Entrepreneurship and University Technology Transfer

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ABSTRACT. This paper argues that it is important to devote greater attention to the study of entrepreneurship in technology transfer in the light of greater government attention, the growth in the phenomenon, the need to identify how wealth can be created from spin-outs, changes in the cultures of universities and differences with technological entrepreneurship in general. The paper summarizes the contributions made by the papers presented in the special issue in terms of their levels of analysis. At the spin-out level, issues are raised concerning identification of typologies of spin-out firms, the evolution of spin-outs and external resources. At the university level, issues concerning policies, internal resources and processes are discussed. An agenda for further research is elaborated which relates to the need to examine further levels of analysis: the academic entrepreneurs themselves and how they recognize opportunities and shape their ideas to meet the market; the nature of internal university environments, processes and resources; and the nature of the scientific discipline which may have implications for the process of creation and development of spin-out ventures.

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1. Introduction

The creation, and sharing, of intellectual property is the core role of a university—the prime asset. Managing it for commercial profit is a serious challenge. Most universities with large research contracts understand how to license. After all, the roles of all parties (the academics, the university, and the commercial organization) during the transfer process, and subsequently, are clear. In particular, the academic will normally continue with the research whilst possibly having a consultancy arrangement with the commercial company. However, forming an independent company is a different matter. Here both the university and the scientist must agree that spinout is the most viable option for technology commercialization and must negotiate a spinout deal. This may include questions of, for example, equity split, royalties, academic and university investment in the new venture, academic secondment, identification and transfer of intellectual property and use of university resources in the start-up phase. In short, it is complicated. What is clear, however, is that there is more than one route to the commercialization of university intellectual property (IP) but that, whatever the route, core to its success will be the role played by the creator of the IP, the individual scientist or engineer. The need to know more about these spin-out companies and the entrepreneurial processes behind them is driven by a number of factors.

First, a growing policy debate has led to increasing pressure from governments to manage university IP and to realize investments in IP to generate wealth for both universities and the wider economy (HM Treasury and DTI, 1998). This applies particularly to the United States and increasingly across Europe and beyond. To promote spin-outs, the U.K. government established the £50 m "University Challenge" venture capital fund and created 12 Government sponsored "science enterprise centers" (SECs). Also in the United Kingdom, the Lambert Report on university–business collaboration published at the end of 2003 drew attention to the scope for wealth generation from the transfer of technology from universities (Lambert, 2003).

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Second, the culture in universities is changing. From being quite varied and in some cases openly hostile, there is greater acceptance of and a more positive attitude towards entrepreneurship across science departments in universities.

Third, while universities' strategies have traditionally focused on licensing as the predominant mode of technology transfer and the general body of research has reflected this emphasis (e.g. Siegel *et al*., 2003; Sine *et al*., forthcoming), more recently there has been greater emphasis on spin-out activity.

Fourth, the role and extent of spin-out activity is, however, in a state of flux. The number of spin-outs created in the United Kingdom in 2001 accounted for 31% of all spin-outs formed in the five year period 1996–2001, representing a remarkable increase over the average annual rate of creation over the previous four years (Wright *et al*., 2002). In contrast, in 2002, the number of spin-outs created fell by a third compared to the previous year (Wright *et al*., 2003). The Lambert Review and other commentators have observed that there is a distinction between the creation of spin-outs per se and the creation of spin-outs that create significant wealth (Lambert, 2003; Clarysse *et al*., 2004). Few spin-outs in the United Kingdom, for example, have been sold or floated on a stock market. It is easier for technology transfer officers (TTOs) to create a legal entity that contains the IP related to a new technology than it is to develop that technology into a venture generating positive cash flows. Recognition of this point focuses attention on the need to understand more about the processes, resources and capabilities required to develop spin-out companies and how this may be different from other new technology ventures.

