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Abstract

Questioning the widespread tendency to view academic spin-outs as a homogenous category, the paper explores typologies of these companies using a Penrosean conceptualisation of entrepreneurial activity. We initially identify five main types of business activities pursued by academic entrepreneurs, which we revise after analysing a database of Cambridge University spin-outs and real-time exemplars of emerging ventures. The refined typology takes into account the dynamic of the entrepreneurial process. As the business models of ventures evolve they may enter a different category of business activity. We conclude by discussing the academic and practical needs for a better understanding of the heterogeneity of spin-outs, the diversity of which has theoretical and policy implications.

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1 Introduction

Spin-outs from universities are usually thought of as new firms commercialising a proprietary leading-edge technology from a university department, and backed by venture capital.[1] They are viewed as the entrepreneurial alternative to licensing by many scientists and technology transfer officers (Lambert 2003). Studies of technology transfer providing descriptive statistics on academic entrepreneurship tend to depict spin-outs as a homogenous category (Charles and Conway 2001; HEFCE 2003; OECD 2002). There is a linear conception of the process of spin-off creation according to which a technology-based idea is generated from research, protected by patents, and transferred to a firm newly established to commercialise the idea.[2] In his 1991 paper entitled "Why do firms differ and how does it matter?" Richard Nelson criticised the neoclassical view of the representative firm in economics (Nelson 1991). We would like to question the idea of a standard academic spin-out going through a linear process of emergence.[3] An undifferentiated approach may restrict the understanding of science-based entrepreneurship and impede appropriate support by policy makers.

This paper suggests an initial typology of university-based spin-outs grounded in a dynamic view of the entrepreneurial process. We argue that the resource-based view, and more particularly Penrose's work (1995)[4], provides a basis for conceptualising the emergence of entrepreneurial firms and for differentiating between science-based enterprises. Empirical evidence from Cambridge University in the UK is used and the paper draws on a database of university spin-outs and on real-time data on the creation of 9 companies.

Cambridge University is an interesting case for the scope and history of entrepreneurial activities from the science-base, allowing us to explore the diversity of academic spin-outs in a single organisational setting. There were early spin-outs from the University of Cambridge, such as the Cambridge Scientific Instruments company founded in 1881 by Horace Darwin, Charles Darwin's son. In the last 20-30 years the emergence of companies rooted in the

[1] Venture capital has not been a significant source of finance for academic spin-outs because it does not provide seed capital of the kind early stage venture need. Some development companies are unusual in that they have been able to obtain venture capital on the prospects offered by outstanding new technologies with large eventual market potential, e.g. in biotechnology.

[2] See Autio (1997) for a critique of this conception.

[3] In the field of entrepreneurship, a tendency to overlook the diversity of entrepreneurs and the activity of their enterprises has also been noted (Ucbasaran, et al. 2001).

[4] Penrose wrote about growth in the mature firm, but her insight can be applied to new firms (Garnsey 1998).

University has become a feature of high-tech activities in Cambridge. Academic spin-outs have made a significant contribution to the Cambridge Phenomenon and today about 20% of the firms have a University founder (Segal Quince Wicksteed 2000).

In the next section a brief review of the literature provides the rationale for the paper. We develop a Penrosean framework of the entrepreneurial process and propose a typology of spin-outs. In the third section we apply our concepts to a database of university spin-outs, and use case studies to exemplify types of business activities in the fourth section. Finally, we discuss the need for recognition of the multi-dimensional issues surrounding university spin-outs.

2 Conceptual framework

2.1 Literature review

The growth of the literature on academic spin-outs, found mostly in the management and public policy disciplines, reflects the increased interest in this form of academia-to-industry technology transfer. Empirically-based studies have identified a range of factors facilitating or hindering the creation and development of spin-outs (Blair and Hitchens 1998; Chiesa and Piccaluga 1998; Rappert and Webster 1998; Smilor et al. 1990; Stankiewicz 1994; Weatherston 1993). Personal motivations, the business competencies of scientist-entrepreneurs, the availability of external resources, and the university environment are found to play a significant role in encouraging or preventing entrepreneurial activity in universities. As universities structure their technology transfer activities, increasing attention is placed on universities policies and strategies that enhance or inhibit technology transfer (Clarysse et al. 2002; Lockett et al. 2003).

