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**The Two Faces of Collaboration:
Impacts of University-Industry Relations on Public Research**

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Abstract:

We analyze the impact of university-industry relationships on public research. Our inductive study of university-industry collaboration in engineering suggests that basic projects are more likely to yield academically valuable knowledge than applied projects. However, applied projects show higher degrees of partner interdependence and therefore enable exploratory learning by academics, leading to new ideas and projects. This result holds especially for research-oriented academics working in the 'sciences of the artificial' and engaging in multiple relationships with industry. Our learning-centred interpretation qualifies the notion of entrepreneurial science as a driver of applied university-industry collaboration. We conclude with implications for science and technology policy.

Keywords: University industry relations; Collaborative research; Contract research; Academic consulting; Science technology links; Engineering

Jel codes:

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Introduction

University research plays an important role in industrial innovation (Cohen et al., 2002; Mansfield, 1991; Salter and Martin, 2001). A considerable body of research has investigated the mechanisms by which this occurs, notably transfer of intellectual property (IP) and academic entrepreneurship (Phan and Siegel, 2006; Rothaermel et al., 2007). Researchers have also analysed the impact of industry involvement on universities. While some emphasize the academic benefits of industrial involvement for universities, others fear that growing involvement might have detrimental effects on core academics activities (Feller, 2005; Krinsky, 2003; Slaughter and Leslie, 1997). In light of the current trend to promote faculty engagement with industry (Mowery and Sampat, 2004), this issue is of considerable significance for science and technology policy. Of particular interest is how interaction with industry affects the development of the body of open science. If increasing industry involvement was found to be detrimental to the accumulation of openly accessible knowledge, policies aimed at promoting it would risk sacrificing the long-term benefits of scientific inquiry for short-term industrial benefits (Dosi et al., 2006; Pavitt, 2001).

Previous research has investigated this question by assessing faculty-industry involvement primarily using measures such as patenting, licensing or participation in spin-off companies. While valuable in its own right, this research does not tell us how different ways of interacting with industry affect the research output of academics. This aspect would seem important in light of recent evidence on the multi-channel nature of university-industry relationships (Perkmann and Walsh, 2007). Collaborative forms of interaction, such as collaborative research, contract research and consulting, are seen by industry as more important and valuable than IP transfer, such as licensing (Cohen et al., 2002; Faulkner and Senker, 1994; Meyer-Krahmer and Schmoch, 1998). Similarly, collaborative forms of industry engagement are more wide-spread among academics than patenting and academic entrepreneurship (D'Este and Patel, 2007).

In this article, we investigate how collaborative university-industry interactions impact on academic research. We deploy an inductive, qualitative research approach because the primary purpose of our analysis is to understand the effects of industry involvement in different circumstances while retaining a relative openness towards possible results. Specifically, we are able to consider both the indirect and the direct effects of industry engagement on academic publishing.

Our findings indicate that joint research with industry often results in academic publications while this is less true for relationships with more applied objectives, such as contract research and consulting. However, the latter relationships tend to involve far closer collaboration between academic researchers and industry partners. Close collaboration facilitates interactive learning which in turn indirectly benefits scientific production by generating new ideas and motivating new research projects. Conceptually, our learning-centred interpretation of university-industry relations questions the 'convergence' between academic and industrial worlds hypothesized in the recent literature (Owen-Smith, 2003). Convergence is implicit in the scenarios of 'commercialization' where academics are seen as economic entrepreneurs (Etzkowitz, 2003), as well as 'manipulation' where the academic system is portrayed as being captured by corporate interests (Noble, 1977; Slaughter and Leslie, 1997). By contrast, our analysis sheds light on the conditions under which collaboration is compatible with maintaining the distinct logics of both academia and industry.

The paper is organized as follows. We discuss the existing literature to establish what is known about the impact of commercial involvement by faculty on their academic work. From this we derive the research question informing this article. We next provide details of the data and methods, and present our findings. We use the evidence to generate a typology of university-industry collaborative activities. Subsequently, we assess the impact of these activities on academic publishing before considering their more indirect effects, especially with respect to academics' learning. We conclude with a discussion of our results in light of the literature, and implications for practice and further research.

Background and research question

Students of technology have long emphasized the interactive relationships between science and technology. Rosenberg (1982) argued that science, far from being an exogenous antecedent to technological progress, often derives important stimuli from technological problems in sectors such as materials, aerospace and electronics. Technology constitutes an 'enormous repository of empirical knowledge' to be scrutinized by scientists (Rosenberg, 1982: 144). Technology performance ceilings can provide important directions for follow-on scientific research, as illustrated by the histories of telephony and semi-conductors.

A series of studies has investigated the ways in which science has contributed to technology. Gibbons and Johnston (1974) showed how science supports industrial innovation through problem-solving. Their analysis of 30 innovations indicated that the scientific literature and contacts with scientists provided important information in approximately a fifth of cases. Rather than providing basic ideas, academics often played a direct, supportive role by advising on the feasibility of solutions, pointing to specialist information and 'translating' information from scientific journals. Mansfield (1991) established that some 10% of all industrial innovations in the US relied substantially on academic knowledge. Faulkner and Senker (1994) documented the multi-channel nature of university-industry relations in their study based on 60 interviews with researchers and executives in three industries. They found informal personal linkages, barter, and materials exchange to contribute significantly to firms' R&D, in line with Kreiner and Schultz's (1993) study on the Danish biotechnology industry. Also, Lenoir (1997), examining the early days of the scientific instruments maker, Varian Associates, emphasized how this company was embedded in a dense network of relationships with academics at Stanford University. While these studies document how academic scientists contribute to private-sector technology development, they fail to capture the impact of collaboration on academic work and science more generally. Moreover, they do not ask whether different types of collaboration have different effects on academic science.

Recent studies have explored how industry involvement by academics affects their research productivity, measured as journal publication output. These studies fall into two groups, with one focusing on academic entrepreneurship, and the other on patenting and licensing.

Work on academic entrepreneurship, particularly in biotechnology, indicates that involvement in commercialization can be compatible with high scientific productivity (Siegel et al., 2007). Zucker and Darby (1996) show that the research productivity of 'star scientists' in the life sciences increases with their commercialization activities as measured by co-authorship with firm scientists. Similarly, Lowe and Gonzalez-Brambila (2007) found faculty entrepreneurs to be the more prolific authors, compared to both their non-entrepreneurial graduate school peers and co-authors. Life science faculty involved in consulting have also been found to generate more scientific publications (Louis Seashore et al., 1989).

Other studies have investigated the relationship between university patenting and scientific productivity (Geuna and Nesta, 2006). Although patenting does not necessarily indicate actual industry involvement, it signals that an academic has 'commercial' sense and hence may be more likely to work with industry than non-patenting colleagues. Stephan et al. (2007) found that patenting US academic researchers publish more than members of a non-patenting control group. Azoulay et al. (2007) showed that academic patenting is generally preceded by high productivity in terms of journal publications. Owen-Smith (2003) argued that US universities have recently moved towards a 'hybrid order' based on positive feedback effects between academic publishing and patenting. Gulbrandsen and Smeby (2005) established that Norwegian professors with higher levels of industry funding publish more than their colleagues. Carayol (2007), Van Looy et al. (2006) and Breschi et al. (2007) obtained similar results using European evidence. All these contributions point to considerable complementarities between high academic output and involvement in commercialization activities.