Fifth, there are important differences between spin-outs from universities (USOs) and new technology based firms (NTBFs). These differences generally concern the environment in which USOs are created and the entrepreneurs involved in their creation. The university environment raises a number of potential issues. For example, as universities have traditionally been non-commercially oriented various organizational barriers may be erected to frustrate the development of entrepreneurship. The IP may not be owned by the academic inventor but by the university, creating issues relating to its exploitation through a spin-out. The academic inventor may also face tensions between pursuing a venture or remaining as an academic and need to make choices in terms of committing full time to one or the other or working part-time at both; this may have implications for the development of the venture.

This special issue was motivated by the need to learn more about university start-up companies and particularly those created on the basis of technology developed in universities in the light of these pressures and issues. Reflecting the diffusion of the concept of entrepreneurship and university technology transfer, we received submissions from a range of countries including the United Kingdom, the United States, Belgium and Sweden. All submissions were double-blind reviewed. We extend our thanks to the reviewers for their timely and constructive responses.

We were encouraged that the papers we received adopted a range of methods, from large scale quantitative studies that tested hypotheses to small scale case based studies that aimed to develop conceptual frameworks. Reflecting the newness of the area and the paucity of online databases on this topic, the studies typically engaged in extensive and pain-staking collection of field data.

In this Introductory paper we discuss the key themes in understanding entrepreneurship and university technology transfer represented in the special issue and then consider areas for further research.

2. Themes and contributions of papers in this issue

The papers in this special issue address the phenomena from two points of view. First, considering the spin out itself, typologies are identified based upon differing resource configurations, how these evolve over time and how external resources can influence spin out performance. Second, from the university perspective, different strategies and processes are proposed to influence entrepreneurial behavior.

3. The spin-out

Typologies of spin-outs

Researchers are beginning to recognize that spin-outs are not homogeneous. Nicolaou and Birley

(2003) identified a trichotomous typology of spin-outs. Clarysse *et al.* (2004) identified three distinct types of spin-out models adopted by research and development organizations, each highlighting the existence of different organizational goals and different environments and strategies. Two papers in this special issue develop this theme.

Heirman *et al.* (this issue) examine the initial resources on which new research based start-ups are based and how these resources interact with the institutional origin and market environment. Using a unique hand-collected dataset of research-based start-ups, they test how technological, financial and human resources relate to each other to form distinct starting resource configurations. They find four different starting configurations: "Venture Capital-backed start-ups," "Prospectors," "Product start-ups" and "Transitional start-ups". The results show that VC-backed start-ups are a minority while half of the firms start as prospectors. Market complexity and growth prospects influence the probability of starting with venture capital. A lack of clarity of the product market at founding characterizes prospectors, while product start-ups mostly have an almost market-ready product targeted at an international niche market. Transitional starters initially commercialize technical know-how through consulting and become product oriented later on.

They suggest that financial and human resources can reinforce or substitute each other depending on the maturity, innovativeness and scope of the product technology. Research based start-ups that develop early stage, innovative and broad technologies are more likely to raise venture capital, which goes hand in hand with larger founding teams and the ability to attract experienced managers during the first year. Those focusing on a concrete product opportunity, on the contrary, are typically financed with debt rather than venture capital and don't attract professional management. They suggest that entrepreneurs with many years of experience prefer business models with short-term revenue streams (through consulting or product sales) and financial independence, that is without venture capital. Starting resource configurations are also linked to the firms' history in terms of the parent institute that spun off the firm. Heterogeneity in the characteristics of the industry that the firm targets at start-up is also linked to different starting resource configurations. However, the causality here is unclear. For instance, is it the characteristics of the resource configuration that attract venture capital funding or does the acquisition of funding subsequently dictate a resource expansion?

