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The implications of academic enterprise for public science: An overview of the empirical evidence

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ABSTRACT

Concerns have been raised that the growing emphasis on the commercial value of academic research may have negative, unintended consequences, notably that it may have a deleterious effect on the production and dissemination of scientific knowledge or on the open-ended nature of public science. These concerns have catalyzed an expanding set of empirical studies, the evidence from which is vast and mixed. We review this body of investigative work, teasing out some preliminary conclusions regarding the broader implications of academic enterprise and promising avenues for further research.

1. Introduction

There is a growing interest in the commercial potential of public science. Policymakers and research organizations alike seek to bolster the speed and effectiveness with which knowledge and inventions generated through publicly funded research are brought to bear on the development of commercial products. As a result, public research organizations are increasingly engaging in *academic enterprise*, that is, systematic efforts to strengthen the short-term commercial value of their research, and to facilitate or pursue the commercialization of their inventions.

Numerous scholars have however raised concerns that the increasing, and at times exaggerated, focus on enterprise in academia may have unintended effects on the long-term progress of science, namely that it will undermine the efficiency of the division of labor that exists between public and private science (e.g. Cowan, 2005; Dasgupta and David, 1994; Nelson, 1989, 2004; Rosenberg and Nelson, 1994), by shifting academic researchers away from the activities in which they are most efficient – that is, supplying a collective good (Feller, 1990; Metcalfe, 1998; Nelson, 1959, 2001). More precisely, as we will see in this review, there are concerns that researchers who engage in academic enterprise are more likely to also undertake research that is more applied in nature, that lends itself more easily to patenting, and/or which has short-term commercial potential (e.g. Azoulay et al., 2006), and that they may do so at the expense of disinterested, long-term research (e.g. Fabrizio and Di Minin, 2008; Florida and Cohen, 1999; Jacobsson, 2002).

These concerns have spawned a number of empirical studies that investigate the broader implications of increased industry involvement, patenting and commercialization efforts for the progress of science. These studies focus on two questions in particular. First, does academic enterprise occur at the expense of the production and dissemination of scientific knowledge, materializing itself as decreases in the volume or quality of publications, or as publication delays? Second, does the growing focus on industry and enterprise force, or entice, scientists to undertake more applied research, at the expense of more fundamental scientific research?

The mounting evidence from these studies is vast, and its interpretation is complicated by the sheer complexity of the issues addressed and the number of different questions, indicators and methods used in the studies. Nonetheless, some preliminary conclusions and promising avenues for further research are emerging.

The purpose of this article is to provide an overview of empirical investigations of the implications of academic enterprise for the production of scientific knowledge and the nature of publicly funded research. As such, the aim of this article is not to yield an exhaustive survey or detailed evaluations of prior work, but rather to point to some general developments in this expanding stream of research, as a starting point for more in-depth comparisons and for the setting of future research agendas.

The article is structured as follows. We begin with a short discussion in Section 2 of the basis for both the growing interest in academic enterprise, and the concerns regarding its broader implications for the progress of science.

We then turn our attention to the expanding stream of empirical work on this issue. Section 3 focuses on the possible effects of aca-

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demic enterprise on the production and dissemination of scientific knowledge. Our review indicates that, despite some inconsistencies in empirical findings, enterprise appears, by and large, to be positively related to traditional academic endeavors as indicated by the performance of scientists who engage in commercially oriented activities. Moreover, a handful of recent studies indicate that we are only just beginning to understand why, and under which circumstances, this positive relationship emerges. In addition, there is some evidence that academic enterprise also brings publication delays and restrictions on the dissemination of public research.

Section 4 addresses the smaller, but related stream of research on the relationship between enterprise and the nature of public research. Here, we find no conclusive evidence that industry involvement, academic patenting or commercialization activities are associated with increasing levels of applied research (or basic research, for that matter). This may be largely explained by the difficulties involved in distinguishing between, and especially measuring, basic and applied research. A number of studies indicate, however, that academic enterprise may be linked to a shift towards research that is oriented or even targeted towards commercial use and exploitation, regardless of whether it might be described as "basic" or "applied". The magnitude and implications of this issue for the overall progress of science remain unclear.

Whether we examine the relationship between enterprise and researchers' scientific performance or the relationship between enterprise and the nature of scientific research, it is important to acknowledge the uncertainty regarding the direction of causality. The studies examined in this review look for significant relationships between commercially oriented research activities and the nature and quality of researchers' performance. The existence of a significant relationship, however, does not necessarily imply a causal relationship. Where there is a positive relationship between for instance a scientists' patenting activities and her scientific productivity, it is possible that neither is a consequence of the other, but that they are both instead related to other factors, such as for example personal characteristics of the scientist, to the presence of additional resources that have not been fully measured, or to the type of research problem that the scientist is working on. Such causality issues increase the complexity and interpretation of the empirical studies included in this review. As will be seen, some of the studies simply acknowledge relationships, while others try to take our understanding a step further by proposing theory-based explanations for the patterns that emerge from the empirical data.

The article ends with Section 5, which presents some concluding reflections.

2. On the rise (and reproach) of academic enterprise

A number of factors have contributed to the heightened focus on the commercial potential of academic research. First, a growing dissatisfaction with the direct and measurable returns from investments in public science has resulted in what Pavitt referred to as a "quest for greater relevance" in public science (Pavitt, 2001, p. 768). This quest has manifested itself in the form of pressure on academic organizations to engage the industry-based users of their research more directly in their activities (Pavitt, 1991, 2001).

Second, increasing costs of scientific research, coupled in several European countries with decreasing government funding for academic research, have forced public research organizations on a search for additional financing (Geuna, 1999, 2001). Scientific researchers pursue a growing proportion of their research funding from public research funding organizations and programs, many of which support selected "strategic" research areas, and from private organizations, many of whom are focused on research of relatively direct or short-term commercial relevance. Meanwhile, the successful patenting and commercialization of a number of academic inventions by American universities have drawn attention to a potential means of generating income more directly from public research. In addition, academic enterprise enhances a research organization's visibility and status in industry, and may therefore help attract both collaborators and funding.

Indeed, policymakers and legislators are increasingly encouraging (and in some countries requiring) universities to patent research results and to pursue their commercialization through for instance licensing deals or the establishment of academic spin-off companies. The past few decades have seen a dramatic increase in the number of patents taken out by academic scientists and organizations in both the U.S. (Henderson et al., 1998) and Europe (Lissoni et al., 2007).

In the U.S., the Bayh-Dole Act of 1980 played an important role in expanding IPR protection for publicly funded research by placing the responsibility for patenting and subsequent commercialization activities with universities (Mowery, 1998; Mowery et al., 2001). More recently, similar changes to the legislation governing the protection of intellectual property created from publicly funded research have been made in a number of European countries. This has been accompanied by efforts to establish technology transfer offices, science parks, and university–industry research centers – all with a view to accelerating and maximizing the returns from publicly funded research, albeit with mixed success (Cervantes, 1998; Mowery, 1998).

Current policy initiatives toward greater enterprise in academia have in fact been criticized for being largely based on anecdotal evidence of successful licensing and spin-off activities from U.S. universities such as Columbia University, Stanford University and Massachusetts Institute of Technology, in spite of the lack of solid, empirical support for the argument that patenting stimulates the transfer of university technology to industry, and in spite of the ambiguous nature of current empirical evidence on the long-term implications of academic enterprise (Geuna and Nesta, 2006; Verspagen, 2006).

