables, such as a dummy for the background of the firm or personal characteristics of the founder(s), in our models, since such a dummy always takes the same value during the estimation period. In the random effects specification of the Poisson model (not reported) we are able to estimate the coefficient of the dummy for the background of the firm, but we find that it is not statistically significant, implying that spin-off's background does not directly determine in our sample firm's innovation performance.

their lagged values (measured in period t-3 to t-5) and a dummy variable indicating whether the firm is vested in the US or in the EU.

We present this analysis of the relationship between alliances and the innovation performance of spin-offs[5] in table 1 and list the non-instrumented versions of our fixed-effects count models in the Appendix. The GMM specification and the non-IV models produce consistent results while the Hansen test does not reject appropriateness of the instruments.

Regarding the control variables, we find, not surprisingly, that R&D expenditures have the expected positive and significant effect on the innovation performance of spin-offs in this industry. The effect of the technological diversification of these spin-offs is significant in model I and model III.

Model I tests and confirms our baseline hypothesis (hypothesis 1), which argues that formation of inter-firm alliances and innovation performance of corporate and public-research spin-offs, are positively related. In support of hypothesis 2a, we find that alliances of spin-offs with large firms have a positive impact on their innovation performance, and obviously, in rejection of hypothesis 2b, alliances with small firms have insignificant impact on their innovative performance (see table 2, Model II). The difference between the two estimated coefficients is statistically significant (χ^2 (1) = 4.34, p-value=0.03). In support of hypothesis 3, in terms of their innovation performance, CSOs benefit more from alliances with other firms than PROs (see Table 2, Model III). The difference between the two estimated coefficients is again statistically significant (χ^2 (1) = 12.84, p-value=0.00).

Supplementary analysis

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5. From the original sample of 135 firms, nine firms report zero patents during the estimation period and one firm has only one observation and hence these firms are dropped from the Poisson fixed-effects regression. Four of these firms are CSOs and six are PROs.

In addition to testing the hypotheses, we also explored whether spin-offs, in terms of either CSOs or PROs, benefit more from having alliances with large firms or with SMEs (see table 2, model IV). In line with some previous studies (Baum et al. 2000; Stuart 2000), we find that both CSOs and PROs improve their innovation performance if they cooperate with large firms. The difference between the two estimated coefficients is not statistically significant. Interestingly, our findings also suggest that, in particular for PROs, cooperation with SMEs has a negative impact on their innovation performance (see table 2, model IV).

The logic behind hypothesis 3 would suggest that, contrary to CSOs, PROs may actually benefit more from alliances with other PROs with which they share a common background. We explored this by estimating an additional regression (not reported) in which we interact PRO alliances with the spin-off dummy. The PRO alliances of spin-offs with a PRO background variable is indeed positive and significant in a random effects Poisson model (and marginally insignificant in the fixed effects model), while the effect for CSOs is negative and marginally significant.

Robustness checks

To test the robustness of our findings we estimated a number of alternative specifications of our model. We explored the models with an alternative alliance portfolio variable, that is, calculated using a 5-year window, to examine a potential influence of longer lags on firm's patent output. These results are largely in line with those obtained from the reported models using a 3-year window. One notable exception is the coefficient on the inter-firm alliances by PROs, which becomes weakly significant. However, in line with hypothesis 2, the coefficient on this variable is statistically significantly smaller than that for the CSOs. This may suggest that the positive effects of inter-firm collaboration are slower to gestate among PROs than among CSOs.

To test whether the underlying main effects of alliance variables are non-linear we considered models with the square terms of the three alliances variables included. However, neither of the three square terms are statistically significant. Inclusion of the square terms also makes the linear terms insignificant, hence we can rule out non-linearity with respect to these variables.