Studies that consider the diversity of spin-outs remain rare. This may be because much of the spin-out research does not focus on the firm level but rather on their environment and the infrastructure support and public policies that encourage the emergence and growth of companies from the science base (Pirnay 2001; Roberts and Malone 1996). This reflects a research field still in its infancy.

Among those who recognised the diversity of spin-outs, Bullock (1983) early on identified 'soft' companies, those that start as technical consultancies solving specific problems and require low initial funding and management skills. As companies develop, he assumed that they grow into 'hard companies' that sell standardised and relatively simplified products to a general market.[5] Mustar (1997) distinguishes between firms according to the links they maintain with the science-base, while Autio (1997) proposes a more dynamic approach linking the niche markets of new technology-based firms and the transformation of knowledge they undertake. This leads him to identify science-based firms, which are "relatively more active in transforming scientific knowledge into basic technologies" and engineering-based firms which are 'relatively more active in transforming basic technologies into application-specific technologies' (p. 267). Stankiewizc (1994) classifies academic spin-off companies according to the way they operate and identifies different modes of operations: consultancy and R&D contracting mode, product-orientated mode, and technological-asset orientated mode. Although he points out that these modes are not necessarily mutually exclusive and that firms can move from one to the other, he holds to his typology because each mode "requires a different set of technical skills, a different approach to management and financing, different linkages to the academic knowledge base, and a different form of infrastructural support" (p. 103).

While these typologies are useful, the dynamic processes leading to firm emergence and growth may be overlooked when classifications represent static categories. Different types of business activities pursued, the differing initial conditions and the distinct opportunities recognised can be expected to have an influence on the entrepreneurial process and on the prospects perceived for the spin-out, but these factors are not static. We propose to develop a typology linked to the entrepreneurial process of firm formation by drawing on the resource-based view of the firm (Barney 1991; Grant 1991; Montgomery 1995; Penrose 1995). The relevance of resource-based approaches to new firm formation has been recognised by Brush et al. (2001) and Autio (1997). But we draw attention to the feedback element central to Penrose's original model, which allows for the way entrepreneurs adapt and modify their business ideas as they gain experience (Penrose 1995).

[5] However this transition has been found only in a minority of actual cases.

2.2 The entrepreneurial process

We view the entrepreneurial process as comprising the pursuit of opportunity, the mobilisation of resources and the creation of a resource base for business activity to deliver value and capture returms. The entrepreneur has to develop a conjecture or business idea of the means to create value and capture returns and, through the entrepreneurial process, translate this into a business model that can be implemented.

Opportunity recognition. For Penrose, entrepreneurs seek to realise a productive opportunity, which refers to "the productive possibilities that the firms' 'entrepreneurs' see and can take advantage of" (Penrose 1995, p. 31). The concept emphasises the cognitive and cultural dimensions of enterprise.

The first difficulty facing academic entrepreneurs is to identify and select a viable productive opportunity. Opportunities are activated by recognition; they are objectively identifiable but their recognition is subjective and often depends on access to special knowledge. Research carried out in the university may result in potential for technologies that are highly generic and require further work to develop applications, with consequent uncertainty. The original patents frequently constitute an insufficient basis for exploitation. Further developments, improvements and intellectual property protection are required if these technologies are to be exploited commercially. The 'pre-competitive' status of this knowledge makes the task of identifying a market opportunity difficult (Garnsey and Moore 1993). For scientists engaged in this type of research, the most suitable opportunity may be to provide 'knowledge services' on a consultancy basis, to make use of the scarce knowledge they have that is valuable to customers. Prior knowledge can be expected to aid opportunity detection (Shane 2000), as will connections and social capital (Aldrich 1999). Individual motivations provide incentives to pursue the opportunity. These incentives may be prospects of gain but there is evidence that other motives (e.g. commitment to a project, prestige, diffusion of inventions to society) are important in the creation of spin-outs (Weatherston 1993).

Mobilisation of new combinations of resources. As compared with other business entrepreneurs, scientists can combine new resources through scarce expertise that may give rise to new productive activity based on leading edge technology. But most scientists lack business expertise and the investment capital required to cover the expenses incurred in the lengthy development work needed to bring a technology closer to market. Academic research grants do not cover these costs. However academics can often make use of university facilities to reduce the expenditure required on infrastructure while an innovative productive base is being created (Druilhe and Garnsey 2001). Scientist-entrepreneurs tend to minimise early resource outlays to keep open the pursuit of shifting opportunities. They find ways to exert leverage from the resources at their disposal. Resources available in the university and market environments are critical in this respect. The availability of investments funds affects the way new enterprises reach the market with their innovations.