Moreover, concerns have been expressed that policy justifications are based to a large extent on unrealistic expectations regarding the income streams that may be generated from the commercialization of academic research (Feller, 1990; Nelson, 2001, 2006). Numerous studies have called for caution in overestimating the economic value of university patenting and regulations like the Bayh-Dole Act. Empirical research suggests that the Act was but one of several key factors behind the rise in academic patenting (Colyvas et al., 2002; Mowery et al., 2001), alongside in particular the increasing ease with which some forms of fundamental research, notably within the life sciences, but also in electronics and software, began lending themselves to patenting (Mowery et al., 2001).[1]

Findings that recent increases in patenting activity in American universities were associated with a decrease in the quality and value of university-held patents (Henderson et al., 1998; Mowery and Ziedonis, 2002), and that a small number of patents accounted for a disproportionately large amount of the revenues from licensing in three universities leading the way in academic patenting, namely the University of California, Stanford University, and Columbia University (Mowery et al., 2001), have raised questions regarding the value of academic enterprise.

A key issue with the debate surrounding the unintended consequences of increasing enterprise in academia is that this debate

[1] The Act was moreover passed in order to simplify and streamline procedures for the appropriation and licensing of inventions developed through federally funded research, and not to encourage the development of new sources of rents for universities *per se* (Mowery et al., 2001; Verspagen, 2006).

tends to get very polarized: academic enterprise is often touted either as the solution to all problems in public science or as the end of academic civilization as we know it.

Clearly, academic enterprise is not the public-science equivalent of the Apocalypse. The idea that universities should contribute more directly to economic growth and society is not new, and has played an important role during several previous periods in the evolution of the university without having a long-term negative impact on teaching or research activities (Martin, 2003). University–industry research collaboration in particular is not a new phenomenon (e.g. Lee, 1996; Rosenberg and Nelson, 1994; Tether, 2002); moreover, it plays a vital role in advancing scientific and technological progress through joint problem solving and by opening up new avenues for research (e.g. Meyer-Krahmer and Schmoch, 1998; Rosenberg, 1990, 1994a,b; Rosenberg and Nelson, 1994).

Similarly, numerous studies have emphasized the role of legislation on university patenting and related policy changes in stimulating and facilitating the transfer of university technology to industry and the development of spin-off companies based on academic research findings (e.g. Di Gregorio and Shane, 2003; Etzkowitz and Leydesdorff, 2000; Meyer, 2006a; O'Shea et al., 2005; Shane, 2004).

The interesting question is therefore not whether academic enterprise is advantageous for or detrimental to science, but rather whether and, if so, how it affects the productivity and nature of academic research. This is the question raised by the empirical studies that will be reviewed in Sections 3 and 4, on the relationship of enterprise to the production of scientific knowledge and the nature of academic research, respectively.

3. On the relationship between academic enterprise and the production of scientific knowledge

In this section, we dive into the rapidly growing stream of empirical research on the implications of academic enterprise for the production of scientific knowledge, as indicated by the performance of the scientists who engage in it. The term *scientific performance* denotes two distinct aspects of academic research performance. First, it refers to the volume of research which is undertaken, that is, the overall research *productivity* displayed by an organization (such as a research institute or a university), an organizational unit (e.g. a department or research group), or by an individual. Scientific productivity is typically measured using data on publications in scientific journals as an indicator of scientific productivity,[2] as they constitute the primary means of diffusing academic research findings. Second, "scientific performance" may also refer to the scientific *impact* of one or more researchers or publications on the research community.[3] It is often approximated using data on citations to publications or to the journals in which they appeared, as a proxy for the awareness and use of published research by the scientific community.

A chief concern regarding the involvement of public scientists in academic enterprise is that patenting and commercialization activities may divert scientists' resources and attention away from scientific research, because academics have limited time and resources available for their research (e.g. Fabrizio and Di Minin, 2008; Lowe and Gonzalez-Brambila, 2007).[4]

It has also been suggested that the growing focus on industry involvement and orientation may be altering long-standing incentive structures – based on norms of openness, universalism and communalism and the importance of scientific priority and reputation (Dasgupta and David, 1994; Merton, 1973) – to widely and promptly disseminate research (Azoulay et al., 2006). Following this line of thought, we expect to see that with greater enterprise comes greater secrecy, and the increased focus on patenting in particular may thus have a deleterious effect on the openness of science, causing scientists to for example eschew or delay publications (e.g. Blumenthal et al., 1996, 1997; Calderini and Franzoni, 2004; Dasgupta and David, 1994; Fabrizio and Di Minin, 2008; Florida and Cohen, 1999; Lee, 2000; Nelson, 2004; Polanyi, 1960–1961; Stephan et al., 2007).[5] Moreover, even when research results are published, this does not necessarily mean that the experiments can be replicated, for example because vital data or tacit knowledge are withheld (Stephan et al., 2007).

The justification for the public funding of scientific research is based on the underlying assumption that the results of this research will be made freely and widely available, unlike the proprietary research outputs generated through privately funded research (Dasgupta and David, 1994). Moreover, scientific and technological progress is a cumulative, evolutionary process (Nelson, 2006). Research-derived knowledge is not, however, a bottomless well, and it is therefore necessary to sustain a certain level of scientific activity in order to maintain the pool of technological opportunities from which firms and entrepreneurs draw in their innovative activities (Klevorick et al., 1995). When academic discoveries and inventions are appropriated, this may slow down or even hinder their diffusion and therefore their use as inputs in further research and development activities (e.g. Mazzoleni and Nelson, 1998; Mowery et al., 2001; Nelson, 2006), resulting in a privatization of the "scientific commons" (Nelson, 2004; see also Argyres and Liebeskind, 1998; Heller and Eisenberg, 1998; Murray and Stern, 2007).

In a recent NBER working paper, Murray et al. (2009) explore whether restrictions on scientific openness (e.g. in the form in formal intellectual property protection) may limit diversity and experimentation in upstream research. The authors examine data on scientific activity within the field of mouse genetics following a lifting of restrictions on the use for downstream research of important patents in the field. They find that the granting of control rights to researchers and the ensuing openness was conducive to both follow-on research and an increased diversity of research lines. The authors argue that restrictions on scientific openness, e.g. through patenting, limits diversity and experimentation in upstream academic research.

[2] While publication counts provide little if any information about the contribution to knowledge that a scientist has made, they do represent a "reasonable measure of scientific production" (Martin, 1996, p. 347).

[3] "Impact" is often used interchangeably with another term, "quality". Although the concepts they cover are related, they are distinct terms. As Martin (1996) pointed out, "impact" refers to the influence that a publication has on surrounding research activities, by virtue of its contribution to knowledge but also other factors such as the affiliation and location of the authors, and the language and status of the journal in which it appeared, whereas "quality" refers to a property of the publication, which is influenced primarily by the quality of the underlying research and the merits of the skill with which the article was actually written. Although the studies examined here draw on both terms, "impact" is deemed to be the more precise term for the concepts and is therefore the term used in this article.

[4] This claim has however been questioned in the context of academic patenting by Azoulay et al. (2006), who point out that university technology transfer offices actually handle many of the tasks involved in patenting on behalf of the academic inventors, and suggest that the potential benefits of patenting are likely to outweigh the amount of time invested.

[5] By its very nature, patenting involves the publication and thus dissemination of research results and methods. Therefore, patenting does not necessarily imply increased secrecy. However, unless patenting is undertaken with a view to non-exclusive licensing at no or little cost, it is generally concerned with protecting research methods or results and restricting their use, and therefore does not divulge more information about the research methods or results in question than necessary for patenting.

The potential growing privatization of the scientific commons is particularly disquieting when inventions require extensive development and refinement before commercialization is possible (Mazzoleni and Nelson, 1998), something which is often the case for university inventions, which tend to be generic and embryonic in nature (Jensen and Thursby, 2001), and of little intrinsic economic value before they have been incorporated into further research and development activities (David et al., 1994).