Evolution of spin-outs over time

This issue is addressed in Druilhe and Garnsey's research which suggests a further way of considering the heterogeneity of spin-outs with respect to the characteristics of each entrepreneurial project. They explore typologies of companies originating in universities, using a Penrosean conceptualization of entrepreneurial activity. They propose three types of spin-out, yet see each evolving through a range of business models First development companies are based on some novel scientific breakthrough where resource creation and opportunity recognition are interdependent. Second, product companies involve opportunity recognition that builds directly on the scientist's knowledge and connections. Third are software companies, making up a quarter of the sample. They appear distinct as they benefit from lower scale up costs and the relative ease of switching from service to product business models. Longitudinal case studies show how the business models of new ventures are modified as entrepreneurs improve their knowledge of resources and opportunities. This modification may imply that the ventures shift from a research contract company to a licensing company, or that the entrepreneurs reconsider starting a product company and develop a technical consultancy instead. Through engagement with others and involvement in entrepreneurial activities, academic entrepreneurs develop relevant knowledge and experience. This allows them to improve their perception of opportunities, while gaining a better understanding of the resource configurations required to pursue the refined or newly perceived opportunities. In the case of development companies, these may initially be set up to commercialize a technology for licensing but may later aim at downstream services and production. A reverse mutation may occur as the objectives of the

business model change from production to licensing, thereby offering a plausible alternative to the transitional type identified in the previous paper. Academics who provide research-oriented services benefit from a ready-made productive base from which to operate and can secure returns more easily than those with generic technologies far-from-market. Academic entrepreneurs who are sufficiently motivated, skilled and market focused can create a productive base in-house that delivers products of high value to customers and secures them very high level of returns.

This study is consistent with other recent research that views spin-out development as an iterative, non-linear process (Vohora *et al.*, 2004). The differences between the studies concern their perspectives on whether the process of development involves clear breaks (junctures) or is a continuous one, and on whether all spin-outs pass through the same phases. Druilhe and Garnsey suggest that the phases that a spin-out passes through are a function of the maturity of the entrepreneurs' initial resources and the business model selected. What is more, they suggest a route to maximize the potential of spin out opportunities. A path dependency is implied where learning processes may substitute for lack of direct commercial experience. It appears that through working on collaborative research projects or consultancy with industrial partners, academic entrepreneurs can learn skills such as negotiating with firms and market intelligence gathering. This may help subsequent attempts to learn from industrial partners the sector specific knowledge necessary to exploit their technologies.

Wright *et al.* (this issue) provide an alternative business model to facilitate this process. They adopt an RBV perspective to explore the joint venture route to commercializing university owned intellectual property. They present comparisons between two spinouts formed as joint ventures between universities and industrial partners and two spinouts where this was not the case. Their comparative examination of the evolution of these two different modes of exploitation show that spinouts typically lack the financial and human capital (managerial) resources and capabilities they need in order to fully exploit the commercial potential of their technologies. They argue that creating a spinout company as a joint venture with an industrial partner, may be a means of overcoming some of the potential problems associated with managing resource weaknesses and inadequate capabilities that may be difficult to achieve as a free-standing spin-out company with or without venture capital backing. Nevertheless the question remains: how do academic entrepreneurs identify a suitable partner?

External resources

Spin-outs and the universities supporting them may lack sufficient internal resources to develop the venture. As a result, it may be necessary to seek external resources. Central to the findings of Wright *et al.* is the identification of the surrogate entrepreneur as a mechanism to leverage external resources into the nascent spin out. Partnering with an industrial corporation may be a means to access key resources where this is not possible.

Löfsten and Lindlehof (this issue) examine external resources in terms of the network benefits of Science Parks. They argue that the NTBF-specific co-operative resources to be found on university Science Parks will provide the firm with a competitive advantage. Proximity between NTBFs and universities promotes the exchange of ideas through both formal and informal networks. Based on a survey of 273 (NTBFs) located on and off Science Parks they find that the level of interaction in the innovation process between firms located on Science Parks and local universities is generally low, but it is higher than the level of interaction exhibited by firms that are not Science Park firms. Statistically significant differences between Science Park NTBFs and off-Park NTBFs were recorded with regard to product development in the last three years.

4. The university

Perceptions of the nature of environmental support have been found to be associated with entrepreneurial behavior (Birley and Westhead, 1993). The ''rules of the game'' for entrepreneurship (Baumol, 1990) as reflected in the environment both of universities and individual departments (the incubator organizations) will vary. A potential issue is that there may be gaps

between the declared strategies of both policy-makers and university management, and how the academic faculty views the entrepreneurial environment.