Organisation of the resource base. To realise the opportunity it is necessary to organise business activity, the conversion of inputs into revenue-generating outputs. This is supported by the firm's resource base that makes it possible to process resource inputs, produce a given type of output and secure returns from customers. Some resources, financial, physical and human, are mobilised from outside, others are created within the firm, where they are combined to make productive activity possible. Building on Penrose, we also find it useful to distinguish between the productive and commercial dimensions of the resource base of a company. The productive base encompasses all the physical facilities of a company whereas the commercial base provides legal and marketing competence and supports partnerships and collaborations.

A productive base may be very simple as in the case of a research services company or very complex in the case of a plant or other installation. Productive resources are made up of those resources that are currently in use for productive activity. Penrose was dealing with mature firms that already had a base of this kind. The new firm, in contrast, rarely starts out with a productive base, except in special cases such as de-merger, but has to build one from the resources the entrepreneurs mobilise. Penrose was concerned with the production base of manufacturing firms ('industrial firms'). The term 'productive base' is used here because Penrose's concept can also be applied to service activities. For example research services require the productive capacity to generate, process, store and retrieve information and convert it into meaningful knowledge communicated to clients. As it grows, the firm's resources may come to support a variety of productive bases, but Penrose pointed out that: ' … movement into a new base requires a firm to achieve competence in some significantly different area of technology' (1995, p. 110).

Both environmental and internal factors are sources of valuable resources in the emergence of spin-outs. They shape one another in a dynamic relationship. Both are used to connect a new idea or invention to a need or problem in the marketplace, thereby opening new opportunities. Penrose describes the environment as 'an image in the entrepreneur's mind' (p. 42) to point to the importance of perceptions and subjectivity in the way in which the entrepreneur makes sense of the environment.[6]

2.3 Types of business activity

Penrose's concepts of productive base and productive opportunity, which bridge firm and market, provide theoretical grounding for the notion of 'business model'. This can be used to refer to the activity of a company, how this is resourced, the way it creates value and how returns are to be realised. We propose here a typology of business activities, that, in the case of successful firms, is underpinned by a business model generating sustainable returns.

The most accessible market opportunity appears to be the provision of research-based consultancy or research services to customers. In contrast the creation of a physical production base requires investment capital and is likely to be remote from the scientists' experience. The next most accessible opportunity would appear to involve developing technological resources and protecting them with intellectual property rights that can be licensed or sold to customers. In this case the productive activity is to develop a technology from 'pre-competitive' on to 'near-market' status and find ways to appropriate returns from their research findings through licensing or sale. The term 'development company' can be used to refer to a company of this kind that pulls together initial intellectual property rights (IPR), on which future IPR are built through research and development. As intellectual resources, these are not embodied in a physical production base making products. Licensing and a variety of research contracts with pharmaceutical corporations is the route chosen by drug discovery ventures which do not aim at integrated drug production because of the production costs. Software start-ups have certain features in common with IP-based start-ups since their product involves licensing software, but there is also a production process for software production, albeit one with lower scaling up costs than for the production of physical products. The most demanding route would appear to be the creation of a physical infrastructure for the output of a product based on research activities. This is the case of those environmental companies that require the establishment of a new infrastructure to

[6] It is generally assumed that Penrose was concerned exclusively with internal factors, but those who go back to her own work see that she emphasises the *interplay* between the firm's resources and its environment. This has been missed in much of the discussion of Penrose but is one reason why her work is relevant to the new firm.

support their green technologies. An infrastructure may also be required to support the products of telecommunication companies.

We propose that university spin-outs fall into these five categories along a spectrum shown in Figure 1. The entrepreneur's prior experience and knowledge will influence progress in interaction with the intensity of resources required. We initially assumed that the closer to the scientist's knowledge and experience of the business activity, and the fewer resources required, the faster will be progress to market.[7]