Indeed, survey-based studies of faculty members have shown that receiving industry funding and engaging in patenting and commercialization activities may all be associated with increased secrecy surrounding research methods and results. For example, Blumenthal et al. (1996) found that life scientists who received industry funding were more likely to restrict their communication with colleagues. Furthermore, related studies found that scientists who had engaged in commercial activities or collaborated with industry were more likely to delay the publication of research results (Blumenthal et al., 1997), to withhold data (Campbell et al., 2000) and to restrict access to research materials (Walsh et al., 2007). Thus, academic enterprise may also affect the informal sharing of knowledge and research inputs by academics

In spite of these concerns, scholars have also advanced a number of arguments for why academic enterprise and scientific performance might coexist in a symbiotic relationship. Many of these arguments stem from discussions of the relationship between academic patenting and scientific performance, but can be extrapolated to other forms of academic enterprise. Breschi et al. (2007), for example, pointed to the possible existence of an "individual productivity effect", whereby both publications and patents may be seen as proxies for scientists' individual abilities. According to this line of thought, a highly accomplished scientist would be likely to exhibit both higher publishing and patenting activity than less accomplished peers.

It has also been pointed out that the same research may naturally lead to both scientific publications and patents (Agrawal and Henderson, 2002; Azoulay et al., 2006; Fabrizio and Di Minin, 2008; Stephan et al., 2007). This is especially likely in research that falls under what Stokes (1997) referred to as "Pasteur's quadrant" – research which is motivated both by a quest for fundamental understanding and by considerations of use. Prior research indicates that the life sciences may be a particularly fruitful arena for research, which is both publishable and patentable (Mowery et al., 2001; Murray, 2002; Murray and Stern, 2007).

Moreover, Fabrizio and Di Minin (2008) argued that scientists are likely to publish results even if they are also patented, because of the continued importance of publications for establishing priority and reputation in academia (see also Stephan, 2008). Also, because the scientific reputation of a researcher can play a crucial role in raising awareness and strengthening the legitimacy of an academic invention (thus for instance improving its chances of subsequent licensing), inventors are likely to publish their research anyway, using their publications to signal the quality of their invention to the scientific community (Agrawal and Henderson, 2002; Azoulay et al., 2006; Fabrizio and Di Minin, 2008). On a related note, patenting may also enhance the prestige of publishing scientists (Stephan et al., 2007), by increasing their visibility and certifying the novelty and usefulness of their work (Owen-Smith and Powell, 2001).

Furthermore, engaging in patenting or other forms of academic enterprise is likely to bring public scientists into contact with industry, which may carry a number of benefits for scientists' research (see e.g. Gibbons and Johnston, 1974; Lee, 2000; Mansfield, 1991, 1995; Siegel et al., 2003). Over time, the resulting interaction with researchers in companies may prompt new research questions, catalyze collaborations that would not have occurred otherwise, and provide direct or indirect access to additional funding for academic research, either from licensing revenue by attracting industry funding (Fabrizio and Di Minin, 2008; Stephan et al., 2007).

As such, Azoulay et al. (2006) suggested that scientists who engage in both academic and industry oriented research are likely to achieve "within-scientist economies of scope", as they bring insights and opportunities from both realms of research together in their own work. On a related note, Breschi et al. (2007) argued that there may be a positive relationship between patenting and publishing explained by what they refer to as a "resource effect", meaning that individual scientists engage occasionally or consistently in patentable research and patenting with a view to attracting additional resources – both financial and cognitive – from industry.

Obviously, many of these arguments regarding the relationship between the production of scientific knowledge and academic enterprise are born out of reflections on the relationship between scientific performance and *patenting*, but they hold relevance for other forms of academic enterprise as well, for instance academic collaboration with industry researchers. We now turn to the mounting evidence from the body of empirical work on this issue, as summarized in Table 1, which indicates that academic enterprise and scientific performance are – at least in principle – complementary activities.

3.1. Emerging evidence of a positive relationship

We begin by reviewing a number of studies that examine the relationship between scientific performance and various indicators of academic involvement with industry, including receiving industry funding (Blumenthal et al., 1996; Gulbrandsen and Smeby, 2005), research collaboration and co-publication (Godin and Gingras, 2000; Hicks and Hamilton, 1999; Landry et al., 1996) and, finally, contract research (Van Looy et al., 2004).

In a survey of 2052 life-science faculty members at the 50 American universities receiving the most research funding from the National Institutes of Health, Blumenthal et al. (1996) found that faculty members who received research funding from industry published more articles than peers without industry support. Gulbrandsen and Smeby (2005) obtained a similar result in their 2001 survey of faculty members employed at Norway's four universities. They found no significant relationship between the production of commercial outputs (such as patents, the development of commercial products, the creation of spin-off companies, and contract research projects) and publishing. However, they did find that scientists with any form of external funding (i.e. from industry, or from other sources such as the Norwegian research councils or European Union programs) were more productive than scientists with no external funding. However, differences in productivity were only significant for scientists with industry funding as compared to scientists with other forms of external funding in two fields, namely the social sciences and medicine. According to Geuna and Nesta (2006), this suggests that in some fields, external funding in general (but not industry funding in particular) is positively associated with productivity.

Research collaboration between public and private scientists has also been found to be positively related to the performance of participating academics. For instance, based on a survey (in an unspecified year) of 1566 professors in universities in Québec, Canada, Landry et al. (1996) found that research collaboration was generally positively related to academic productivity, and that this relationship was particularly strong when the academics' collaborators were industrial researchers.

While Landry et al. (1996) thus focused on the effects of university–industry collaboration and academic *productivity*, Hicks and Hamilton (1999) took a closer look at the impact of university–industry collaboration on scientific *impact*. They ana-

Table 1
Studies of the relationship between academic enterprise and scientific performance (as indicated by productivity and/or scientific impact)[a].

Study	Explanatory variable	Relationship to productivity	Relationship to impact
Blumenthal et al. (1996)	Industry funding	Positive (with diminishing returns)	N/A
Gulbrandsen and Smeby (2005)	Industry funding	Positive	N/A
Landry et al. (1996)	Research collaboration	Positive	N/A
Hicks and Hamilton (1999)	Co-publication	N/A	Positive
Godin and Gingras (2000)	Co-publication	Positive	None
Van Looy et al. (2004)	Contract research	Positive	N/A
Agrawal and Henderson (2002)	Patenting	None	Positive
Van Looy et al. (2006)	Patenting	Positive	N/A
Carayol (2007)	Patenting	Positive	N/A
Stephan et al. (2007)	Patenting	Positive	N/A
Meyer (2006b)	Patenting	Positive	Positive
Buenstorf (2006)	Patenting; licensing	Positive	Positive
	spin-off creation	Negative	Negative
Lowe and Gonzalez-Brambila (2007)	Spin-off creation	Positive	Positive
Franzoni et al. (2007)	Patenting	Positive (timing depends on field)	Depends on field
Bonaccorsi et al. (2006)	Industry funding	Positive (with diminishing returns)	N/A
Fabrizio and Di Minin (2008)	Patenting	Positive (with diminishing returns)	None (but negative relationship emerges with repeated patenting)
Calderini and Franzoni (2004)	Patenting	Positive (high productivity both predates and follows patenting)	Positive (associated with a period of high impact publishing)
Azoulay et al. (2006)	Patenting	Positive	None
Azoulay et al. (2007)	Patenting	Positive (associated with response to scientific opportunity sets)	N/A
Breschi et al. (2007)	Patenting	Positive (high productivity both predates and follows patenting)	Positive

[a] N/A: not applicable. Studies listed in the order in which they are discussed in the article.

lyzed the 2.1 million articles published in journals covered in the ISI Science Citation Index (SCI) between 1981 and 1994, for which all authors were from the U.S. They found that academic publications co-authored by industry researchers were more highly cited than publications without industry affiliated co-authors.

Godin and Gingras (2000) examined the relationship between public-private co-production of publications and collaboration and both academic productivity and impact. Using data compiled from the database of publications by Canadian researchers in SCI-indexed journals from 1980 to 1997, produced by the *Observatoire des Sciences et des Technologies* (OST) under the patronage of Statistics Canada, they found that co-authorship with industry, hospitals and government laboratories was positively related to productivity, but that it was not significantly associated with scientific impact (as indicated by the impact factor of the journals in which publications appeared).