Kassicieh *et al.* (1996) identified a number of institutional variables that might affect academic entrepreneurship. These include formal policy and support for entrepreneurial activity from management; perceived seriousness of constraints to entrepreneurship, for example IPR issues; and the incidence of successful commercialization, which demonstrate feasibility and provide role models. From a survey of 778 life scientists working in 40 U.S. universities Seashore Louis *et al.* (1989) concluded that developing formal policies may send a signal, but the effect on individual behavior depends very much on whether these policies are reinforced by behavioral expectations. Indeed, they suggest there are entrepreneurial universities, rather than isolated entrepreneurial academics. However, the precise relationship between formal institutional policy and individual performance remains unclear. Samsom and Gurdon (1993) share this view. They studied twenty-two biomedical spin-offs founded by university scientists and confirmed the need to acknowledge the potential conflict between the pursuit of knowledge and its commercial exploitation, and the dual risks of demotivation of potential entrepreneurs and lower research standards. This, they conclude, argues for explicit guidelines for the conduct of business in a university

A recent survey of TTOs in the United Kingdom undertaken by one of the authors identified the main internal promoters of spin-out activity within universities as: incentives and rewards for academics; the level of marketing, technical and negotiating skills of staff involved in IP exploitation; internal processes for conducting IPR due diligence; internal processes for spinning out new companies; and internal processes for conducting business development (Wright *et al.*, 2003) in addition to environmental factors including university facilities, dual employment, and financial ownership.

DeGroof and Roberts (this issue) analyze the characteristics of academic spin-off policies in environments outside high tech clusters and where technology transfer and entrepreneurship infrastructures have been weak. They explore whether the policies could explain the lack of growth potential of spin-off ventures that academic and policy studies have repeatedly observed. Taking the case of Belgium, they obtain data from nine cases of spin-off policies in the eight largest academic institutions and in 47 firms. Examining policies in terms of the extent to which they engaged in origination, concept testing and start-up phase activities, they identify four archetypes of spin-off policy: an absence of proactive spin-off policy; minimalist support and selectivity; intermediate support and selectivity; and high support and selectivity. They propose that spin-off policies in academic institutions do affect the growth potential of ventures and suggest that environments with weak entrepreneurial infrastructure and culture require academic spin-off policies involving high selectivity and high support in order to generate growth oriented ventures. However, they note that high selectivity and high support spin-off policies represent an ideal to achieve rather than an immediate accessible policy since such a policy requires considerable resources which individual academic institutions seldom have access to in these environments. Most individual academic institutions may not, therefore, be suited to select and support spin-off ventures with high growth potential in such an environment. They suggest that their framework can be used to assess spin-off policies targeting the creation of growth oriented ventures and as a management tool to link each stage with the resources necessary to fulfill each of its functions. This study has parallels with the pan-European study conducted by Clarysse *et al.* (2004) who identify three broad types of spin-off incubator. Clarysse *et al.* (2004) argue that an alternative policy approach in the light of both difficult to surmount resource constraints and variability in spin-off opportunities is for universities to match their objectives for spin-offs to their contexts. This approach may be preferable to engaging in a futile attempt to create high growth spin-offs where they have neither sufficient resources nor the science base to generate potential high growth ventures. Universities should, however, adopt multiple but separate spin-off policies where they have new spin-off opportunities that range from modest self-employment to high growth potential cases.

Markman *et al*. (this issue) shed light on whether financial incentives to scientists, their departments and UTTO personnel affect entrepreneurial activity using both qualitative data (structured interviews with 128 UTTO directors) and quantitative data from surveys and databases available on the web. This interesting combined methodology shows a surprising result that is opposite to theoretical predictions that incentives to scientists and to their departments are negatively related to entrepreneurial activity. They speculate that this may be related to the quality of staff in that high quality staff who make breakthrough discoveries may either be less concerned with its commercialization or not motivated by financial rewards to identify such opportunities. In addition they find that pay to TTO personnel is positively related to entrepreneurial activity but that experienced TTOs are significantly but negatively related to entrepreneurial activity. They attribute this finding to possibly capturing the effect of more traditional TTOs being focused on licensing rather than spin-outs. This raises an interesting and important conundrum. Is this the result of inertia or is it linked to their greater expertise which leads them to recognize that in many cases licensing may be the more appropriate route to exploitation of IP?