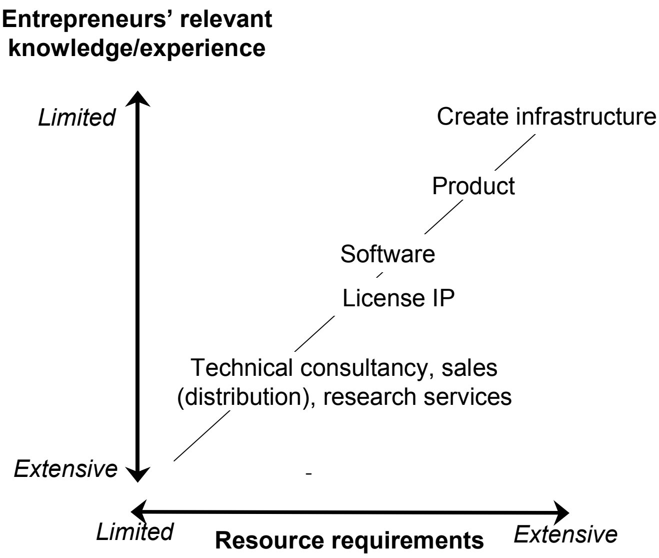

Figure 1: Five broad categories of university spin-outs

We argue that the type of business opportunity selected influences the entrepreneurial process and activities outlined above. These do not unfold in a sequential manner but rather involve feedback loops and setbacks. Entrepreneurial projects progress through the continual interaction between shifting opportunities and emerging combinations of resources. In order to overcome constraints on knowledge and other resources, enterprise requires collective endeavour. Entrepreneurs must build partnerships integral to their business models. In what follows we apply these concepts to the analysis of Cambridge spin-outs, drawing first on a database and then on case studies.

[7] We have reported elsewhere that our empirical investigation revealed how motivated and knowledgeable entrepreneurs in some cases can overcome what appear to be inhibiting factors (Druilhe and Garnsey 2003).

3 Spin-out activity at Cambridge University

The evidence from Cambridge is presented here to illustrate the range of entrepreneurial activities originating from the science base and the influence of the environment on spin-out activity. Cambridge high-tech activity was not confined to spin-outs from the University but these have had significant influence. In 1985 it was found that 25% of the high-tech firms in the Cambridge area had a founder originating from Cambridge University or a research establishment coming from the Cambridge area. As the high-tech complex grew, an increasingly higher number of ventures spun out of existing companies. Others were attracted to the region. By 1999, of the companies founded since 1990, only 17% had a founder coming directly from Cambridge University or a Cambridge research centre (Segal Quince Wicksteed 2000).

3.1 Methodology: spin-outs database

We use a database developed by the University of Cambridge Entrepreneurship Centre since 2001 to gather information at University of Cambridge spin-outs. Although not exhaustive, this is the most complete database available about Cambridge University to date. However it uses a broad definition of university spin-outs, including all academic fields and counting as spin-outs companies that were started by Cambridge graduates long after they had left the University. For the purpose of this research, we restricted our analysis to direct spin-outs, i.e. companies drawing on university-based technological and scientific knowledge and involving academics or students who were still members or had just quit the University. From 184 companies we only retained 109 companies started since 1979, excluding those started in management fields or by Cambridge graduates having long completed their degree. The database included new firms at their date of creation; some of these companies have since ceased their operations or have been acquired.

3.2 Growth in spin-out activity

Over the last twenty years, the number of spin-outs emerging from Cambridge University has steadily increased, largely reflecting an improvement of the environment for entrepreneurship (see Table 1).[8] In the past ten years, about 9 companies a year spun out from Cambridge University. The number of companies has increased in three periods. Until 1991, figures were below five a year. This corresponds to the period where high-technology activities were emerging and growing in Cambridge. From 1992 to the late 1990s, figures increased to 5-10 a year. From 1998, the number of spin-outs has tended to exceed 10 per year.

These data, relatively high compared to most other UK universities reveal the existence of a favourable environment for entrepreneurship, recognised as early as 1985 (Segal Quince & Partners 1985). The approach of Cambridge University to technology commercialisation was distinct from that of many UK universities: Cambridge did not directly provide support for entrepreneurship, but in the context of world-class scientific research, the University's *laissez-faire* approach to technology transfer and lack of formal policy and infrastructure did not prevent academic inventors from taking their technologies to market.

The University allowed academic staff to undertake outside work as long as their commitment was to the advancement of university's teaching, scholarship and research. It was up to individual academics whether and in what manner they engaged in outside work. This allowed individual academics to undertake ad hoc activities such as private consultancy and business creation. This liberal standpoint differed from the situation in other universities in the UK, the US or many European countries where clear rules usually regulate the involvement of scientists in outside work so as to prevent the emergence of potential conflicts of interest and to ensure that academics devote enough time to their core activities (Bower 1992; Matkin 1990).