DISCUSSION AND CONCLUSIONS

As the combinatorial chemistry industry emerged and reached its phase of early maturity, spin-offs in this field were bracing for serious challenges presented by a globalizing environment that is characterized by a fast pace of technological change (Malo and Geuna 2000). In order to survive in this environment, these firms needed to initiate shrewd alliance strategies (Mohr et al. 2014). Interestingly, it seems that this is exactly what spin-offs in the field of combinatorial chemistry did during the period 1990 – 2003. Specifically, as also demonstrated through Figures 1 and 2 show, their level of engagement in alliance activity steadily increased during the larger part of that early period. As reported in the above, this increase in alliance formation in the early period of the combinatorial chemistry industry is in line with the general alliance formation trend across a wider range of industries.

In the context of that general trend, there is an abundant literature on the performance effects of alliances in general (e.g., Das et al. 1998; Chan et al. 1997; Hagedoorn and Schakenraad 1993; Stuart 2000; Niosi 2003; Baum et al. 2000; Rothaermel 2001; Li and Tang 2010). However, relatively little attention has been paid to the effects of alliance strategies of spin-offs on their innovation performance. Our contribution clearly demonstrates that spin-off firms operating in a nascent industry can benefit from increasing numbers of alliances that positively affect their innovation performance.

In addition to such a general observation, our current contribution indicates a number of more specific interesting findings related to the preference of spin-offs for particular partners and their corporate or public research background. First, during this early period of the combinatorial chemistry industry, inter-firm alliances with specific partners, in terms of their firm size, benefitted spin-offs in different ways. While alliances with relatively large partners generated benefits in terms of increased innovation performance, those with SME partners did not. In line with previous research, this finding suggests that spin-offs can benefit from collaborating with large firms that bring superior alliance management capabilities to joint projects (Rothaermel and Deeds, 2006), while these alliances with large firms also increase spin-offs' status and reputation that make it easier for these firms to attract other capable partners (Baum et al. 2000; Stuart 2000; Dacin et al. 2007; Rao et al. 2008). Our findings suggest that through these alliances with large firms, spin-offs are able to learn from their large partners and improve their innovation performance. As also indicated by Haeussler et al. (2012), Miotti and Sachwald (2003), Fritsch and Franke (2004) and Nieto and Santamaria (2007), spin-offs find fewer learning opportunities through alliances with SMEs that offer fewer opportunities for advanced technology and product development as there is a high likelihood that these SME partners, unlike larger partners, have somewhat similar capabilities.

Second, when looking at the background of spin-offs we see that during the emergence and early growth of the combinatorial chemistry industry, CSOs benefitted more from their inter-firm alliances than PROs. While both types of firms, CSOs and PROs, stand to gain from alliances with larger firms, PROs seemed to lose when they ally with SMEs, while such effect was neutral for CSOs. The greater benefits from inter-firm alliances for CSOs, compared to PROs, can be interpreted in light of the corporate or public research backgrounds imprinted in these spin-offs. Previous studies on entrepreneurship indicate that the founding team's origins affect firm success (e.g., Roberts and Weiner 1966; Cooper 1971; Eisenhardt and

Schoonhoven 1990; Mangematin et al. 2003). In the context of PROs vs. CSOs there is evidence that CSOs outperformed PROs in terms of return on assets and productivity, in large part because CSOs' founders had an advantage in using their prior experience, networks and connections (e.g., Lindholm-Dahlstrand 1997b; Zahra et al. 2007). We expect that similar advantages, in terms of prior experience, networks and connections, played a role in creating greater innovation performance benefits from a broad range of inter-firm alliances for CSOs that, during the nascent state of the combinatorial chemistry industry, were still connected to their corporate origins while PROs lacked these advantages and had fewer options but to search for alliances with more visible larger corporate partners.

Limitations and future research

Our study has a number of limitations, which at the same time suggest avenues for future research. First, our sample of a single industry could limit the generalizability of our findings. The role of different types of alliances for young, innovative spin-offs in different industrial settings is worth further investigation in light of renewed academic and policy interest to such firms (see Schneider and Veugelers, 2010).

Second, our empirical setting largely covers the emergence and gradual maturing of the combinatorial chemistry industry, a period characterized by high growth and high alliance activity of spin-offs. Further research could determine whether alliances continue to play a significant (positive) role as an industry further matures.