However, there are also some more sceptical views. Agrawal and Henderson (2002) found that, among MIT faculty, patent volume is not a predictor of publication volume although faculty with more patents achieve higher

research impact as measured by paper citations. Blumenthal et al. (1996) suggested that although life science faculty in receipt of industry funding publish more, their productivity decreases if this funding exceeds two-thirds of their total funding. Goldfarb (2008) established that faculty who maintain long-term relationships with 'applied' sponsors publish less, suggesting that careers might be affected by the types of relationships academics maintain with their sponsors. Czarnitzki, Glänzel and Hussinger (2009) reported that German professors' patenting was positively associated with research productivity if patents were filed via non-profit organizations while the opposite was true when patents were filed via for-profit organizations. Finally, Buenstorf (2009) found no clear relationship between involvement in start-ups and research productivity. Shinn and Lamy (2006) argued that this might be due to different 'models' of academic entrepreneurship: while some academics are very good at exploiting complementarities between academic and industrial work, others privilege their industrial work to the detriment of their academic output. Similarly, Jong's (2006) study on the birth of the biotechnology industry in the San Francisco area suggests that new enterprises might not always be spawned by the most prestigious academic environments.

This ambiguous picture emerging from the literature suggests that previously unexplored aspects might be at play. For faculty, collaborating with industry poses potential dilemmas rooted in the different institutional logics prevailing in academia and industry (Colyvas, 2007). Extant research suggests there are two factors that potentially exert a negative impact on research productivity. The first is the 'secrecy problem' (Florida and Cohen, 1999). To secure commercial appropriation of research results, academics might be required to delay or even forego publication (Geuna, 2001). This leads to a tension between open science and proprietary knowledge, potentially restricting public dissemination of research results (Blumenthal et al., 1996; Nelson, 2004). Patenting and publishing, therefore, may be substitutes rather than complements (Agrawal and Henderson, 2002; Murray, 2002). In their study of US university-industry engineering centres, Cohen et al. (1994) observed that collaborating with industry implied restrictions to publication.

The second factor is the 'complementarity problem' (Rebne, 1989). This relates to the lack of complementarity between industry-related activities and open science. Complementarity refers to a connection between pairs of inputs in the sense of a relationship between groups of activities (Milgrom and Roberts, 1990). Academics might be hampered in their publishing intentions by the fact that their work with industry is neither novel nor sufficiently academically innovative to warrant publication in an academic journal. Equally, they might spend time and resources on activities that are not directly conducive to academic output (Calderini et al., 2007).

Arguably, different types of university-industry relationships might be affected by these factors in different ways, with consequences for academic publishing. However, little is known about the way that different collaboration modes shape academics' scientific outputs. The existing studies predominantly use aggregate measures, such as patenting, as indicators of industry involvement. However, they do not tell us how academics engage with industry. Research points to the various ways in which firms work with scientists via 'bench-level' research collaboration (Cockburn and Henderson, 1998; Liebeskind et al., 1996; Zucker et al., 1998). Notably, Cohen et al (2002) distinguish between two modes in which faculty contribute to firm R&D: *initiation* of projects and *completion* of projects. The first type of contribution consists of providing new ideas, concepts and artefacts –as open science results or as IP. The second type enlists academics as experts and assistants into already initiated projects in which the emphasis is on problem-solving and participation in development work. The Carnegie Mellon survey (Cohen et al., 2002) indicated that the majority of large US firms view 'contributing to project completion' as a more important benefit of collaborating with universities, than 'suggesting new projects'. Similar results were reported for the UK (Faulkner and Senker, 1994; Meyer-Krahmer and Schmoch, 1998).

Organizationally, such collaboration is manifested in multiple ways. The most frequent types of interaction are represented by collaborative research, contract research, and consulting (Perkmann and Walsh, 2007). Collaborative (or joint) research refers to arrangements under which universities and industry co-operate to pursue research objectives together (Hall et al., 2001).

Contract research consists of research carried out by universities under the direction of industry clients (Meyer-Krahmer and Schmoch, 1998). Academic consulting consists of advice and expertise provided by academics to industry clients, usually for personal compensation (Perkmann and Walsh, 2008). These different types of university-industry relationships can be expected to have varying impacts on academics' generation of academically relevant knowledge for publication in scientific journals. This leads to our research question: How do different types of industry involvement impact on academics' research output?

The policy significance of this question lies in the need to gain insights into the value of the 'networking' initiatives currently being pursued by science funding organizations (Dosi et al., 2006). Such initiatives seek to encourage academic interaction with industry in the expectation of the benefits that will accrue to both academia and industry. Given the ambiguous results in the literature, it seems worthwhile to investigate the conditions that generate these benefits.

Data and methodology

Our research question is a 'how' question, which requires inductive research. Such an approach is suitable when extant research is incomplete or contradictory and fails to explain variations in the phenomenon requiring clarification (Eisenhardt, 1989).

Research site

We designed our study to capture the large variety of ways in which academics engage with industry. We collected information on a significant number of instances of university-industry collaboration by interviewing participant-informants. Using theory-driven sampling (Eisenhardt, 1989), we identified academics involved in a project with a private or public sector corporation. We selected our respondents from a single research-intensive UK university to minimize organizational variation. Within this university, we selected members of the engineering faculty and engineering-related individuals in other faculties, with the help of technology transfer officials and department heads. The head of academic consulting in the university

technology transfer office referred us to academics who had been engaged in consulting with outside organizations in the recent past. Department heads referred us to colleagues with high levels of industry involvement. The majority of the departments in which our respondents worked had received a rating of 5 or above in the UK's 2001 research assessment exercise (RAE), indicating research excellence. To allow us to triangulate the information, wherever possible, we interviewed the industry collaborators of our respondents.

We chose engineering in order to widen the narrow perspective on life sciences in much of the previous literature. In life sciences, IP plays an important role and therefore many studies focus on patenting and licensing. In other disciplines, collaboration is seen as being more important than just transfer of IP. Among these, engineering has high levels of university-industry collaboration (Schartinger et al., 2002). Our sample therefore promised a range of different ways in which this collaboration was pursued. Engineering encompasses a set of disciplines that are guided by the perception of technical problems (Vincenti, 1990). This implies a relative affinity between academic engineers and industry users. Simultaneously, engineering is an academic discipline with similar rules for novelty, priority and reputation as in basic sciences (Merton, 1973).