The IP policy was similarly liberal, and unless their research was funded by research councils or the ownership of IPR imposed by an industrial contract, academics could claim the IPR of their inventions. This is reflected in the statistics outlined in Table 1: in only 42 cases, i.e. about one-third of the companies, did the University formally participate in firm

[8] Cambridge is well positioned compared to other UK universities: there were 248 spin-outs formed in 2000/2001 in the UK, 203 in 1999/2000 but the concentration of spin-offs among a few universities is significant: in 1999/2000, only 24 HEI had more than 2 spin-offs and these accounted for 136 of the 183 reported (Charles and Conway 2001, HEFCE 2003).

formation. This mainly involved the University owning the IPR on the invention and taking an equity stake in the company.[9]

The informal and diffuse approach to technology transfer in place in Cambridge was long considered to have a positive influence on the growth of the 'Cambridge Phenomenon' and innovation from the science base (Druilhe and Garnsey 2001; Garnsey and Lawton Smith 1998; Segal Quince & Partners 1985). The conscious avoidance of a structured and detailed policy governing links with industry created a favourable environment, flexible and non-bureaucratic, in which industrial links of all kinds have been allowed to prosper and the spontaneous creativity of researchers has been enhanced. [10]

Since the late 1990s, the University has entered a period of transition and the IP position is being reconsidered. Initially providing academics with little support but significant independence in their interactions with industry to a proactive and more structured approach to research commercialisation and technology transfer. The growth observed after 1998 in venture creation figures may reflect not only the high-tech enthusiasm of the end of the century but also the fact that Cambridge University started new initiatives to encourage and assist academic entrepreneurs. Several organisations, often supported by government initiatives, were established and include Cambridge University Entrepreneurs, a student-run association organising business plan competition, and from 2000, the University of Cambridge Entrepreneurship Centre (CEC), the University Challenge Fund (UCF), and the reorganised and better resourced technology transfer office (TTO). The impact of the creation of such infrastructure on firm birth rates will only be clearly observed over a longer time period.

[9] The liberal position of the University of Cambridge is currently undergoing significant change and pressures to align with other UK universities. After a first move in 2001 towards University ownership of all externally-funded research, University officials put forward a proposal according to which all IPR originating from Cambridge University would be owned by the University. Facing strong opposition from University academics in the fall of 2002, the project was withdrawn. A new report was written in spring 2003 and was expected to go through another process of examination and assessment.

[10] The rationale for the traditionally liberal policy was as follows: "The University has for many years adopted a non-bureaucratic stance towards the exploitation by staff of inventions, software, and other revenue-producing ideas. This policy has been considered to be the major factor in the development of the 'Cambridge Phenomenon' (Segal, Quince, Wicksteed 1985), and has also been of considerable advantage to the University. Encouragement to academic staff to pursue their own ideas and to develop the results of their research has been a key factor in the success of the Cambridge Science Park run by Trinity College, and more recently the Innovation Centre run by St John's College. It is not intended to change this policy in any major way, since the incentive that it provides for members of staff has been found to produce substantial returns to the University." Cambridge University Reporter, 11 July 1996, p. 934.

Table 1: Growth in spin-out activity from Cambridge University

Year	All spin-outs that year	Consulting / Services company	Development company	Product-based company	Software company
1979	**1**	1			
1984	**1**			1	
1985	**3**	1		2	
1987	**2**		1	1	
1989	**5**	2	2	1	
1990	**2**		1		1
1991	**2**				2
1992	**4**		1	2	1
1993	**6**	1		2	3
1994	**5**		3	1	1
1995	**6**			3	3
1996	**7**	1	3		3
1997	**7**	2	3	1	1
1998	**11**	3	5	1	2
1999	**16**	3	5	2	6
2000	**8**	1	3	3	1
2001	**15**	3	8	2	2
2002	**8**	2	2	1	3
TOTAL 1979-2002	**109**	**20**	**37**	**23**	**29**
Percentage	*100%*	*18%*	*34%*	*21%*	*27%*

3.3 Diversity of entrepreneurial activity: distribution by category

We classified the companies according to our typology. It may seem surprising that only 18% of the companies were involved in *consulting or research services*, the most accessible opportunity in relation to the scientist's knowledge and experience and resources needed. However, the number of spin-outs does not reflect the extent of academics' involvement in consultancy. Because of their small scale and the autonomy granted to Cambridge academics, these activities are difficult to track. In particular, research services and consultancy do not require the formation of a company since they can readily be provided on a private or freelance basis.[11]

Most of the consulting companies are technical, building directly upon the research activities of the founding scientists (e.g. Topexpress, Cambridge Discovery Chemistry[12]). Others are

[11] As an indicator, the number of consultancy contracts signed through the Technology Transfer Office by a University member of staff and a company was 44 in 2001-2002 and although this probably represents only a small proportion of all contracts signed, it is much higher than the figure of two consulting companies started in 2001 found in Table 1.