On a similar note, Van Looy et al. (2004) examined the publication profiles of professors from 14 research divisions engaged in contract research to industry at the Catholic University of Leuven, and found that professors working in divisions undertaking contract research published more articles than colleagues in similar fields who were not affiliated with industry oriented divisions.

We now turn our attention to a group of studies that examined the relationship between scientific performance and academic patenting, and that all found some indication of a positive relationship between the two (Agrawal and Henderson, 2002; Buenstorf, 2006; Carayol, 2007; Meyer, 2006b; Stephan et al., 2007; Van Looy et al., 2006). We will also address the findings of two studies that look at academic licensing and start-up creation (Buenstorf, 2006; Lowe and Gonzalez-Brambila, 2007), where the relationship to scientific performance is less clear-cut than for academic patenting.

To the best of the author's knowledge, only one study of the relationship between academic patenting and scientific performance found no evidence that patenting and productivity were positively associated. Incidentally, this is also the first study that explicitly addressed the relationship between patenting and publishing in academia. Agrawal and Henderson (2002) studied faculty patenting behavior in two departments at the Massachusetts Institute of Technology (MIT): the Departments of Mechanical Engineering (ME) and Electrical Engineering and Computer Science (EECS). They examined data on the publication and patenting activity over a 15-year period, from 1983–1997, of all 236 professors on faculty in the two departments in September 2000, who had at least one patent or publication during the period of study.

For the small subset of professors in their sample who engaged in patenting, they found no significant relationship between the number of patents and the number of publications.[6] However, they found some evidence that professors' patent counts were linked to their research impact, as indicated by the number of total citations to their work. The authors acknowledged that high patent volume may reflect the fact that a given professor's research is more immediately applicable in industry, thus (at least partially) explaining higher citation counts, but emphasized that their citation data included citations by both academic and industrial researchers and therefore put forth a tentative conclusion that, at least in the departments they studied, patenting does not appear to substitute for publishable research, and that the two activities might even be complementary.[7]

In contrast to the results of Agrawal and Henderson (2002), three studies published in 2006 and 2007 that only address the relationship between academic patenting and productivity (and not impact) find that patenting and productivity are positively related. In one of these studies, using data on patents (1995–2001) and

[6] Fabrizio and Di Minin (2008) suggested that a possible explanation for this finding might lie in the fact that Agrawal and Henderson's (2002) data was derived from an elite institution such as MIT. They suggested that if a positive relationship between publishing and patenting is explained by the fact that it facilitates access to industry funding, then this might be relatively less important at an elite institution than at other universities, implying that elite researchers benefits relative less from such funding in terms of e.g. productivity. They also proposed that the relationship between publishing and patenting may differ for faculty members in general and faculty members at elite institutions.

[7] Calderini and Franzoni (2004) also suggested that an alternative explanation for this finding may be that industry seeks out professors with a good scientific reputation who, in the course of their subsequent interaction with industry, are directed toward patenting activities.

publications (1998–2000) by all faculty members cum inventors at the Catholic University of Leuven, Van Looy et al. (2006) found that academic inventors published more than a matched sample of their non-inventing colleagues. In another study, Carayol (2007) studied patenting behavior during the period 1995–2000 of nearly 900 faculty members during their employment at the University Louis Pasteur, France. Controlling for, among other things, scientists' age and position, as well as the size of the research laboratories with which they were affiliated, he also found a positive relationship between publishing and patenting. Finally, using data from the 1995 Survey of Doctorate Recipients in U.S. universities, Stephan et al. (2007) examined the patenting activity of a sample of 10,962 doctoral scientists and engineers working in institutions of higher education. Using a variety of instrumental variables and methods of estimation, the authors consistently found patenting to be positively and strongly related to the number of publications. A break-down of their analysis by the four scientific fields covered in their data set – computer sciences, life sciences, physical sciences, and engineering – however showed that the positive relationship remained strongly significant only for the life sciences, and somewhat significant for the physical and engineering sciences.

Several other recent studies explore the relationship between academic enterprise on the one hand, and both the productivity and scientific impact of the scientists who engage in it on the other. Meyer (2006b) examined data on the performance of both publicly and industry funded inventor-authors working in nanoscience and nanotechnology in three European countries (the United Kingdom, Germany and Belgium), and the performance of a matching sample of their non-inventing peers. Meyer found that patenting scientists were both more productive and more highly cited than non-patenting scientists.

Another study to have found a positive relationship between patenting on the one hand and both scientific productivity and impact on the author, is a study by Buenstorf (2006) of the Max Planck Institute, a non-university public research organization in Germany. He examined the disclosure of inventions, licensing and firm foundation activities of Max Planck directors during the period 1985–2004. Buenstorf not only found a positive relationship between *patenting* and scientific performance, but also between *patent licensing* activity and scientific performance. However, when he turned his attention to the directors who had been involved in the establishment of new, research based firms, he found that involvement in the establishment of academic spin-off companies had an adverse effect on scientific productivity and impact. This last finding stands in sharp contrast to the results of a study by Lowe and Gonzalez-Brambila (2007). They looked at all 150 faculty entrepreneurs at 15 North American research institutes, that is, faculty members who founded a firm to develop and commercialize an invention within medicine, engineering, biology, chemistry or physics, during the period 1990–1999. Unlike Buenstorf (2006), they found that faculty entrepreneurs were generally both more productive (based on differences in mean publication rates and the skewness of publication rates) and more highly cited researchers (based on citations to the journals in which they published) than control groups consisting of their graduate school peers, co-authors, other faculty members from their university, and the general population of faculty members.

This finding did not, however, hold for all research fields. In certain fields, particularly in mechanical engineering, faculty entrepreneurs were significantly less productive than researchers in the control groups. In addition, the authors find some indications that the positive relationship between entrepreneurship and scientific impact may be particular to the field of biomedicine, though they are unable to confirm this statistically.

The authors also found, controlling for possible life cycle effects, that the publishing productivity of faculty entrepreneurs did not decrease following the establishment of a firm. Here, the authors again found important differences across scientific fields: they found no significant difference in publication output subsequent to firm foundation for biology and chemistry entrepreneurs, when compared to the respective control groups. However, engineering faculty experienced a significant increase in publication volume as compared to their control group after having founded a firm. The authors themselves point to the limitations of the relatively broad categorization of research fields that they apply.

Nonetheless, the findings by Lowe and Gonzalez-Brambila (2007) support those by Gulbrandsen and Smeby (2005) and Stephan et al. (2007), and suggest that publishing and patenting may be complementary only in some fields (most notably biomedicine and the life sciences). On a related note, Franzoni et al. (2007) found striking differences the in the relationship between patenting and publishing in two sub-fields of materials science. For example, in materials engineering, the authors found evidence of an increase in productivity subsequent to patenting, whereas in materials chemistry they found indications that patenting was followed by a decrease in the number of publications. They also found major differences in scientific impact. Clearly, deeper understanding of the relationship between academic enterprise and scientific performance in different research fields requires further, more fine-grained analysis.

3.2. A positive relationship... with decreasing returns to productivity?

The studies described above all found some evidence of a positive relationship between academic enterprise and scientific performance. But is more enterprise in academia really always better? There is something counterintuitive about the idea that increasing degrees of industry involvement and commercial orientation would always be beneficial to academics' scientific performance.

Indeed, some recent studies have found evidence of diminishing returns to individual researchers' scientific productivity from high levels of industry funding (Blumenthal et al., 1996) and from repeated patenting (Fabrizio and Di Minin, 2008). In addition, Bonaccorsi et al. (2006) found indications of diminishing returns to a university's aggregate publication profile from large proportions of industry funding.[8] Key methods and findings of these studies will now be outlined.