A potential answer may be found within Lambert's (2003) review of U.K. business-university collaboration. This report suggests that technology transfer activity should not necessarily be solely evaluated via economic returns to the University but should be considered by wider social and economic benefits such as the diffusion of knowledge. Such metrics would be more consistent with the current Research Assessment Exercise evaluation of research activity and would therefore reduce potential conflicts between research and commercialization activities if adopted by Universities as a strategic goal. Examining the relative effectiveness of different technology transfer methods by using different output measures would provide more insight into this area. Designing metrics to cover different aims may be problematical. The number of licences and spin-outs created are fairly clear objective measures, although setting objectives in terms of the wealth generation from spin-outs in particular is perhaps less straightforward (Lockett *et al*., 2004).

5. Agenda for further research

The papers reviewed here reflect the predominant, and logical, trend of considering the spin out as the unit of analysis. This has highlighted a number of important avenues for further research, that may be understood more clearly from differing levels of analysis such as the academic entrepreneur, the university and the scientific discipline. First, with regard to the academic entrepreneurs themselves, how do they recognize opportunities and shape their ideas to meet the market? Second from the spin-out perspective there are questions relating to the factors that influence the stage of progress and the choice of stand alone versus joint venture mode of development. Third from the university perspective, how does the nature of internal university environments, processes and resources influence entrepreneurial behavior? Finally, from the scientific discipline level, how does the nature of the technological opportunity vary between scientific disciplines and how do differing scientific research networks influence the process of creation and development of spin-out ventures?

Academic entrepreneurs

There remains little evidence on the nature of entrepreneurs and their behavior in university technology transfer. In the entrepreneurship field generally, several studies suggest that individual traits can influence the decision to start a business (Gartner, 1985). However, doubts have been raised as to whether individual motivations are the key determinants influencing the supply of entrepreneurs (Birley and Westhead, 1994). Moreover, the view that entrepreneurs are by definition, relatively uneducated is no longer valid. For example, Kassicieh *et al*. (1996) study of 237 scientists working in three large national laboratories in the United States found clear differences between the levels of education in inventors in national laboratories and those in a study of technical entrepreneurs from MIT (Roberts, 1991). The Kassicieh *et al*. (1996) study also found significant differences between entrepreneurs and non-entrepreneurs in terms of situational variables such as the level of involvement in business activities outside the laboratory or the receipt of royalties from past inventions. Beyond this, there

remains very little data on the characteristics of those academics involved in creating new ventures. This may, of course, be because the "rules" within which they have operated (Baumol, 1990), particularly as they apply to IPR and equity sharing, has meant that many have been unwilling to identify themselves. It is also probable that this is compounded by inadequate university data capture systems. There is, therefore, a need for research that fills this gap.

A second issue concerns understanding of the behavior of academic entrepreneurs. Opportunity identification is central to entrepreneurship. Knowledge (and information), cognitive and behavioral differences help explain why certain individuals recognize opportunities while others do not (Venkataraman, 1997). Shane (2000) found that prior knowledge of markets, ways to serve markets and customers' problems influence the discovery of opportunities. The ability to connect specific knowledge and a commercial opportunity requires a set of skills, aptitudes, insights, and circumstances that are neither uniformly nor widely distributed (Venkataraman, 1997). Entrepreneurial cognitive processes may enable individuals to build on specific information to make new leaps in the identification and development of new discoveries and opportunities. Entrepreneurs with strong entrepreneurial cognition may be more likely to quickly develop new hunches about how a new piece of information such as that relating to a technological breakthrough will impact a specific project idea long before it can be methodically and rationally explained. The creation of significant scientific breakthroughs by university researchers may require leaps of intuition rather than deterministic logic. Leading researchers may also be entrepreneurial in identifying new research areas and sources of funds. But to what extent are they able to identify opportunities with commercial market applications? Evidence is limited on the extent to which academic entrepreneurs themselves recognize opportunities or whether TTOs and surrogate entrepreneurs have an important role to play (Lockett *et al.*, 2003).