Data collection

We conducted 43 interviews in the second half of 2006 of over an hour on average, which were all recorded and transcribed. Interviews are referenced using interview codes (e.g. i15) as listed in Appendix Table A1. We used the literature and initial pilot interviews to design the interview protocol. The questions asked during pilot interviews revolved around themes extracted from the literature. The results of the pilot interviews enabled us to iteratively revise the interview protocol, resulting in a final semi-structured interview protocol. After asking respondents to summarize their backgrounds and careers, we invited them to reflect on the whole range of different ways in which they interacted with industry. We suggested that they distinguish between different types of projects and provide examples of current or recent projects for each of these types. We encouraged them to describe specific

examples in detail (approximately 20 minutes for each project). While most respondents gave detailed information on one type of project, twelve respondents described two types of project. We asked how each project was initiated, what were its objectives and who were the partners. We enquired about the precise nature of the activities at various phases of the project, and how they were organized. We used prompts to obtain a picture of the type and frequency of meetings, the frequency of visits and other exchanges, and the nature and degree of interdependence of the various participants more generally. We asked respondents to describe how relationships with partners were established, how they viewed the relationships they had developed and whether they had experienced any problems or barriers. We enquired about the rationales for their decisions to work with industry partners, for each project, and what were the benefits from their viewpoint. Finally, we asked about IP terms, whether project outputs lent themselves to publication in peer-reviewed journals and whether publication activity had been hampered or encouraged in any way. The types of projects described by the respondents were not meant to be representative of the whole spectrum of the relationships in which they were involved. Rather, we attempted to understand in depth the dynamics associated with specific types of projects by seeking saturation rather than representativeness (Miles and Huberman, 1994).

We adopted various measures to improve validity. We prompted interviewees for facts rather than opinions to reduce cognitive bias and alleviate impression management (Miller et al., 1997). For instance, we asked what exactly in a specific project had posed barriers to the writing of scientific articles. Respondents were promised confidentiality in order to improve the accuracy of the detail given (Miller et al., 1997). To reduce retrospective bias, we consulted individuals only about activities they were involved in at the time of interview or in the preceding six months.

Data analysis

From the interview transcripts, we extracted information on 55 instances of collaborations ('projects'). These projects formed our unit of analysis. The relatively large number of projects allowed us to generate variety for the

analysis. We ‘pooled’ the information on all projects to devise generalizable statements about them (Elsbach and Kramer, 2003). A third of the 55 projects involved small and medium-sized firms as partners; the remaining two thirds involved either large firms or a mixture of large and small and medium-sized firms. The majority of partner firms belonged to sectors with above-average R&D intensities (Table 1).

Table 1 about here

Initially, we created a narrative summary for each project based on the details provided by the informants, complemented if required by information about individuals and organizations drawn from the Internet and bibliographic databases. We documented the main characteristics of each project in terms of: type of industrial partner; type of interaction; academic researcher’s rationale for initiation of the project; type of activities pursued; outputs generated; and academic benefits generated. We compiled these reduced data into a ‘mega matrix’, which we used for subsequent analysis (Miles and Huberman, 1994). Table 2 shows a selection of exemplary projects. Below, we refer to projects via a project code (e.g. p7).

Table 2 about here

Working through the mega-matrix, alongside the narrative summaries, we attempted to extract general patterns in line with our research question. In a first step, we grouped projects into categories according to what they were trying to achieve. We attempted to grasp this by developing a construct called ‘project goals’. Strictly speaking, ‘goal’ is an ego-centric concept in the sense that each partner in a collaboration arrangement will have his or her own objective and agenda (Nooteboom, 2004). Yet it is possible to emphasize the shared goals for each specific instance of collaboration, in the sense that projects will usually have a set of agreed objectives.

We explored the project goals using the information given by interviewees about what each collaboration was trying to achieve. We synthesized the answers into short phrases such as: 'Identify the cause of engine prototype failure and seek technical solutions' and compiled them into the mega matrix. We then reduced these data by abstracting from the concrete characteristics of the activities to obtain a small number of different types. Our main criterion for grouping projects goals was inspired by the concept of finalization, i.e. the degree to which a project was aimed at achieving 'basic' or 'applied' objectives (Weingart, 1997).

Subsequently, using the NVivo software¹, for each project we explored whether and how it contributed to researchers' scientific publishing, and what obstacles were experienced. The final step was to investigate the degree of interdependence between the partners for each type of project. We operationalized this by assessing how the partners worked together - via: (a) meetings, (b) use of equipment and materials exchange, (c) joint activity. Joint activity was defined as activity requiring ongoing mutual adjustment and information sharing, e.g. high interdependence (Gulati and Singh, 1998). We reasoned that, in the context of an inter-organizational relationship, these three types are linked via subset relationships (a so-called Guttman scale): interactions that involve joint activity will always involve both meetings and equipment/materials exchange, and interactions that involved equipment/materials exchange will always involve meetings. Interactions involving joint activity would hence indicate the highest degree of interdependence. In other words, such interactions would refer to 'bench-level' collaboration between university and industry scientists (Zucker et al., 2002).

¹ NVivo 7, QSR International Pty Ltd 1999-2007.

Findings

Types of projects in university-industry collaboration

Here we present our findings on how university-industry collaborative projects differ and the effect on the generation of academically relevant outputs. We generated these insights by inductively exploring the intended outcome of collaborative projects. We evaluated the results with respect to how finalized – how basic or applied – the activities pursued were. The results allowed us to generate a four-fold typology of collaborative projects with differing degrees of finalization. Below, we describe exemplary projects for each type.

Problem solving. In some instances, firms approached academics to assist them with specific problems encountered in their R&D, engineering or manufacturing operations. Firms sought specialist advice provided by academics on particular problems, or involvement in the actual problem solving activity. The projects involved products, processes or concepts that were either close to market or already on the market, or parts of firms' machinery and equipment. Therefore, the projects were characterized by low degree of technological or scientific uncertainty as the requirements were strictly defined by the problems to be resolved.

For example, a large manufacturer of gas turbines consulted its academic collaborators when it experienced critical vibration problems with a prototype turbine that occasionally led to its self-destruction (p1). As the company engineers were unable to identify the cause of this recurring problem, they hoped the academic research group, which specialized in turbine aerodynamics, would be able to provide the needed expertise. The research group decided to take on the challenge despite concerns that this was 'far more development-oriented and short-term than our usual research project' (i13). The company's prototypes were installed in the university's laboratories. The project required the collaboration of four academics at different levels of seniority, over a period of six months. The research group finally identified the cause of the problem as auto-ignition, i.e. the uncontrolled explosion of fuel within the engine, and was subsequently engaged by the company to collaborate on experimenting with various designs to overcome the problem.

In another instance, an engineering professor specializing in risk modelling was asked by a multinational oil company to provide a risk assessment for a planned oil platform refurbishment (p2). While maintenance staff argued that safety equipment should be installed on the main, populated platform, the safety managers maintained it should be installed on a remote platform where the oil was actually being extracted but which was more costly to service. To inform this investment decision, the professor was commissioned to model the risks associated with these designs. In another instance, a mid-career academic specializing in renewable energies was asked by a large utility company to provide a model for predicting blade failure on wind turbines, potentially leading to punctures in a nearby gas pipeline (p38). Mainly based on desk-work, using data existing in her research group, this project resulted in a detailed report with recommendations to inform decision-making in the client organization.

Technology development. A second project type focused more directly on improving or developing specific technologies relevant to commercial users. Often such projects resembled conventional, formally established academic research projects although substantially they pursued proprietary technology development. These projects dealt with concepts, products or processes, which, compared to problem solving projects, were a step removed from 'market readiness'. They were afflicted by relatively higher degrees of uncertainty as only general requirements were known, while the actual problems to be resolved were not tightly specified ex ante.