In the previously mentioned study by Blumenthal et al. (1996), the authors found that faculty members with research funding from industry were more productive than peers without industry support. However, they also found that those faculty members who received *the most* industry support (that is, more than two thirds of their total funding) were less productive than those who received lower levels of industry funding. On a related note, in a recent study

[8] On a related note, Larsen (2007) presents the results of a study that examined whether increasing degrees of collaboration with industry could be associated with diminishing benefits for scientific performance. Using co-authorship of publications as an indicator of collaboration with industry, this study drew on a small dataset of publications by full professors at the Technical University of Denmark over a 32-year period. Professors with no collaboration with industry were found to have fewer publications and citations than their collaborating peers. For the professors who did collaborate with industry, the study found evidence of a curvilinear relationship (in an inverted U-shape) between the degree of collaboration that professors engaged in and their scientific productivity, indicating that the positive relationship between collaboration and productivity was eventually curbed by decreasing (and, ultimately, possibly negative) returns from increasing degrees of collaboration. A recent working paper from the Solvay Business School (Sapsalis, 2007) also mentions indications of a curvilinear relationship between productivity and co-publication with industry, in a study of publishing and patenting activity at the School of Engineering and Applied Science of Columbia University.

of Italian universities, Bonaccorsi et al. (2006) investigated whether a tradeoff exists between research for publication and research for industrial use or patenting. They found some indications that although collaboration with industry (as indicated by the average percentage of university budgets funded by industry from 1994 to 1999) might initially improve aggregate productivity, beyond a certain level it appeared to deteriorate publication profiles in some universities, possibly because of the difficulties in meeting industry expectations that increase with the extent of collaboration.

Fabrizio and Di Minin (2008) investigated the relationship between publishing and patenting using a cross-institutional panel data set covering 166 faculty members who had engaged in patenting, and a matching sample of non-patenting researchers. Using individual-level fixed effects to control for time-invariant heterogeneity across individual scientists, and controls for life cycle effects in publication patterns, they found that patenting activity was positively associated with the production of publications by university researchers.

However, Fabrizio and Di Minin (2008) also found diminishing benefits to patenting for researchers with several patents: with increasing numbers of cumulative patents, the positive relationship between researchers' publication and patenting activities declined, and the average number of citations to publications fell.[9] Based on this finding, the authors proposed that while sporadic or small-scale patenting may yield the kind of complementarities with publishing described at the beginning of this section (through interaction with industry and the attraction of additional resources for research), diminishing or negative effects on productivity may arise as a result of repeated and consistent patenting activity, because of the constraints on time associated with patenting and possibly constraints imposed by close relations to industry.

An important implication of the findings in these studies is that greater industry involvement or commercial orientation in academia may not be problematic. In fact, it may be beneficial for scientific performance, at least in certain research fields and for certain researchers. However, they also suggest that there may be some optimal level of industry orientation or involvement in academia, beyond which the complementarities between enterprise and scientific performance are eroded.

3.3. A closer look at patenting and publishing

In the following, we examine a handful of studies that further our understanding of the relationship between publishing and patenting by taking a closer look at the timing of academic and commercially oriented activities, and by exploring different explanations for the complementarities that appear to exist between the two.

Calderini and Franzoni (2004) examined data on 1323 researchers at Italian universities and public research institutions, working in engineering chemistry and nanotechnology for new materials. Although they found some evidence of publication delays in connection with academic patenting, they found patenting to be positively related to the quantity of publications and their quality (as indicated by the impact factor of the journal in which they were published, and by the number of citations they had received). In addition, they found that patenting activity was both pre-dated but followed by a period of high volume and high impact publishing activity, lending support to the argument that the same research may be both publishable and patentable.

Using a panel data set of a random sample of 3862 life scientists working in universities and non-profit research organization between 1968 and 1999, Azoulay et al. (2006) found that both the stock and flow of scientists' patents was positively related to their subsequent publication volume. They found no evidence that the productivity benefit came at the expense of the quality of publications (as measured both by the order of authors on the publications, and by measure of the quality for the average publications by a given scientist in a given year, derived from a composite measure based on the impact factors of the journals in which publications by that scientist in that year appeared), though they found no substantial or consistently significant relationship between patenting and the average quality of publications.

In a companion paper, Azoulay et al. (2007) found that patenting appears to be associated with distinct surges of productivity that presumable arise as a result not of steady research performance on the part of the scientist, but rather in connection with variations in scientific opportunities. More specifically, they discovered that patenting was often preceded by a burst of publication activity in the year leading up to the patent application. According to the authors, this implies that patenting is not only a function of time-invariant demographic factors, but that it also occurs in response to variations in the scientific opportunity set (and their exploitation by researchers).

On a related note, Breschi et al. (2007) used a longitudinal data set of 299 Italian academic inventors (who were listed as inventors on patent applications to the European Patent Office, from 1978 to 1999), and a matching sample of scientists with no patenting activities. The inventors were distributed across four fields with a high occurrence of academic inventors, namely chemical engineering, biology, pharmacology, and electronics. The authors found a positive relationship between patenting and publishing, and that patents were discrete events associated with productivity increases for individual scientists. More specifically, they found that inventors demonstrated superior productivity, as compared to their non-inventing peers, both around the event of the patent application and during a period of time leading up to the patent. The authors also found indications of the superiority of inventors when examining citation-weighted publication rates as when they examined non-weighted publications rates; however, they found a drastic decrease in the scientific impact of inventors in biology from 2000 and onwards.

Moreover, the authors proposed that the explanation for the superior productivity of academic inventors lies partly in an "individual productivity effect", meaning that some researchers are simply more brilliant researchers (regardless of the activities they engage in, whether it comes to patenting or publishing), and partly in a "resource effect" derived from the financial and/or cognitive resources that often come with technology oriented projects, that also result in patenting. In fact, Breschi et al. (2007) found that the strongest complementarity between patenting and publishing emerged when patents were applied for by firms rather than by individual scientists or universities, suggesting that the links to industry, not patenting in itself, were the crucial determinant of productivity. In contrast, Fabrizio and Di Minin (2008) reached an opposite conclusion, namely that the positive relationship between patenting and publishing was driven by university patents rather than corporate or unassigned patents, which they suggested indicated that the research encoded in university assigned patents may be closer to academic (as opposed to commercial) research, and therefore yield more publications (or that university technology transfer offices may simply choose to patent the research with the greatest scientific merit, and which is therefore also associated with more publications, whereas less promising research remains unassigned or is picked up by a firm).

[9] The authors argue that the decrease in citation intensity with repeated patenting may be explained either by a decrease in the quality of the work or by restrictions on use that emerge in connection with patent protection.

3.4. Looking ahead

In this section, we have reviewed the mounting empirical evidence on the relationship between academic enterprise and scientific performance.

Clearly, the most often used indicator of academic enterprise in the studies reviewed here was academic patenting. Its popularity is probably largely explained by the availability of patent data and by the relative ease with which patents can be linked to for example publication data. However, patenting constitutes only a small channel of transfer of university knowledge and technology to industry, particularly when compared to other forms of university–industry technology transfer such as e.g. informal collaboration, consulting, conferences etc. (e.g. Agrawal and Henderson, 2002; Cohen et al., 2002; Geuna and Mowery, 2007; Levin et al., 1987). Moreover, being listed as an inventor on one or a few patents may still be a long way off from e.g. being a serial inventor or starting an academic-spin-off – in other words, it is a very limited indicator of academic enterprise, and one in which very few faculty members engage in at that (as pointed out by e.g. Agrawal and Henderson, 2002). As such, there is a need to broaden the range of indicators used to proxy academic enterprise, to move beyond patenting to other, more representative forms of indicators, and particularly to examine the implications of engaging in a number of different modes of academic enterprise in combination with each other (Geuna and Mowery, 2007).

Nonetheless, these studies (partly because of the richness and qualities of the data they draw upon) generate important insights. In spite of some inconsistencies in the findings reviewed, it certainly seems that industry involvement and orientation in public science are complementary to what we think of as traditional academic endeavors.