There is also growing appreciation in the general entrepreneurship literature that opportunity recognition and exploitation or realization are distinct. Some universities have adopted approaches whereby TTOs work very closely with departments and academics to proactively identify opportunities that may have significant market applications. We need to know more about these processes of opportunity realization.

Extending these issues, it is an empirical question whether leading scientists are homogeneous with regard to their ability to identify commercial opportunities.[1] There is increasing evidence that the phenomenon of habitual entrepreneurs, i.e. those individuals who undertake multiple entrepreneurial ventures, is widespread in the general economy (Birley and Westhead, 1993; Westhead and Wright, 1998). Issues arise both in terms of understanding the behavior of habitual entrepreneurs versus first time (novice) entrepreneurs and the nature of support for entrepreneurship (Ucbasaran *et al.*, 2003; Westhead *et al.*, 2004). We know little about the extent to which habitual entrepreneurs exist in universities. To the extent that these individuals do exist, there may also be implications here for the development of university processes regarding technology transfer.

Spin-outs

The findings from the papers presented in this special issue emphasize issues concerning the evolution of different types of spin-out. While there is some work on this process, further research is needed that examines such issues as the stage of development at which spin-out companies are formed and at what stage spin-out companies fail to develop further. For example, to what extent is the problem a failure to develop beyond initial alpha prototypes or a lack of human capital expertize or finance or market?

The studies presented here also indicate that there may be important network links between academic entrepreneurs, TTOs and existing corporations, yet these links are not well-understood. There would appear to be a need for more longitudinal studies considering potential academic entrepreneurs and their interactions with industry. By following such academics as they explore different networking and partnering options it should be possible to investigate the influence of different paths upon entrepreneurial behavior. A particular issue arises with respect to whether ventures become stand alone spin-outs or

joint ventures with other corporations. The cases studied suggest that the partners emerged through contract research arrangements. What is not clear is whether the partners explicitly saw contract research agreements as a precursor to a joint venture or whether these evolved passively out of the research process. If the former is the case, there may be issues here concerning whether universities need to be more proactive at the contracting stage in searching for the appropriate industrial partner and the conditions in the initial contract concerning the future exploitation of the research.

Eisenhardt and Martin (2000) propose that the formation of such alliances requires the development of dynamic capabilities within the firm. They argue that learning processes are necessary for the sustained identification and exploitation of partnerships within markets where the boundaries are blurred and successful business models unclear, a situation common to many nascent spin-outs. The implication here is that spin-outs with a management capability to change and refine their resource configurations to meet the emerging needs of the market will outperform those who do not. Nevertheless to investigate this area is methodologically challenging as it involves consideration of the relative success of different management processes acting upon heterogeneous resource configurations.

Universities

Internal University Entrepreneurial Environment. The Kassicieh *et al.* (1996) study referred to earlier found that local norms or "culture" provided a strong mediating effect between the institutional context and individual perceptions. Seashore Louis *et al.* (1989) found that individual characteristics and local norms appear to be equally effective predictors of entrepreneurial activity, but only provided "weak and unsystematic predictions of the forms of entrepreneurship" (p. 128). Owen-Smith and Powell (2001) found differences in the extent and nature of commercialization between scientists in different subject areas. There are two explanations for the existence of local norms. First, there may be self-selection during recruitment at the departmental level resulting in staff with similar personal values and behavior. Second, peer pressure or behavioral socialization may result in a convergence of personal values and behavior. What is not clear is whether these are immutable or whether they change with changes in the environment relating to academic entrepreneurship. Although there is anecdotal evidence that science departments are becoming more positive towards entrepreneurship we still know little about whether and to what extent this varies across disciplines and universities and according to the research strength of the department.

Business schools as an internal resource. The debate on technology transfer and entrepreneurship in universities has very much focused on science faculties. Issues concerning resource constraints on the development of spin-out ventures has links to a parallel debate on the relevance of research in business schools (Starkey and Madan, 2001) and raises the question about the role business schools can play in the development of entrepreneurship in universities.