One project involved a manufacturer of industrial ovens that had approached a manufacturing engineering research group to assist it with further development of one of its products (p3). The objective was to equip an existing oven model with automation technology to provide for higher productivity and through-put rates. The initiator firm was a relatively small capital goods producer, and did not have any formal R&D operations. The project participants succeeded in securing public funding for their plans, partly by co-opting other industrial suppliers and users. The academic group used relatively standardized automation concepts to tackle this specific challenge. The output of the project was a series of business process and operational

production models, as well as top-level design specifications that the firm consortium could use to implement this product innovation.

Another project was aimed at developing flexible printed circuit boards to replace wire harnesses in cars (p4). The project involved a small manufacturer of flexible electronic circuit boards alongside two other automotive suppliers and the academic research group. The collaborators received a public research grant, with additional funding provided by a government R&D support scheme. Though aimed at developing an explicit product, the project generated several publications in peer-reviewed journals. The lead firm viewed the project as an opportunity to initiate development of a new product line without having to bear the full R&D cost. One of the university research assistants was employed part-time by this company, ensuring continuing close interaction between university researchers and industry engineers over the course of the project.

Ideas testing. A further type of projects was inspired by the desire to investigate potentially commercially interesting ideas. These projects sometimes built on concepts and technologies developed by academics which they 'sold' to firms to pursue tentative exploration of their application potential. In other cases, specific ideas had emerged within firms' R&D or manufacturing units and the firms had approached the academics to explore these ideas because they were seen as having the required expertise. Typically, these were low-cost projects often initiated by individuals within firms who saw them as an opportunity to pursue low-key exploration activities outside their organizations' mainstream development activities. The ideas were seen as 'high-risk' concepts with commercial potential if successfully translated into a concrete concept, prototype or technology. The funding or part-funding of a PhD studentship was a common way to pursue such idea testing.

For instance, an academic specializing in laser measurements of combustion processes within car engines was approached by engineers from a large automotive components supplier (p5). They were interested to know whether it was possible to measure certain aspects of the combustion process within engines using the academic's laser-based measurement techniques. This

enquiry resulted in a firm-sponsored PhD project, exploring the issues involved in implementing the technology in this way. While the industrial partner provided the test engines and the fuel injection equipment, the scientific work rested predominantly with the PhD student in collaboration with her supervisor. A company engineer provided co-supervision, and several colleagues attended quarterly meetings to monitor project progress.

While in the above case the industrial sponsor was attracted by the academic's previous work, in other instances firms were more agnostic about how such exploratory projects should proceed. They often chose to rely on the general expertise of the collaborating academics and the labour provided by research assistants. This was typically the case when an idea had originated on the industry rather than on the academic side. In one case (p6), a public security agency approached an academic research group to investigate whether and how it might be possible to build telecommunications aerials into the structure of cars so they would be invisible. The project was carried out on the basis of the requirements provided by the clients, and the results were fed back via a feasibility study.

Knowledge generation. The last project type consisted essentially of academic research projects with industry participation. These projects in most cases were initiated by academic researchers. The objectives of these projects tended to be informed by the challenges arising at the frontier of academic research. In all cases analysed, projects of this type were completely or partially supported by public research funding. In general, the industry partners were approached at the stage when project proposals were already well defined. They often agreed to take part by contributing 'in kind', i.e. by committing management time, materials and occasionally access to prototypes and their laboratories.

One project was aimed at advancing 'zero-breakdown' machines by equipping them with intelligent electronic monitoring systems (p7). According to the principal investigator, the project was oriented towards the long-term ('maybe this is 12 years away') and could therefore be considered a 'research project' with little immediate commercial payoff. The project was predominantly government-funded but the initiators had enlisted various automotive and

construction equipment manufacturers. While the objectives of the project were aligned with academic priorities, i.e. the generation of novel knowledge and subsequent publishing in a peer-reviewed journal, firms contributed by providing prototype machines and 'real world' data from their testing laboratories and other sources. An additional academic motive for enlisting industry partners was to improve the funding odds for the project proposal. While the company representatives would attend quarterly progress meetings, they had relatively little involvement during the actual execution of the project.

Another project explored a new design principle for a jet engine component, and was led by an engineering professor within the context of a formal relationship with an aerospace company (p8). The objective was to investigate whether air could be passed through a jet engine at a higher speed than previously thought possible, resulting in improved efficiency and emissions. Due to the controversial nature of his idea, the professor's direct funding request was rejected by the aerospace company but he was successful in attracting public research funding, with the company loosely enlisted as an industrial partner. The research was carried out in the university laboratories, and involved several faculty members and research assistants for three years. It also concentrated purely on the aerodynamic aspects of the design, without considering thermal, mechanical and other aspects that would be relevant for the actual implementation of the technology. However, to demonstrate the potential value of the discovery, the research team persuaded the company to run the same experiments on their 'rigs'. As the outcome was positive, the company supported a follow-on research project, again with public funding, to investigate the implications of the findings and generate top-level design specifications.

Table 3 about here

To summarize, we identified four types of university-industry collaboration projects (Table 3). They differ with respect to their 'appliedness', i.e. their proximity to market. While problem-solving projects addressed issues relating

to products, processes or services that were close to market, at the other end of the scale, knowledge generation projects made only very generic reference to market-ready products or services.

We noted a second regularity. Projects that were more applied were generally initiated by firms; only occasionally had academic researchers developed technologies which attracted industry attention. Hence, academics were de facto employed by external organizations to resolve specific technical problems, or to improve and develop specific technologies. By contrast, academics were more proactively involved in driving the agendas within projects focusing on ideas testing and knowledge development. Many knowledge generation projects were predominantly focused on creating novel insights and their value for firms resided in providing ‘windows to technology’ rather than actual developmental outcomes. Ideas testing projects were also used by academics to work on concepts they wanted to explore. All knowledge generation projects, and some of the ideas testing projects, were initiated by academics in which, in the majority of cases, public funding was used to entice industrial collaborators to participate. Two thirds of knowledge generation projects involved large firms in sectors with R&D expenditures of more than 4% of sales among large firms.²

We schematically summarize our results in Figure 1. By cross-tabulating two dimensions, degree of finalization and agenda-setting, we obtain a corridor within which university-industry collaborative projects are likely to fall. Projects that are more applied are likely to be shaped by industrial partners’ agenda, while those that are more basic tend to be shaped by academics’ agendas.

 Figure 1 about here

² See 2007 UK R&D scoreboard (www.innovation.gov.uk/rd_scoreboard, accessed 13/07/2008).

Types of projects and academic publishing

We next explore what determines whether university-industry projects result in academic outputs.