However, several of the studies revealed substantial differences in the nature of this relationship across research fields, and several found the strongest (and sometimes only) evidence of a complementary relationship in biomedicine and the life sciences (Breschi et al., 2007; Franzoni et al., 2007; Gulbrandsen and Smeby, 2005; Lowe and Gonzalez-Brambila, 2007; Stephan et al., 2007). This points to the importance of continuing to look beyond the life sciences, which relies heavily on patenting as a means of knowledge transfer to industry (Cohen et al., 2002), and which accounts for a large proportion of academic patenting activity (Henderson et al., 1998; Mowery et al., 2001), and trying to better understand the differences across research fields.

On a related note, it would also be interesting to further our knowledge of differences in the relationship between enterprise and scientific performance across universities (e.g. Bonaccorsi et al., 2006)[10] and in lesser-studied types of institutions, such as public research organizations.

Moreover, it is also clear that there is not a simple, positive one-to-one relationship between instances of university–industry interaction or academic patenting on the one hand, and scientific publications or citations on the other. On the contrary, two important nuances emerge from prior work. First, the studies by Blumenthal et al. (1996), Bonaccorsi et al. (2006) and Fabrizio and Di Minin (2008) pointed towards the existence of a curvilinear relationship between enterprise and scientific performance in academia, suggesting that there are diminishing returns to performance from different modes of academic enterprise, particularly at higher levels of enterprise as in the case of high patenting activity. Second, the work by, among others, Calderini and Franzoni (2004), Azoulay et al. (2006, 2007), and Breschi et al. (2007) have furthered our understanding of the timing of entrepreneurial and academic achievements, and of possible drivers of the complementary relationship between enterprise and scientific performance.

The studies also revealed a move towards more sophisticated data sets, methodologies and analytical approaches (including, for instance, the growing use of panel data, longitudinal and event history analyses, and cohort analysis). Other important areas for further research include the role of individual characteristics such as age, life cycle effects, academic position and status, gender, institution and field of training, sources and amounts of funding, motivation to engage in academic enterprise etc. (see e.g. Carayol, 2007; Ding et al., 2006; Goldfarb, 2008; Jensen et al., 2003; Levin and Stephan, 1991; Murray and Graham, 2007; Owen-Smith and Powell, 2001; Stephan and Levin, 1992; Stephan et al., 2007; Thursby and Thursby, 2002) and the importance of norms and behavior in the local work environment (e.g. Bercovitz and Feldman, 2008) or collective research and inventive work in research groups or teams.

There is clearly also much more to learn about differences in individual ability to publish or engage in academic enterprise, as reflected in the "individual productivity effect" or "within-scientist" economies of scope described by Breschi et al. (2007) and Azoulay et al. (2006), respectively – what Stephan et al. (2007) refer to simply as "the right stuff". This is in line with the idea of "accumulative advantage" in academic science (Cole and Cole, 1973; Allison and Stewart, 1974), namely, the idea that the skewness in productivity among scientists can be at least partly explained by beneficial feedbacks on prior performance in the form of for instance recognition and resources.[11] Individuals are different and possess different sets and levels of capabilities, as illustrated for example by the existence of "star" scientists who exhibit both superior scientific performance and entrepreneurial performance and play central roles in the development and successful commercialization of science, particularly within emerging fields of technology such as biotechnology and nanotechnology (Darby and Zucker, 2001; Zucker et al., 1998a,b, 2002; Zucker and Darby, 2001). This implies that it should be possible to identify various types of researchers and examine how these various researcher types fare in terms of academic and/or commercial performance. This also raises the question of whether all researchers should strive for the same performance objectives, academic and commercial, or whether it is more effective to engage in some degree of division and specialization of labor, for example within or across departments or research organizations.

In the next section, we turn our attention to a smaller but closely related stream of research, namely on the relationship between enterprise in academia and the nature of publicly funded research.

4. On the relationship between academic enterprise and the nature of public research

The second main issue regarding the broader effects of academic enterprise that we examine in this article pertains to a change in the nature or content of public research. As universities have come under pressure to involve industry more directly in their research activities, and to pursue the appropriation and commercialization of their research outputs, concerns have been raised that such activities may come at the expense of open-ended scientific research as

[10] In the aforementioned study of 25 Italian universities by Bonaccorsi et al. (2006), the authors found substantial differences across universities, among other things in their ability to balance the degree of industry funding with their scientific output in terms of the aggregate number of publications.

[11] This is closely linked to the notion of a "Matthew effect" in science, put forth by Merton (1968), although the accumulative advantage hypothesis can be seen as a generalization of the Matthew effect that includes both productivity and recognition (Allison and Stewart, 1974).

researchers are either motivated or forced to engage in research with a view to its commercial potential (e.g. Azoulay et al., 2006; Blumenthal et al., 1996; Fabrizio and Di Minin, 2008; Florida and Cohen, 1999; Lee, 1996; Valentin and Jensen, 2002).

Why might it be problematic for universities to engage in less (or no) basic research? The contemporary rationale for the division of scientific labor into public and private domains, which dates back to the late 1950s, presents a case for publicly funded research in basic science (see Arrow, 1962; Nelson, 1959). Because the results of basic research are difficult to appropriate, private individuals and firms lack incentive to engage in it. Basic research, with its open-ended and generic qualities, however, also holds a potentially large payoff to society as a whole and it is therefore in the interests of society to fund such research in autonomous institutions, which are distinct from the key beneficiaries of the output of such research, and to ensure the free and wide dissemination of their results.

As such, Nelson (1959) argued that universities should, insofar as possible, be relieved of the "burden" of applied research that draws their resources away from fundamental scientific research, because their comparative advantage lies in basic research and the dissemination of its outputs. Thus, increasing commercial orientation and industry involvement may serve to shift academic researchers from the social roles in which they are most efficient, as suppliers of a collective good – scientific and technological knowledge (Feller, 1990, p. 347).

On a related note, Dasgupta and David (1994) argued that academic and industrial/military science rest on distinct norm and incentive systems that should be kept separate; blurring the boundaries between the two systems upsets the synergistic equilibrium between them and leads to a sub-optimal allocation of public resources.

This has spawned concerns regarding the impact of industry involvement in university research, notably that increased collaboration with industry may lead universities to dedicate more resources to the pursuit of applied research objectives, to the detriment of basic research:

> ... the process of reorienting Science to the needs of industry is often seen as coming only at a very heavy price, namely that universities will be deflected from their primary mission of undertaking basic research, in the interests of commercialisation (Ranga et al., 2003, p. 302).

Due to the limited resources available to public science, developing such practical relevance may come at the expense of long-term basic research (Lee, 1996). Thus, publicly funded research institutions may face a trade-off between basic research – which provides a window onto new scientific developments and helps guide research activities – and industry-relevant applied research – which ensures the industrial relevance of the research undertaken and therefore helps guarantee continued funding (Valentin and Jensen, 2002). This may result in a shift in public science towards shorter-term, application-oriented research driven by industry interests, referred to by Florida and Cohen (1999) as the "skewing problem", which leads to a greater emphasis on incremental improvements and applications to the detriment of path-breaking research (Jacobsson, 2002).

Azoulay et al. (2006) suggested that patenting, for example, and particularly repeated patenting, is likely to be associated with a willingness on the part of the scientist to explore questions of commercial relevance. In addition, the added industry interaction which is likely to occur in connection with or as a result of patenting activities is likely to increase the scientists' awareness of promising research issues in industry.

However, as Azoulay et al. (2006) also pointed out, engaging with industry or pursuing research questions of commercial interest does not automatically or necessarily imply that academics will produce applied research (as opposed to fundamental or basic research).

This brings attention to an important distinction, which is not always made in the literature on the relationship between academic enterprise and the nature of public research, and that is the difference between the "basic" versus "applied" content of research, and its "academic" versus "commercial" content.

It is not possible to draw clear lines between basic and applied research on the one hand, and academic or commercially oriented research on the other. Even when research has no direct application, this does not necessarily imply that it does not hold practical relevance, or that it is undertaken without consideration of practical problems.[12] Indeed, Rosenberg and Nelson (1994) argued that the bulk of academic research remains relevant in that is guided by technological problems and utility-oriented concerns but that most university research can still be described as fundamental in the sense that it involves studying and understanding phenomena on an elementary level.