In principle, business schools may be able to play indirect and direct roles. With respect to indirect roles, universities can provide generic tools such as: courses on entrepreneurship for undergraduates and post-graduates; courses for academics in Science Departments; courses on general marketing, financial, etc. dimensions of business. For example, at the University of Nottingham, the Institute for Enterprise and Innovation has developed an M.Sc. program in Entrepreneurship for science and engineering graduates, a "germinator" where students are provided with support to develop ideas for new ventures, and a range of undergraduate courses on entrepreneurship. Such courses are prevalent across a large proportion of research active Universities in the United Kingdom through the government funded SECs. Nevertheless, any long term impact upon entrepreneurial behavior has yet to be established. There is also an increasing emphasis upon technology transfer fellowships. For instance, the Medici scheme (www.midlandsmedici.org), funded by HEFCE, provides one year fellowships for fifty academics across five U.K. Universities. Here the focus is "on the job" training where the fellows perform a dual role to facilitate the commercialization of

biomedical research. Many are engaged in commercializing their own research and thus benefit from experiential learning supported by a cross-university network of academic and TTO mentors. Others focus upon culture change initiatives where they raise awareness of the benefits and limitations of commercialization within their own faculty and introduce systems and procedures appropriate to their own context. The rationale behind such schemes is that culture change is a slow and painstaking task that is best achieved by education based initiatives sensitive to local values and norms. Clearly, there is a need to evaluate the relative effectiveness of this and similar initiatives with a consideration of "softer" output metrics such as awareness and attitudes in addition to the "harder" metrics of invention disclosures and patents filed.

Research in business schools may also have an indirect impact on start-ups and spin-offs from universities in terms of identifying for entrepreneurs and technology transfer officers as well as policymakers the barriers at a systemic level to the development of companies from universities.

In terms of a direct role, business school academics may be able to provide resources and capabilities by acting as non-executive directors on spin-off company boards or acting as consultants on particular business plans. At an institutional level, business school academics may serve on the boards of universities' technology transfer operations.

A number of potential problem areas arise in the role of business schools in filling the knowledge gap by transferring knowledge. First, there may be a mismatch of the language used by business school faculty and faculty in science departments. There is a gap between the provision of courses and what it is really like to be involved "hands on" in the creation of a spin-off. As with academic scientists and TTOs there are issues to do with the incentives to undertake such activities. There is a question relating to the comparative advantage of business school academics vis-à-vis other providers such as TTOs and outside consultants, especially for specific knowledge required for TT.

Further research is required to examine the extent and nature of business schools' involvement in the development of entrepreneurship related to the transfer of technology in universities.

Scientific discipline

Much of the research on the commercialization of technology has been based on the experience of specific technical disciplines. For example, the experience of life sciences in the United States suggests spinouts are the preferred route, whereas licensing agreements are more commonplace in the electronics sectors. However, there is unlikely to be "one best way" to manage commercialization as disciplines will differ in terms of technological opportunity and commercial potential (Tidd, 1997). Moreover, organization-specific characteristics are likely to undermine the notion of a universal formula for the successful commercialization of research. For example, some institutions have experience and expertise in licensing, but not joint ventures. Organizational context is, therefore, a potentially important influence on the development of spin-outs as are industry dynamics on the generation and commercialization of innovations (Drazin and Schoonhoven, 1996; Tidd *et al.*, 1997).

A further implication of these findings is the potential effect of technological differences upon growth strategy. From the papers in this issue it appears that particularly software-based firms are distinct in terms of requiring different resource configurations and business models due to their differing market, financial and technological requirements. It seems that software firms are able to make more use of a service business model to test the market, are able to develop products for niche markets and subsequently expand into broader markets in a relatively fast and low cost manner. These options are somewhat more limited for most novel biotechnology and material based technologies. Also, the type of technology will influence the extent of the need for external funding. For example, most biotechnology-based new ventures have higher initial capital requirements than electronics or software. Nevertheless, an electronics or software-based venture will also demand high initial funding if a strategy of aggressive growth is to be achieved. Oakey's (1995) study of technology start-ups in the United Kingdom shows that both the amount and source of initial funding vary considerably by field. For example, software-based ventures typically require less start-up

capital than either electronics or biotechnology ventures, and therefore it is more common for such firms to rely solely on personal funding whilst biotechnology firms tend to have the highest R&D costs, and consequently most require some external funding. This implies that research should be conducted at the department or technology discipline level in order to isolate critical differences between the human, financial and technological resource requirements in these different domains.