Of the four types identified above, knowledge development projects were in most cases highly complementary with academic research as they almost always allowed the academic collaborators to generate scientific publications. These projects were essentially academic research projects, with some degree of participation of industry partners. The knowledge generated tended to be based on curiosity-driven research that was publishable in academic journals and not immediately connected with firms' ongoing development activities. For instance, one computer scientist had received funding through a research programme partly sponsored by a major defence contractor (i12). The programme addressed ways in which future battle spaces could be modelled, taking account of a multiplicity of weapon systems networked in real time. The academic was unclear about how this knowledge was to be used by the sponsoring organization, and focused on the academic exploitation of this research. The only contact with the sponsor was through quarterly meetings where results were presented. A relatively low level of interaction between sponsor and university researcher was a common feature of knowledge generating projects, with quarterly meetings being the norm.

By contrast, ideas testing, technology development and problem solving projects were only in some cases conducive to scientific output, for differing reasons. Many problem solving projects suffered from the 'complementarity' problem. Often the knowledge they produced, or the data they generated were not suitable for publication. For instance, in problem-solving projects, data were not collected and documented in a sufficiently systematic manner to enable subsequent application. As one professor specializing in combustion processes explained in relation to a piece of contract research commissioned by a diesel engine manufacturer:

The project just wasn't as rigorous as I would want, just because of the sheer time pressure. You know, you're making something work that day and then you're moving on to the next test point. We were trying something

that was quite ambitious, whereas if you had a researcher for three years, they would do a pilot study and they would then document everything. Everything would be done and your results would be there at the end of the three years. But this project did not allow us to do this for time reasons. (i7)

Similarly, another professor stated:

If you are delivering consulting, sometimes it's not much actual research. It's like looking at stainless steel to see if it is contaminated; so in practice you are examining stainless steel for six months. But is there a paper in it? No, just lots of data. (i24)

By contrast, projects aimed at testing ideas were more likely to be affected by secrecy considerations. The technological novelty of such projects meant that results were suitable for publication in the relevant engineering journal but open science considerations were sometimes affected by IP concerns on the part of both firm and academic. For instance, a professor in automotive engineering approached a firm with a proposal to develop a diesel engine emissions control system based on a novel micro-wave device. He recounted:

On that particular programme, we've decided not to publish too many papers because we want to retain confidentiality. Again, if every project we were doing were like that, then we wouldn't have enough papers. But we've had enough peripheral papers on that project to get some brownie points (...). We've been more keen to hold back than [the firm] has actually been. I think there were times when they were saying, 'Oh, well maybe you should publish now.' And we were saying, 'No, actually we'll hold back a little bit.' And it will have its day in the sun in terms of publications (...). We've got three patents that have gone through, so we could publish something on it, but it's a question of being sensible. (i7)

In another example, an academic also considered the potential trade-off between (early) publishing and the potential exploitation benefits accruing to her research group:

I suppose in one sense we know that if we publish, we lose the opportunity to get any exploitation directly with the company. We don't want to give

everything away before we've had a chance to seek exploitation by patenting it. (i17)

This example illustrates that even projects that are proactively pursued by academics can be affected by secrecy considerations, hence limiting their academic results, as measured by publications.

Finally, technology development projects occupied an intermediate position between problem solving and ideas testing projects. While within some of the projects the industrial sponsors were concerned about appropriability and hence demanded secrecy, others did not yield academic results or data that were sufficiently 'interesting' or novel.

We can summarize two main findings. First, university-industry collaborative projects that are farthest from the market are the most likely to result in academic publications. Second, for projects closer to the market, there are two reasons why they are less academically exploitable than knowledge generation projects. For projects with an intermediate proximity to the market, i.e. ideas testing and technology development, secrecy considerations on the part of both the industrial and academic partners can hamper academic exploitation. By contrast, more applied projects tend to be affected more by complementarity considerations in the sense that their outputs are often not academically novel enough to warrant publication.

Types of projects and learning effects

Even though many applied projects did not result in direct academic benefits, i.e. journal publications, they often yielded indirect benefits that were eventually conducive to enhancing academics' research output. Our analysis suggests that learning is the foremost among these benefits. Interestingly, learning effects appear to be more pronounced in the more applied projects. We established this by exploring how closely the partners worked together within different types of projects. Learning across organizational boundaries is facilitated by close collaboration, involving face-to-face encounters and repeated exposure of the partners to each other (Hamel, 1991). This is because close partner involvement enables the transfer of non-codified knowledge (Senker, 1995). Valuable expertise can often be tacit (Polanyi,

1958) and complex, and hence naturally exclusive (Zucker et al., 2002). While this does not necessarily mean that the underlying knowledge is by definition uncodifiable (Cowan et al., 2000), its codification may be too costly in relation to its perceived value, meaning that it remains latent (Agrawal, 2006). An additional reason for the relevance of close collaboration lies in the potential contribution to creating and maintaining communities of practice in which social learning occurs (Brown and Duguid, 1991). Therefore, enduring interaction between the partners, trust and long-term orientation are likely to facilitate the collective learning process in interorganizational contexts (Larsson et al., 1998).

To capture such 'learning by interacting', we determined the interdependence among the partners on the basis of three criteria: (a) meetings; (b) use of equipment and materials exchange; (c) joint activity (Table 4).

Table 4 about here

Meetings are the most basic mode of interaction, and collaboration instances that involved only meetings can be seen as having rather low degrees of interdependence between the participants. Equally, the frequency of meetings and whether they are used to merely exchange information or to additionally make decisions, indicate different levels of interdependence. On this measure, knowledge generation projects were generally characterized by low interdependence. Meetings tended to be rather infrequent – most respondents mentioned that meetings occurred every three months or so – and they served mainly for updating the industrial partners on the progress of the projects and receiving feedback. As one electronics engineer remarked:

In [research-oriented] projects that I've been on, the industrial partners are far less responsive. They kind of sit there at meetings and look interested, but they're not really driving things forward. (i14)

By contrast, more applied projects tended to involve frequent meetings, both to exchange information and make decisions.

As for materials exchange and use of equipment, some projects required the use of equipment at the industrial partner's sites or the use of materials, data or other artefacts provided by it. Materials exchange and use of equipment was important when the assignment required the academic researcher to tackle concrete problems with client's technology. This was the case in a project aimed at installing infrared sensors into postal sorting machines (i35). The project involved extensive site visits by the academic researchers who were given open access to prototypes, measurement instruments and technical assistance; most of the technology was also installed in their university laboratory. Exchange of materials was also relevant for some ideas testing and knowledge generation projects. For instance, one project involved analysing data from fan-blade manufacturing at a large defence company and was the empirical basis for a PhD project in data-mining (i12). While industry staff helped extract and clean the dataset, the research itself was pursued mostly autonomously by the PhD-student and her supervisor apart from several meetings with the company to provide a 'reality check' and enable feedback of results. Similarly, in a larger-scale research project, an engine-manufacturer and an automotive component manufacturer supplied the university with a test engine and novel injection nozzles to facilitate measurement of combustion processes (i7).

Finally, many applied projects relied on jointly pursued activities. In the turbine prototype project mentioned above, company engineers spent weeks in the university laboratories assisting the researchers in their work. Although the academic partners were clearly leading the project work, they relied on ongoing input from their industrial clients to provide back-up information, modify experimental set-ups and cross-check data (i13). One professor remarked: 'Often there was a [company] engineer sitting at the experimental rig next to the [university] researcher doing the measurements, often through till 8 or 9pm' (i13). The parties met on a weekly basis to monitor progress, interpret results and decide on next steps.