Moreover, it is widely acknowledged that undertaking research with practical or commercial relevance helps guarantee continued industry funding for public science institutions (Pavitt, 2001). Interplay with industry may also be fruitful for universities, as it can provide additional funding for academic research, or insights into the technological frontier that may open up new avenues of scientific research (Brooks, 1994; Kline and Rosenberg, 1986; Lee, 1996, 2000; Meyer-Krahmer and Schmoch, 1998; Rosenberg, 1994a,b). This may, for example, be the case in sectors where technological innovation is closely linked to scientific advances; academic and commercial science may thus be complementary or, at least, not mutually exclusive (Feller, 1990).

To the best of the author's knowledge, only a small handful of studies exist that examine the relationship between industry involvement or orientation in academia and the proportions of basic or applied nature, or the academic versus commercial orientation, of research undertaken by universities (see Table 2 for an overview).

However, this issue is often investigated as a side story to the main story of the relationship between academic enterprise and scientific performance, which we reviewed in the last section. This is underlined by the fact that almost all the studies discussed in this section were introduced in Section 3. An explanation for why studies of the relationship between enterprise and the nature of academic research rarely make headlines in empirical studies may lie partly in the aforementioned conceptual confusion surrounding the basic/applied and academic/commercial content of the research, and partly in the difficulties associated with measuring a change in the nature or content of academic research.

Calvert (2004, 2006), for instance, pointed to the lack of consensus regarding the definition of basic research and argued that it "is a flexible and ambiguous concept" (Calvert, 2006, p. 199) with many dimensions that are selectively brought into play by scientists and policy makers in order to gain authority or access resources. Any theoretical boundary between basic and applied research is therefore, by definition, a blurred and artificial distinction. Precisely because of their multifaceted nature, basic and applied research are inherently difficult to measure.[13] Nonetheless, to make meaningful

[12] However, the contribution of basic research is often indirect and may emerge long after the research has been undertaken (see e.g. Salter and Martin, 2001; Rosenberg, 1994a; Salter et al., 2000). As a result, applied research is often linked more directly to practical relevance than basic research.

[13] On the measurement of basic research, Martin (1996, p. 346) emphasized that "no single indicator of research output or performance will ever reveal more than a small part of the multi-dimensional picture." Quantitative assessment of basic research should be based on a range of different evaluation approaches and the

Table 2
Studies of the relationship between academic enterprise and the nature of academic research[a].

Study	Explanatory variable	Implications for nature of research
Breschi et al. (2007)	Patenting	Associated with higher productivity, both with regards to overall productivity and to basic research alone
Ranga et al. (2003)	Industry orientation	No indication of a negative impact on basic research (the study found simultaneous increases in both basic and applied research)
Van Looy et al. (2004)	Contract research	Associated with similar volume of basic research publications and a higher volume of applied research publications
Van Looy et al. (2006)	Patenting	Associated with more publications, especially in basic research
Blumenthal et al. (1996)	Industry funding	Commercial considerations grew more likely to influence research agendas
Gulbrandsen and Smeby (2005)	Industry funding	Associated with a higher proportion of applied research
Godin and Gingras (2000)	Co-publication	Associated with a higher volume of applied research publications
Azoulay et al. (2006)	Patenting	Associated with a moderate shift towards more commercially relevant research, e.g. with higher "patentability", and with more co-publication with industry
Fabrizio and Di Minin (2008)	Patenting	Negative relationship between repeated patenting and scientific impact indicates a possible shift toward more commercially oriented research

[a] N/A: not applicable. Studies listed in the order in which they are discussed in the article.

use of these concepts, it is often valuable to draw a line between them, raising the question of where it is reasonable to draw this line.

These difficulties notwithstanding, some studies, based on scientometric data find that commercially oriented research may be complementary to more fundamental research or, at least, that increasing levels of applied research are not substituting for basic research (Breschi et al., 2007; Ranga et al., 2003; Van Looy et al., 2004, 2006). In contrast, studies based on scientometric data or on surveys of academic researchers, have found that industry funding or collaboration with industry renders individual scientists more likely to engage in greater proportions of applied research (Godin and Gingras, 2000; Gulbrandsen and Smeby, 2005), or to be influenced by commercial considerations (Azoulay et al., 2006; Blumenthal et al., 1996; Fabrizio and Di Minin, 2008).

We begin by examining the set of studies that find that academic enterprise does not appear to have any deleterious effect on the amount of basic research which is undertaken in academia.

4.1. No indications of a negative effect on basic research

We begin by taking a closer look at four studies that find no indication of a negative impact of university–industry collaboration or academic inventorship on basic research activity (e.g. Breschi et al., 2007; Ranga et al., 2003; Van Looy et al., 2004, 2006).

The first three studies draw on data on research activities at the Catholic University of Leuven, Belgium. In a bibliometric study of 22 research groups involved in collaborative research projects with industry, Ranga et al. (2003) found no indication that an increase in applied research crowded out basic research activity (except to a limited extent in research groups that already had a strong applied research orientation). Indeed, their findings showed a predominance of basic over applied publications, and the authors suggested that the relationship between basic and applied research might be characterized by complementarities rather than tradeoffs.

In their study professors from university divisions involved in contract research, Van Looy et al. (2004) found that the latter not only published more scientific articles than their colleagues affiliated with university divisions that were not engaged in collaboration with industry, but that they published a similar amount publications in basic research publications as their non-collaborating colleagues, and higher amounts of articles in applied research journals. In the study of academic inventors at the same university, Van Looy et al. (2006) found that academic inventors published more, particularly in basic research journals, than their non-inventing colleagues.

In another exploration of academic patenting, Breschi et al.'s (2007) study of academic inventors in Italy, the authors reached a similar conclusion: academic inventors published more than their non-inventing colleagues, even when only considering basic-science-oriented journals.

It should however be noted that all four of these studies use broad operationalizations of basic research using the CHI classification of scientific journals covered in the SCI database. This typology was originally developed by Francis Narin and colleagues using data on citation patterns in biomedical journals, based on the finding that basic publications tend to receive many citations, and that while applied publications tend to cite basic publications, the opposite does not apply (Narin et al., 1976, 1997; Narin and Rozek, 1988; Pinski and Narin, 1976). The CHI classification categorizes SCI journals according to their general research orientation. Originally, it was developed as a classification of journals in biomedical and clinical research only, based on a four-level typology: (1) clinical observation, (2) clinical mix, (3) clinical research, and (4) basic biomedical research. A more general four-level typology was later designed as an extension of the specialized typology for biomedical and clinical research, to cover all SCI journals: (1) applied technology, (2) engineering and technological science, (3) applied research, targeted basic research, and (4) basic scientific research.

The CHI classification has been criticized for, among other things, its conceptual reliance on the linear model of innovation and for the feasibility and usefulness of characterizing the research orientation of any given journal using just one research level. Because of its simplicity (and presumably the lack of satisfactory alternatives), the CHI classification has nonetheless been applied in a number of academic studies (e.g. Bordons et al., 2002; Brusoni and Geuna, 2003; Brusoni et al., 2005; Godin, 1996; Godin and Gingras, 2000; Malo and Geuna, 2000). It is often used to approximate the research orientation of individual publications based on the research orientation of the journal in which they were published.

Two of the studies just reviewed (Breschi et al., 2007;[14] Ranga et al., 2003) operationalize basic research broadly as consisting of both research levels 3 and 4 journals. In their review of empirical

recognition "that no absolute quantification of basic research is possible" (Martin, 1996, p. 346).

[14] Breschi et al. (2007, p. 111) explain that they chose to use this broad categorization of basic research because "Limiting the comparison to 4-scored journals forced [them] to drop too any [sic] observations for any comparison to be meaningful."

studies on the effects of university patenting on academic research in Europe, however, Geuna and Nesta (2006) expressed concern regarding this reclassification of the CHI levels and its potential impact on subsequent findings:

This seems to be a peculiar classification given the fact that usually only class 4 is considered basic research while class 3 is judged to be applied research or clinical investigation [...]. A different reclassification could have resulted in different conclusions [...]. (Geuna and Nesta, 2006, p. 796).