Technical fields also differ in the amount of resources devoted to R&D, and in the rate of technological advance, whatever measure is used. These differences in technological opportunity have a significant effect on the potential for commercialization (Geroski, 1994). Although difficult to measure and model, three potential sources of technological opportunity have been identified (Klevorick *et al.*, 1995): advances in scientific understanding; technological advances in other, related industries; and positive feedback from prior technological advances.

At any time the relative importance of these different mechanisms varies by technical discipline. For example, the pharmaceutical and semiconductor sectors both have strong links to basic science; the former to a narrow range of scientific fields, the latter to a much wider range of fields. In the food and electronics industries, material suppliers and equipment manufacturers are important sources of innovation. Customers are important sources of innovation in the machinery, electrical equipment and medical instrument sectors. Pavitt (1990) develops a similar taxonomy based on the primary sources of innovation: science-based; scale intensive; information intensive; and supplier-dominated.

This is further complicated by the influence of strategic choice upon firm growth. For new technology based spin-outs Tidd *et al.* (1997) distinguish between the two desired outcomes of superstar and specialized supplier. Superstar firms grow extremely quickly by pursuing broad based global markets whereas specialized suppliers are more restrained in their ambitions, focussing upon smaller market niches. They argue that these outcomes are not predetermined by technological, financial and human resources upon start up or even at an early stage but are heavily influenced by learning processes such as networking and partnering. This appears consistent with the papers in this issue. Here it is illuminating to consider research into spin-out activity within the private sector. Broadly speaking the trend is for the development of joint ventures and strategic alliances between leading corporations to develop discontinuous technologies (see Leifer *et al.*, 2000; Dyer and Singh, 2000). The justification is that only by such mechanisms can the cross-disciplinary and cross-market options be fully explored. It appears that the University spin-out may be able to benefit from such strategies and therefore for Universities to maximize the benefits from their technologies they should engage in cross-disciplinary commercialization as a natural development to the many instances of cross-disciplinary and cross-institutional research. One such initiative within the United Kingdom is the investment company IP2IPO. It has made a number of deals with a portfolio of United Kingdom universities including Oxford, Southampton, Kings College London and the University of York. Investigations of this and similar partnerships may offer insight into the strengths and weaknesses of the approach but investigation of this phenomenon requires consideration of networks and technologies as units of analysis and also comparisons between different network strategies (see Galambos and Whittaker, 1993).

There are also significant disciplinary differences in the degree and nature of faculty interaction with industry, and these differences are not only field-dependent but also reflect technology life cycles (Peters and Etzkowitz, 1991). For example, differences are apparent between chemical process engineering and life sciences. Such differences will influence the local norms and behavior noted earlier, and are likely to contribute to differences between the degree and type of entrepreneurial activity of departments and research centers within a single university.

This discussion suggests that there is a need for more fine-grained analysis of the both the nature of academic entrepreneurship and the manner in which ventures are framed and developed between different disciplines.

Policy implications

An important policy debate concerns the nature of support to be provided to spin-out companies. The studies reported here add to other recent research in recognizing the heterogeneity of spin-outs in terms of the environments in which they emerge, the skills of the entrepreneurs and the resources they require. This suggests that policy measures need to be more sophisticated than simple one-size fits all support. Further research is required to integrate the differing perspectives on the types of support required.

Finally, a key policy issue concerns the need to reconcile the objectives of the different levels involved in the broad domain of entrepreneurship and technology transfer, that is the levels of the universities, academic departments, spin-out firms and the academic entrepreneurs.

Note

1. As an anecdotal example, a university business development officer recounted to one of the authors the case of a highly successful academic who had created what is now a multi-million £ turnover technology based company who as a teenager had run a market stall selling fabrics.

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