Our results indicate that the majority of applied projects involved high degrees of interdependence using our measure, with only some desk-based consulting assignments exhibiting minimal task interdependence. By contrast, knowledge

generation or ideas generation rarely involved joint activity. The relatively low level of task integration, and hence interdependence, manifested itself in several ways. These projects were commonly initiated by academic researchers who would usually bid for public grants, and simultaneously involve industrial partners. As this meant that project agendas were relatively 'academic', the industrial partners tended to conceive of themselves more as sponsors than active project participants. An R&D engineer at a large chemicals company explained:

Sometimes, we get a call from an academic; they want us to be partners in a project they have funding for. Very rarely do we have direct control over what is being done. For example, we are involved in a project with [a well known university] about nanotechnology – we would never do this otherwise. This is very different from our normal main activity. We do it out of intellectual interest – to meet other people in the industry but we cannot engage in this too much. It does not achieve concrete results. (i43)

In general, we found that more applied projects often had much higher degrees of interdependence than basic projects. By interacting closely with firms, academics gained insights into firms' activities and knowledge bases that would otherwise have been inaccessible. A professor described how the above mentioned consulting project concerning risk analysis for oil platform equipment resulted in a follow-on academic output:

What we developed was an optimization process after we had done the work for [oil major]. (...) In fact, we wrote that up as a paper and was published in RMK Journal and got an award. So it showed that the involvement with industry showed us the sort of problems that we could work on, although we didn't ever do it for the company. (i16)

Similarly, the problem solving project aimed at identifying the causes of turbine failure described above did not yield direct academic outcomes but resulted in a follow-on research programme. According to the leader of the research group:

This project got us interested in these very rare events and the probability of trying to predict their occurrence. In our experiments, we might have to

make measurements for seven hours and we'd see one event. If you scale that up to the real engine, that's probably like one event in a few weeks of running. These engines run for years – so this could be potentially very dangerous. Therefore we did a follow-on project looking at what we call very rare event statistics. That's a fundamental bit, and we wouldn't have gotten into that at all if we hadn't gone through the bloody nightmare [stress and time pressure associated with project]. (i13)

Even though many applied projects did not result in academic publications, they often led to novel insights and ideas for follow-on projects, which in turn were academically valuable. These effects amount to exploratory learning to the degree that they change the academics' code to take account of new alternatives (March, 1991). The mechanism by which this was achieved was close collaboration with industry partners. The academic value of applied projects therefore lies primarily in offering the opportunity to work closely with firms –while for more academically oriented blue-skies projects this was often not required and not supported by firms.

A final regularity we noted was that many academics were engaged in several types of projects, sometimes with the same industry partners. Such multi-modal engagement served to cement relationships through a kind of generalized exchange but could also serve to 'rotate' ideas between theory and practice. The typical pattern was that academics would 'help out' their partner firms by engaging in applied projects. This was reciprocated by firms via by financial or other assistance for subsequent knowledge generation projects. For instance, a professor of applied thermodynamics agreed to carry out a short-term project for a multinational company, aimed at implementing an instrument system for studying thermal flows within diesel engines. In its turn, the company offered its assistance for a large, publicly funded project to explore the fundamentals of combustion within diesel engines involving several other manufacturers (i7). Similarly, in the case of the applied project aimed at resolving problems with a faulty gas turbine mentioned above (p1), the academic researchers persuaded the manufacturer to support a publicly supported knowledge generation project aimed at converting the lessons learnt into new design principles for this type of engine. These examples

illustrate that academics were able to derive significant benefits from engaging in several types of projects, particularly if they involved the same industrial partner. In these situations, familiarity with the partners' technology and challenges in the more applied projects compensated for the relatively lower level of interactivity during the more basic projects.

Discussion

Our analysis suggests that academics face a potential dilemma when they collaborate with industry. While more basic projects are more likely to generate academic output, they also offer fewer cross-boundary learning opportunities. As such projects are often led and carried out by academics and address topics less directly relevant to industry, partners tend to be less involved and hence interactive learning effects are reduced. By contrast, although the attractiveness of applied projects is hampered by secrecy and complementarity problems, they offer more learning opportunities during via highly interdependent interaction with industry.

Our results have implications for how we think about the impact of industry engagement on scientific production. Many observers have emphasized commercialization as the primary rationale informing academics' involvement with industry. The claim is that the role of academics is gradually shifting. Rather than concentrating on 'blue-skies' research, academics are seen to be increasingly eager to bridge the worlds of science and technology entrepreneurially, notably by commercializing technologies emerging from their research (Clark, 1998; Etzkowitz, 2003; Shane, 2004). Critical authors have responded by underlining the potentially detractive effects of such 'entrepreneurial' science on the long-term production of scientific knowledge. These authors fear that academic science is being instrumentalized and even manipulated by industry (Noble, 1977). Perceived risks include a shift in scientific research away from basic research towards more applied topics and a reduction in academic freedom (Behrens and Gray, 2001; Blumenthal et al., 1986), the slow-down of open knowledge diffusion (Nelson, 2004) and lower levels of research productivity among academics (Agrawal and Henderson, 2002).

Our study allows us to go beyond these opposing viewpoints and comment on the conditions in which industry involvement might have certain effects on scientific production. Our results suggest that working with industry does not necessarily mean commercialization in the sense of university-developed technologies being converted into commercial applications. In most of the applied projects in our sample, academics contributed to projects that were already ongoing within firms, as opposed to providing ideas and technologies for new products. Similarly, in almost all cases, academics (or universities) did not have any commercial stake in the innovations being developed.

However, the academic researchers were often able to exploit even the most applied industry projects to benefit their research activities. In light of the above debate, this suggests that industry involvement *under certain conditions* will benefit the production of scientific research. We comment on three such conditions.

First, our insights appear to be particularly relevant for the ‘sciences of the artificial’ (Simon, 1969). The objects of disciplines such as engineering are constituted by evolving technological artefacts. In its industrial application, engineering focuses on problem solving for practical ends (Vincenti, 1990). To this purpose, engineers are involved in the generation of knowledge via various processes, ranging from transfer from science to direct trial. Among these, the more theoretical methods of generating knowledge tend to be deployed at universities by academic engineers (Vincenti, 1990). Often this involves gathering knowledge about the functioning or non-functioning of technological processes and artefacts, as for instance documented for the early aviation industry (Vincenti, 1990). As industry is the main locus for the production of technology (Rosenberg and Nelson, 1994), academics working in the science of the artificial need access to industry to provide them not just with research materials but also with information about where to direct their research (Balconi et al., 2004). This research in turn facilitates and inspires technological progress (Klevorick et al., 1995; Nightingale, 1998). Against this background, our insights are likely to apply particularly to the sciences of the artificial while they may be less valid for disciplines concerned with non-technological objects of analysis. The learning effects induced by the more

applied forms of interaction – contract research and consulting – are most valuable for academic researchers interested in the technological artefacts being designed, developed and used within industry. This may explain why, in these disciplines specifically, high degrees of university-industry interaction are associated with high research performance (Balconi and Laboranti, 2006; Mansfield, 1995).