[12] Topexpress was initially started in 1979 by Professor J. E. Ffowcs-Williams from Cambridge University's Engineering Department who drew on his research to support the Ministry of Defence with acoustics problems which to that date had proved intractable, and to branch out into other areas such as active noise control, drag reduction, internal waves in the ocean, and various fluid-dynamics problems. Cambridge Discovery Chemistry provides innovative chemistry services to accelerate discovery and process research serving the pharmaceutical, agrochemical and biotechnology industries.

more oriented towards the provision of business services or are involved in sales (e.g. Abcam, Invest Solutions, Handheldsfordoctors, Envisional).[13]

Development companies set up to commercialise an immature technology. These make 34% of the companies in the sample. Their proportion has significantly increased over the period to represent 40% of the sample in the 1998-2002 period (see Table 2). This illustrates a tendency observed in Cambridge whereby high-tech companies commercialise their patented technologies through a licensing model. This model is most commonly found in biotechnology (30 companies out of 37), but also in other sectors, particularly advanced materials which also have a long gestation period. Some earlier spin-outs adopted this model including Cambridge Display Technology, which was founded in 1992 and conducts R&D in light-emitting polymers for use in a wide variety of electronic display products. Recent spin-outs in the Engineering or ICT sectors have also opted for the development company route, including Polight Technologies[14] and Plastic Logic.[15]

Product companies. These form a significant part of the sample. However, many do not correspond strictly to our category, which defined the establishment of production facilities as an important characteristic. They tend to target a niche market and remain small. They engage in prototype production or high-quality low-volume production. Their need for resources may not be as significant as that of development companies. Niche high-tech production companies[16] tend to be concentrated in the engineering and ICT sectors. Some of

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[13] Abcam drew directly upon Dr Milner's research experience: "Like many life science researchers, I was frustrated by the time it took to locate and select antibodies essential for my research. This was largely due to poor information and out-of-date catalogues from the vast range of suppliers who were spread across many countries. In some cases, I also experienced difficulties with companies whose products were unreliable and whose customer service was slow and unhelpful. My vision was to build a company that offered reliable products, great customer service and that would enable researchers to quickly find the best antibodies for their research" (source: www.abcam.com) Invest Solutions provides flexible solutions to website needs; Handheldsfordoctors provides consultancy services on the use of handheld technology in healthcare; Envisional offers intellectual property protection and monitoring solutions.

[14] Polight Technologies develops novel glassy-like materials with unusual opto-mechnical properties when exposed to laser light.

[15] Plastic Logic develops of plastic electronics technology. Founded in November 2000, as a spinout from Cambridge University's Cavendish Laboratory, Plastic Logic builds on over 10 years of fundamental academic research. It develops and exploits a portfolio of intellectual property based on inkjet printing of active electronic circuits using advanced plastic materials.

[16] e.g. Biorobotics, Adder Technology, CEDAR Audio, SmartBead Technologies, Cambridge Positioning Systems.

these companies are patent-based[17] but not all: for instance, a number of instrumentation companies do not rely on patents.[18]

Software companies [19] Overall, these represent about a quarter of all spin-outs in the sample, reflecting the strength of the Computer Laboratory and the Engineering Department in Cambridge.

Table 2: Distribution of business activities by category over the three periods as a percentage of all Cambridge University spinouts over that period

	1984-1991	**1992-1997**	**1998-2002**	**1984-2002**
No of years	8	5	5	***18***
Consulting firms	3	4	12	***19***
Percentage	***20%***	***11%***	***21%***	***18%***
Development companies	4	10	23	***37***
Percentage	***27%***	***29%***	***40%***	***34%***
Product-based	5	9	9	***23***
Percentage	***33%***	***26%***	***16%***	***21%***
Software	3	12	14	***29***
Percentage	***19%***	***34%***	***24%***	***27%***
All spin-outs over the period	**15**	**35**	**58**	***108***
Percentage	*100%*	*100%*	*100%*	***100%***

4 Case exemplars by category

The classification of university spin-outs on the basis of our categories revealed a greater diversity than encompassed in our initial typology. We turn to case studies from this database used as exemplars of the entrepreneurial process in order to refine our analysis and proposed typology. The data collection process was grounded in the Penrosean notions of productive opportunity and productive base, which provide theoretical grounding for the current concept of the business model ('how the company makes money').