Third, as is the case with most innovation studies, we cannot fully exclude the possibility of reverse causality. Interestingly, a number of studies have examined a reverse relationship, i.e. the impact of firm's innovation on its partnership formation. For example, Ahuja (2000) concludes that innovativeness has a significant positive effect on partnership formation in the chemicals industry. Stuart (1998, 1999) and Podolny, Stuart and Hannman (1996) report similar findings in the semiconductor industry. The logic behind this relationship, using

Ahuja's terminology, is that a firm's propensity to form partnerships is determined by both 'inducements' and 'opportunities'. Innovative firms may have greater 'opportunities' to engage in alliances, because these firms are more attractive partners for joint technology development. On the other hand, high levels of technical and commercial expertise will reduce firms' 'inducement' to engage in collaboration. As firms engage in alliances, successful innovative firms face a danger of involuntary dissipation of their knowledge to potential competitors, which can lead to weakening of their competitive advantage. Our research suggests that for resource inhibited spin-offs it is primarily positive 'inducements' that play an important role, thus mitigating the reverse causality logic. In addition, in an attempt to further minimize this possibility in the analysis, we estimated our models with the instrumental-variables method.

Fourth, our analysis took into account the technological diversity of the firms in a broad sense, ignoring possible technological relatedness between dyads in a focal firm's alliance portfolio (Sampson, 2007). Further insights into an optimal alliance portfolio will require taking into account additional characteristics of alliance partners such as their knowledge base and the intensity of the collaboration. The interplay between the characteristics of the firm, its alliance partners, and the host countries could refine the model. Our analysis could not include potential organizational moderators of the effects of alliances on innovation performance. In our analysis we controlled for such firm-related time invariant characteristics via the fixed effects. However, it is conceivable that firms with specialized alliance departments, and/or superior alliance capabilities may be more effective at building shrewd alliance strategies and handling the complexity associated with handling multiple partnerships (Heimeriks and Duysters, 2007).

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Table 1 Descriptive statistics and pairwise correlations

	Mean	SD	1	2	3	4	5	6	7
1. Patents	6.96	15.48	1.00						
2. Firm size (log)	4.63	1.14	0.38	1.00					
3. R&D expenditures	9.44	1.50	0.39	0.66	1.00				
4. Technological diversification	0.58	0.58	0.32	0.41	0.42	1.00			
5. Alliances with own parent firm	0.16	0.48	-0.07	-0.11	-0.12	-0.04	1.00		
6. Alliances with PROs	1.07	1.69	0.05	0.01	0.05	0.12	0.23	1.00	
7. Alliances with large firms	3.07	3.49	0.27	0.47	0.39	0.34	-0.01	0.14	1.00
8. Alliances with SMEs	2.87	3.66	0.32	0.42	0.36	0.24	0.01	0.17	0.65

Note. Correlations based on 929 observations for 125 firms. Correlations greater than .07 are statistically significant at an alpha level of .05, and correlations greater than |.05| are statistically significant at an alpha level of .01.

Table 2 Alliances and the innovation performance of corporate and public research spin-offs

Variable	Model I	Model II	Model III	Model IV
Constant	-4.195***	-5.625***	-4.241***	-5.406***
	(0.504)	(1.184)	(0.522)	(0.972)
Firm size	-0.031	-0.231	0.009	0.026
	(0.119)	(0.402)	(0.107)	(0.137)
R&D	0.504***	0.761***	0.489***	0.620***
	(0.060)	(0.210)	(0.049)	(0.081)
Technological diversification	0.446***	-0.217	0.565***	0.127
	(0.081)	(0.482)	(0.085)	(0.286)
Alliances with own parent firm	-0.031	0.161	0.020	0.165
	(0.107)	(0.162)	(0.084)	(0.119)
Alliances with PROs	-0.073**	-0.105	-0.098***	-0.118***
	(0.035)	(0.070)	(0.031)	(0.037)
Alliances with other firms	0.059***			
	(0.019)			
Alliances with large firms		0.258**		
		(0.110)		
Alliances with SMEs		-0.071		
		(0.074)		
Alliances of CSOs with other firms			0.059***	
			(0.016)	
Alliances of PROs with other firms			0.025	
			(0.020)	
Alliances of CSOs with large firms				0.093***
				(0.034)
Alliances of PROs with large firms				0.187***
				(0.062)
Alliances of CSOs with SMEs				0.048
				(0.044)
Alliances of PROs with SMEs				-0.153**
				(0.078)
Hansen test, p(value)	2.248 (0.13)	1.451 (0.48)	2.481 (0.29)	1.490 (0.47)