Second, academics' motives for working with industry play a role. For many scholars, access to learning opportunities are likely to play a key role in deciding whether to engage in consulting and contract research for industry. As indicated by our evidence, for academics intent on seeking out these opportunities, neither secrecy nor complementarity problems constitute significant hurdles to exploitation, particularly if they maintain high-trust relationships with their industry partners. Therefore, involvement in applied projects with industry does not automatically lead to lower or higher research productivity, but will be significantly informed by academics' underlying motivation to seek collaboration. Analogies can be drawn with Shinn and Lamy's (2006) study, which found that some academic entrepreneurs perfectly combined commerce and science, while others focused on commerce at the expense of science. Previous research has demonstrated that highly productive researchers use consulting engagements and advisory board appointments to 'co-mingle' with industry in the attempt to gather new ideas for research, learn about new industry applications and access data and materials (Murray, 2002). Boyer's (1990) report about the state of scholarship in US universities also stressed that effective academics need to engage with practice to complement and improve their research and teaching activities. To summarize, when judging the impact of industry collaboration, the main point is not whether academics engage in applied industry projects, but whether they make efforts to exploit them for research purposes. Cohort and group effects are likely to play an important role as academics in research-intensive environments are more strongly oriented towards generating research outputs (Bercovitz and Feldman, 2008).

Third, our results provide insights into the complementarities between different forms of university-industry interaction. Previous survey-based research has

shown that many academics are simultaneously engaged in several modes of collaborating with industry, particularly in applied disciplines (D'Este and Patel, 2007). Cohen et al. (2002) carried out statistical factor analysis on the relationship between different 'channels' of university-industry links and found, somehow counter-intuitively, that consulting goes hand in hand with the mechanisms of open science, i.e. conferences, informal interaction and joint research. Drawing on the evidence above, this result makes sense if such consulting activities are intrinsically connected to academics' research, enabling them to learn about technological problems and challenges. Consulting allows their involvement in highly interactive projects. Therefore, although it might not be directly amenable to academic publications, consulting can enable current academic research or inform future research projects. This suggests high complementarity between problem-solving for industry, and academics' research.

Our conclusion is supported by the fact that academics who work with industry (Mansfield, 1995) or engage in consulting (Link et al., 2007) are more likely to have raised funding for their research from government sources. It also resonates with other authors' findings that 'informal interaction' is judged as important as more formal collaborative arrangements by both industry R&D executives and academics (Arundel and Geuna, 2004; Faulkner and Senker, 1994; Meyer-Krahmer and Schmoch, 1998). Overall our analysis suggests that, even in the sciences of the artificial, learning effects from practical engagement with industry would appear most pronounced if pursued in conjunction with other, more research-focused types of collaboration. In turn, this means that faculty who engage in a series of one-off consulting or contract research activities, or limit themselves to these types of interactions, will derive less academic value from interacting with industry compared to colleagues engaged in multiple types of interactions over time.

Implications

Industry collaboration has differing effects on the production of academic knowledge, depending on the objectives pursued. While basic projects lead to immediate scientific output, more applied projects involve high degrees of

interactivity which in turn generate learning opportunities. Our discussion suggests that academics are able to capitalize on these opportunities for the benefit of scientific production particularly if: (a) their discipline is associated with the sciences of the artificial; (b) they are highly research-driven; and (c) they have a portfolio of different types of relationships with industry.

In terms of policy implications, our findings suggest that university-industry relationships constitute a two-way exchange rather than a one-way transfer of university-generated technology. It is the latter metaphor that tends to inform policy-makers' emphasis on spin-off companies and university-generated IP. By contrast, our findings emphasize the recursive nature of university-industry relationships where academics' access to industrial technology generates learning in universities which in turn can lead to innovation in technology. In spite of claims that the academic and commercial worlds are converging (Etzkowitz, 2003; Owen-Smith, 2003), we encountered a scenario where both sides are benefiting from close collaboration to suit their own purposes (Nelson, 2005). In many applied projects we studied, the locus of entrepreneurial action, e.g. opportunity recognition, resided in the firms that recruited academics into project solving or technology development. An overemphasis on turning academics (and universities) into economic entrepreneurs seems therefore misplaced, particularly as far more academics engage in collaboration with industry than in spin-off companies or patenting (D'Este and Patel, 2007). Equally, firms consider these interactions as more valuable than IP transfer (Cohen et al., 2002). Instead of making scientific research directly relevant to industrial applications, policy should promote the capability of academic researchers as skilled experts and consultants rather than entrepreneurs. In other words, 'universities should leverage talent not technology' (Florida, 1999). This would facilitate fruitful interaction between the worlds of science and industry while preserving and building their respective strengths.

In terms of managerial implications for university administrators, our results point to a possible dilemma. On the one hand, applied collaboration with firms might distract academics from engaging in long-term academic research. The results originating from such interaction with industry might not be publishable

in academic journals, either due to secrecy considerations or simply because they are not sufficiently novel or systematic. On the other hand, our discussion suggests that even seemingly non-academic projects can produce academic pay-offs by generating know-what about technological problems, user requirements and market trends. However, this mechanism might primarily apply to the sciences of the artificial. Overall, university administrators would be well advised to ensure that the consulting activities they encourage are complementary to academics' research activities. Notably, this means that consulting and contract research should be carried out whenever possible in conjunction with other forms of industry collaboration. In practice, this will be best achieved by providing research-intensive environments that attract research-motivated faculty and encourage high-quality research output.

Our research focused on university-industry collaboration within the engineering disciplines that are traditionally close to industrial application. Further research needs to explore to what degree our considerations apply to other circumstances. Variation is possible across several dimensions. First, other disciplines such as the life sciences and chemistry have also traditionally been strongly linked with industrial application yet they emphasize 'basic' rather than 'applied' science. Secondly, a variety of disciplines, such as management studies, are claimed to be highly practice-relevant yet have failed to achieve an impact commensurate with other disciplines (Van De Ven and Johnson, 2006). Thirdly, it is still an open question how engagement with industrial users is related to the research standing of universities. Future research should explore the variation of the incidence and structure of innovation-oriented collaboration across these dimensions.