Picking up on the point made by Geuna & Nesta, Larsen (2007) discusses this issue in further detail before exploring how the use of two alternative operationalizations of "basic research" – as CHI level 3 and 4 publications on the one hand, and level 4 publications only on the other – might influence subsequent conclusions regarding the relationship between collaboration with industry (as indicated by co-publication with non-academic researchers) and scientific performance in a group of professors from the Technical University of Denmark. The study found that the more conservative operationalization of "basic research" as indicated by CHI level 4 journals alone has a major impact on resultant findings, and revealed a more concerning picture of the state of basic research than the one obtained using the broader operationalization of "basic research" as indicated by both level 3 and 4 journals. This finding emphasizes that the interpretation of findings in studies of the basic or applied nature of research should be firmly anchored in an explicit consideration how these forms of research are defined and measured.

The remaining two studies discussed here (Van Looy et al., 2004, 2006) use another aggregation of the CHI research levels to identify basic research publications, re-classifying CHI levels 1 and 2 as "technology-oriented" and levels 3 and 4 as "science-oriented", but also re-categorizing levels 1 and 3 as "applied" and levels 2 and 4 as "basic". Though the implications of using this redefinition of the CHI classification have not been examined, it is likely to be subject to similar issues as the aggregation of research levels used in Breschi et al. (2007) and Ranga et al. (2003).

4.2. A shift in the orientation of academic research?

We now turn our attention towards a series of studies that, in contrast to the studies just discussed, suggest that academic enterprise might involve a shift towards either more applied research or more commercially oriented research in academia.

In their survey of life science researchers at the 50 American universities receiving the most research funding from the National Institutes of Health, Blumenthal et al. (1996) found that not only did faculty members who received industry research funding produce more scientific publications than their peers without such support; they were also more commercially active and more likely to take commercial considerations into account when choosing research topics, suggesting that industry involvement may indeed influence academic research agendas.

On a related note, in the aforementioned survey of academic researchers in Norway by Gulbrandsen and Smeby (2005), which showed that faculty members who had received industry funding were more productive than colleagues with no industry funding (or other types of external funding), also indicated that the industry-funded scientists carried out more applied research than their peers without external funding. It should be noted, however, that the respondents were asked to characterize their own research as basic research, applied research or development work, according to the OECD Frascati Manual definitions (OECD, 1994). As the authors point out, the fact that a third of the respondents chose not to answer the question about the characterization of their research activities indicates that the distinction between basic and applied research may be problematic.

Nonetheless, a similar conclusion was reached by Godin and Gingras (2000), who, based on their analysis of the Canadian bibliometric database compiled by the OST, found that academic researchers who collaborated with industry, hospitals and government laboratories (as indicated by co-authorship of scientific publications) were more likely to engage in applied research (as indicated by an aggregate measure of "appliedness" based on the CHI classification of the journals in which publications appeared) than their non-collaborating colleagues.

As discussed in Section 3, Azoulay et al. (2006) found a positive and significant relationship between academic patenting and publishing productivity. They also found evidence of a moderate shift in the content of patenting scientists' research, towards more commercially relevant issues, as indicated among other things by a higher "latent patentability" (determined based on keywords in the titles of their articles) of research published subsequent to patenting activity. In addition; their analysis showed that patenting scientists were more likely to co-author publications with industry-affiliated researchers and that their work was published more frequently in journals with a higher proportion of scientists from industry.

A similar conclusion was reached by Fabrizio and Di Minin (2008), who suggested that their finding that repeated patenting was associated with fewer citations to scientific publications might indicate that these patenting scientists are reorienting their research toward "more applied or commercializable research, at the expense of fundamental science" (p. 929).[15]

Thus, these studies indicate that academic enterprise is associated with a shift in the nature of the scientific research which is undertaken, towards research which is more applied, patentable, commercially oriented, or some combination thereof. However, the precise nature of this shift, and how it affects the work and output of academic researchers, remains unclear. Similarly, the direction of causality is not very well understood: To which extent is commercially oriented research a prerequisite for academic enterprise, and to which extent is it a consequence?

4.3. Looking ahead

In spite of the ambiguous nature of evidence on the relationship between academic enterprise and the nature of research, some preliminary consensus seems to be emerging: in so far as we can distinguish between basic and applied research in academia – they, like publishing, patenting, and various other forms of academic enterprise, appear to be complementary rather than competing activities (at least for some fields, organizations, departments, and/or individuals).

In fact, in a theoretical model of the effects of the financial returns to patent licensing on research by faculty members over the life cycle, where faculty may choose to work on basic or applied research, or to enjoy leisure, Thursby et al. (2007) show that licensing is associated with an increase in the proportion of applied research which is undertaken. However, total research increases, as the additional research activity occurs at the expense of leisure time, not at the expense of basic research.

However, in view of the difficulties in ascertaining what "basic" and "applied" research actually is, and especially in view of the problems in operationalizing and measuring these concepts that we addressed in Section 4.1, it seems more pertinent to ask whether academic enterprise is associated with a shift in the academic versus commercial orientation of public

[15] The authors briefly mention that this finding might also be the results of restrictions associated with property rights on published research results, limiting their use in subsequent studies.

research, rather than a shift in basic versus applied nature of research.

In fact, as discussed in Section 4.2, several of the studies reviewed (notably Azoulay et al., 2006; Fabrizio and Di Minin, 2008) point to evidence of a shift in the research orientation of individual academic researchers who engage in academic enterprise, towards questions and research areas of commercial interest and value. Provided that further empirical evidence will lend support to this conclusion, this raises the question of the magnitude – and especially the nature – of the effect that greater commercial orientation will have on the fundamental and open nature of academic research in the long-run.

All in all, there seems to be grounds for caution in drawing any final conclusions regarding the relationship between academic enterprise and the nature of research, and to explore this relationship further.

5. Reflections

The amount of empirical work on the possible, negative unintended effects of increasing industry involvement and commercialization focus in academia illustrates that the concerns regarding its possible implications for the progress of science were effectively raised.

In this review, we have reviewed two closely related streams of research on the broader implications of academic enterprise, one on the production of scientific knowledge, and the other on the nature of academic research.

It is important to note that the studies reviewed rest on data and observations that emanate from many different university systems and national systems of research and education, both within Europe and across the Atlantic Ocean. This implies that caution must be taken in extrapolating results from one national context to another and in drawing broad, general conclusions. With this mind, we can nonetheless draw a number of emerging conclusions and promising avenues for further research that emanate from recent studies.

Certainly, our lack of a solid understanding of the nature and breadth of the implications of academic enterprise suggests that while greater industry involvement and orientation may and certainly will play an important role in university research, great care should be taken in basing funding decisions or the performance assessments of individuals, groups of scientists, or entire universities on indicators of academic enterprise.

In addition, the question of the nature and direction of causality in the relationship between enterprise and performance or research orientation in academia remains an open question. Does an academic researcher for instance publish more articles because he is active in patenting, or does he patent more as a result of his high degree of scientific productivity? Or, is the correlation, as suggested in some of the studies reviewed, spurious, explained by the benefits of collaboration with industry partners?

Most importantly, it is still unclear how academic enterprise will alter incentive structures and work environments in public research organizations in the long term, particularly as highly skewed activities such as patenting and licensing grow and become a part of the daily work life of the average scientist.

These are important questions that point to the continued relevance of studying the long-term effects of academic enterprise on the effectiveness and progress of public science.

While universities and other public research organizations are likely to successfully adapt to the demands of academic enterprise, improving their capabilities for involving industry and commercializing their research, important questions remain regarding how academic enterprise will impact the efficiency of the current division of labor between public science and private science, as the former increasingly extends into the realm of the latter.

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