Note: Results from fixed effects instrumental-variables Poisson models. Robust (clustered) standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01. All models are estimated on a sample of 929 observations for 125 firms and include 8 time dummies. The dependent variable is measured in year t+1 with respect to the right-hand-side variables. The Hansen test statistic is the test of overidentifying restrictions.

Figure 1 Spin-off alliance formation with large and small & medium-sized firms by year

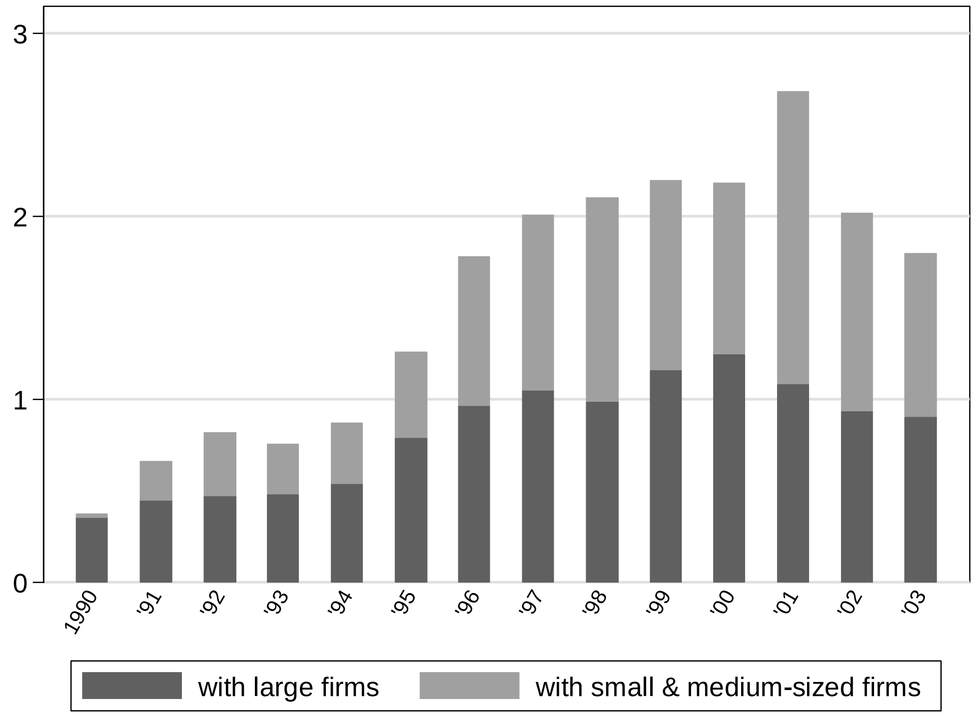


Figure 2 Spin-offs alliance formation by year and type of spin-off firm

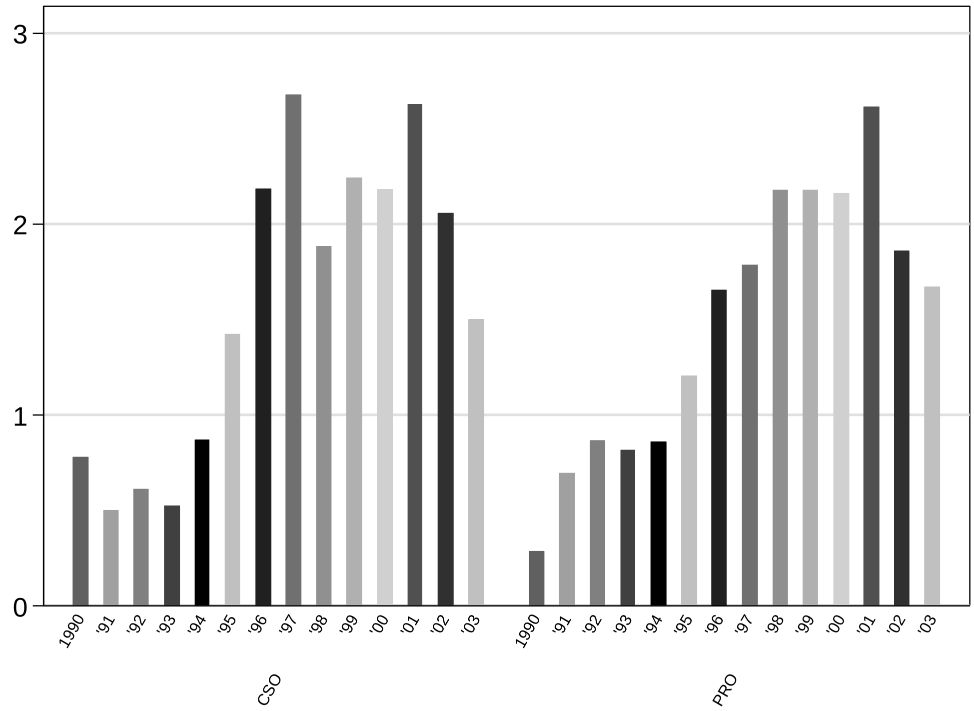


Figure 3a Distribution of R&D alliances, licensing agreements, and other forms of cooperation for CSOs

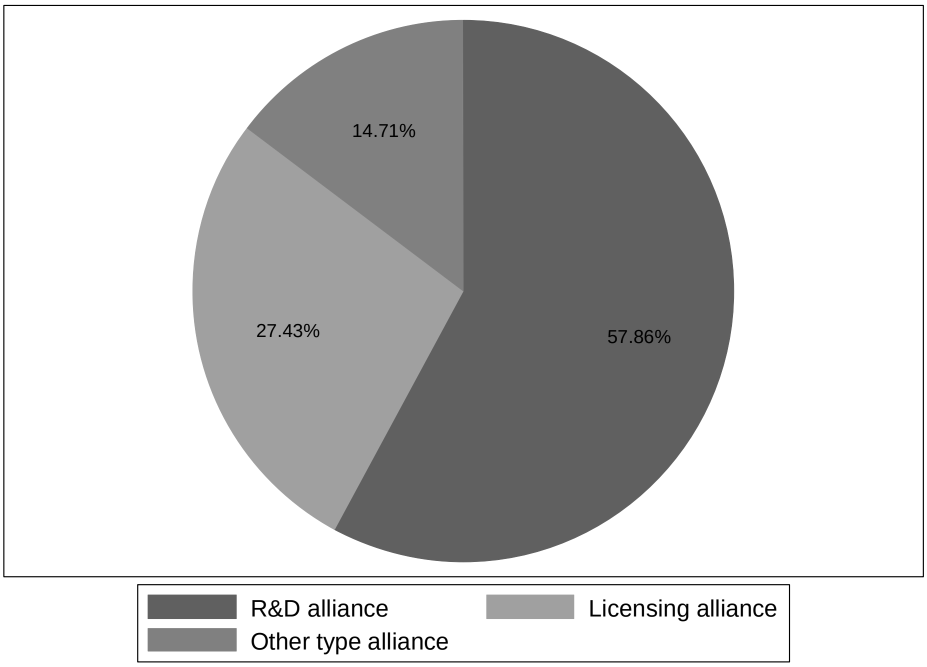
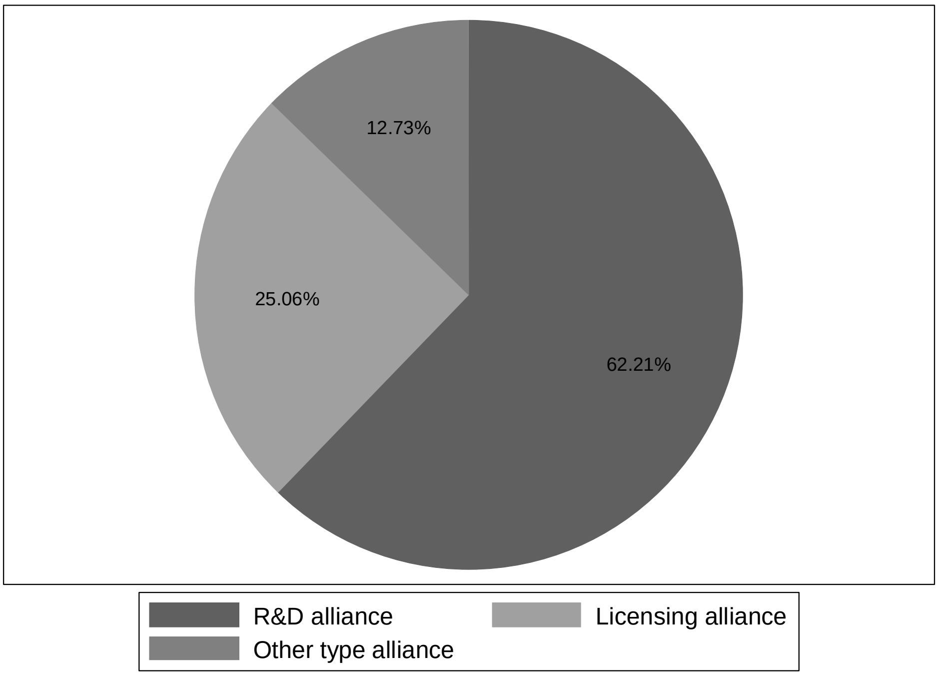