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Appendix

Table A1: Interviews

Interview codes, interviewee roles and affiliations in chronological order
(May 2006 - Dec 2006)

Code	Interviewee Role	Affiliation
i1	Technology transfer co-ordinator	Academic
i2	Head of technology transfer	Academic
i3	Head of academic consulting	Academic (administrative)
i4	Dean of Engineering	Academic
i5	Professor of Photonics	Academic
i6	Professor of Manufacturing Processes	Academic
i7	Professor of Applied Thermodynamics	Academic
i8	Automotive Engineering Fellow	Academic
i9	Senior Lecturer in Electronics manufacturing	Academic
i10	Senior Lecturer in Automotive Engineering	Academic
i11	Professor of Healthcare Engineering	Academic
i12	Senior Lecturer in Software Design and Information Modelling	Academic
i13	Professor of Combustion Aerodynamics	Academic
i14	Senior Research Fellow in Electronics Manufacturing	Academic
i15	Professor of Risk and Reliability	Academic
i16	Professor of Chemical Engineering	Academic

i17	Senior Lecturer in Electronics Manufacturing	Academic
i18	Researcher in Ergonomics	Academic
i19	Researcher in Materials Characterization	Academic
i20	Professor of Control Systems Engineering	Academic
i21	Senior Lecturer in Alternative Energies	Academic
i22	Professor of Ceramic Materials	Academic
i23	Director of Engineering	Industrial (automotive consultancy)
i24	Professor of Structural Engineering	Academic
i25	Senior Lecturer in Sports Physiology	Academic
i26	Professor of Wireless Communications	Academic
i27	Professor of Electronics Manufacturing	Academic
i28	Director of Business Development	Industrial (fuel cells)
i29	Advanced Power Train Engineering Manager	Industrial (automotive)
i30	Technical Specialist Signal Processing	Industrial (automotive)
i31	Head of Mobile and Telecoms Ergonomics	Academic
i32	Senior Lecturer in Human Sciences	Academic
i33	Research scientist	Industrial (fuel cells)
i34	Professor of Analytical Chemistry	Academic
i35	Professor of Mechatronics	Academic
i36	Professor of Moving Image	Academic
i37	Professor in Music	Academic
i38	Technical director	Industrial (opto-electronics)

i39	Senior Lecturer in Alternative Energies	Academic
i40	Consultant	Industrial (consultancy)
i41	Medical director	Industrial (financial)
i42	Head of Powertrain Research	Industrial (automotive)
i43	Senior R&D scientist	Industrial (chemical)

Table 1: Sector distribution of academics' partner firms

Figures denote percentage of projects involving collaboration with firms belonging to specified sectors

Sectors	% of collaboration instances
Automobiles & components	20.7
Aerospace & defence	19.0
Technology hardware & equipment	12.1
Mobile telecommunications	8.6
Electricity	8.6
Electronics & electrical equipment	8.6
Other	22.4

Table 2: Sample of exemplary projects referenced in the article

	Project goal	Type of partner	Type of interaction	Initiation	Main outputs	Type of project
p1	Identify causes of vibration problems with gas turbine engine	Large multinational	Consulting	Firm – within context of organizationally established long-term collaboration	Identification of root problem, and options to resolve it	Solving problems
p2	Carry out risk assessment of oil platform process designs, and improvement of the latter	Oil major	Consulting	Firm	Assessment and feedback on design options	Providing advice
p3	Develop an automated industrial oven	Oven manufacturer (SME), some suppliers	Collaborative research, EU-funded	Consortium convened by firm	Business process modelling, top-level design specifications	Developing technology

p4	Develop flexible printed circuit for cars	Small technology company, plus other companies	Collaborative research – government research funding plus government R&D support funding	Lead firm identified several university partners	Reports; prototypes	Developing technology
p5	Measure specific combustion processes within engines	Large multinational, engineering consultancy	PhD project, with external advisor from industrial partner	Firm	Part of PhD research	Generating knowledge
p6	Devise feasibility study on invisible aerials equipment in cars	Public-sector agency	Consulting	Public-sector agency	Report outlining possible solutions	Testing ideas
p7	Reduce unplanned breakdown by using intelligent machines	Large Multinationals	Collaborative research, government-funded	Consortium convened by academics	Reports and academic papers	Generating knowledge

p8	Develop a new design for jet engines	Large multinational	Collaborative research EU funded (with consortium of firms); driven by academics	Academic – within context of organizationally established long-term collaboration	Research results in academic publications	Generating knowledge
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Table 3: Typology of university-industry projects

Goal	Description
Problem solving	Providing advice regarding technical problems arising within a firm's R&D, manufacturing or other operations
Technology development	Developing design specifications or prototypes for new or improved products or processes
Ideas testing	Exploring a high-risk concept on behalf of a firm – outside the firm's mainstream activities
Knowledge generation	Carrying out research on topics of broad interest to a firm

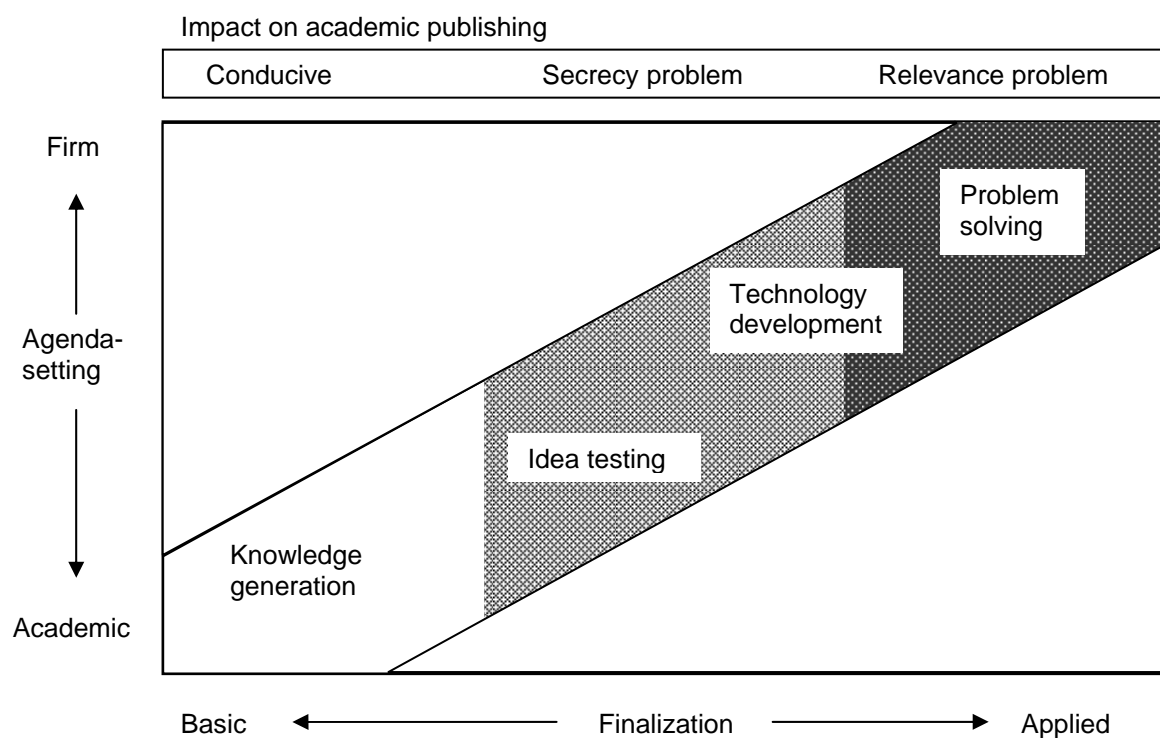
Figure 1: Finalisation, agenda setting, and effects on academic publishing

Table 4: Types of project and degrees of interdependence

Goal	Meetings	Equipment and materials exchange	Joint activity
Problem solving	Very frequent – information exchange and decision making	Implicit in nature of project	Always
Technology development	Frequent – information exchange and decision making	Implicit in nature of project	Always
Ideas testing	Relatively rare – information exchange	Sometimes	Rare
Knowledge generation	Relatively rare – information exchange	Sometimes	Very rare