Figure 3b Distribution of R&D alliances, licensing agreements, and other forms of cooperation for PROs



APPENDIX

Alliances and the innovation performance, fixed-effects Poisson without instrumental variables

Variable	Model I	Model II	Model III	Model IV
Firm size	0.101	0.033	0.097	0.025
	(0.204)	(0.167)	(0.202)	(0.177)
R&D	0.225**	0.252**	0.236**	0.256**
	(0.108)	(0.109)	(0.104)	(0.112)
Technological diversification	0.198	0.216*	0.210*	0.222*
	(0.123)	(0.128)	(0.120)	(0.127)
Alliances with own parent firm	-0.002	0.017	0.008	0.015
	(0.119)	(0.113)	(0.115)	(0.112)
Alliances with PROs	-0.044	-0.026	-0.048	-0.024
	(0.041)	(0.022)	(0.041)	(0.027)
Alliances with other firms	0.026***			
	(0.009)			
Alliances with large firms		0.081***		
		(0.016)		
Alliances with SMEs		-0.035**		
		(0.014)		
Alliances of CSOs with other firms			0.031***	
			(0.008)	
Alliances of PROs with other firms			0.021	
			(0.015)	
Alliances of CSOs with large firms				0.085***
				(0.018)
Alliances of PROs with large firms				0.074**
				(0.030)
Alliances of CSOs with SMEs				-0.039
				(0.027)
Alliances of PROs with SMEs				-0.031*
				(0.019)
Log-likelihood	-2665.13	-2570.98	-2663.13	-2570.42
χ^2 test of improved model fit		188.29***	3.99**	185.43***

Note: Results from fixed effects Poisson models. Robust (clustered) standard errors in parentheses.
* p<0.1, ** p<0.05, *** p<0.01. All models are estimated on a sample of 929 observations for 125 firms and include 8 time dummies. The dependent variable is measured in year t+1 with respect to the right-hand-side variables. The χ^2 test statistic is the likelihood-ratio test comparing the focal model with the more parsimonious model