[17] e.g. Teraview, Cambridge Gemonics.
[18] e.g. Cambridge Magnetic Refrigeration.
[19] e.g. Apama, Wax Info, Cambridge Cell Networks.

4.1 Real-time data[20]

Most studies of academic spin-outs concern academic ventures that have actually become operational enterprises (Blair and Hitchens 1998; Brett et al. 1991; Chiesa and Piccaluga 1998; Downes and Eadie 1998; Rappert and Webster 1998; Roberts and Malone 1996; Smilor et al. 1990). The survival bias in these studies reflects the difficulty of obtaining evidence on scientists' intentions to commercialise research findings if these do not actually eventuate as incorporated ventures. This often results in a retrospective bias. Through participant-observation, we collected real-time data on the emergence of spin-off projects, without prior knowledge of whether they would become operational. Participant-observation data was collected through the Anglia Enterprise Network (AEN), a mentoring service for scientists and technologists and a means to introduce them to private investors.[21] Between 1997 and 1999,[22] over sixty academics and local entrepreneurs were contacted by the advisors of the Anglia Enterprise Network. Participation in AEN furnished real-time evidence collected through participant-observation in 1998-1999 of over 40 scientists and academic engineers. Among these, nine cases progressed significantly over the consulting period and provided the core of the case studies.[23]

In selecting cases, we were able to obtain exemplars of a variety of business activity types pursued by science-based enterprise: those applying knowledge through consulting and other services, through licensing intellectual property, and through production.

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[20] In what follows we draw on material presented in a forthcoming paper in the Journal of Technology Transfer but with a different objective, viz. to clarify differences between types of spin-outs in the light of new evidence from our database analysis (Druilhe and Garnsey 2003).

[21] The Anglia Enterprise Network was conceived and implemented by a group of people working in enterprise support before active programs of this kind were available to scientists in the Cambridge area. While scientists who wanted to take out a patent or start a company could go to the University's Industrial Liaison Unit, in the 1990s this was understaffed and unable to be proactive in approaching scientists. An initiative was undertaken to introduce entrepreneurs to private investors and run a proactive mentoring service for the region. A grant was obtained from the Department of Trade and Industry under a program for SMEs administered by the local Business Link. This initiative was supported by the University of Cambridge Institute for Manufacturing. Negotiations with interested parties in the community were chaired by Walter Herriot, the Director of the St John's Innovation Centre in Cambridge. The Anglia Enterprise Network was given a regional focus and managed by St John's Innovation Centre with a part time administrator. The regional focus of the Anglia Enterprise Network made it possible to extend the service beyond the university. A business advisor with relevant experience at the British Technology Group was engaged and a graduate taken on to ferret out projects in science and engineering laboratories. Regular meetings to introduce entrepreneurs and private investors were organised, drawing on the investor network that had been developed at the Innovation Centre off the Science Park. Mentoring was provided to prepare entrepreneurs to present their projects to investors. One of the authors worked for the Anglia Enterprise Network and obtained first hand experience and detailed evidence on the spin out process while working on her PhD on technology transfer

[22] In 1999, the remit was transferred to the newly founded University Challenge Fund.

[23] For those 9 companies, participant-observation data collected during 6 to 8 meetings over a nine to twelve-month period was complemented by follow-up interviews in 2001 with the scientist-entrepreneurs.

4.2 Enterprise emergence by category

Table 3: 9 case studies and their progress in the entrepreneurial process

Technology	**Type of business activity envisaged or pursued**
1. Optical device	Development company (licensing or manufacturing)
2. Novel type of antenna	Development company (licensing)
3. Rapid diagnostic kits for the developing world	Development company (licensing or manufacturing)
4. Anaesthetic technique for laser surgery	Development company (licensing or manufacturing)
5. Scientific instrument: magnetic refrigerator for low-temperature experiments	Product company
6. Instrument: motion capture system and analysis software	Product company
7. Instrumentation for seafloor projects	Product company
8. Robotic equipment for biotechnology sector	Product company
9. Voice recognition technology	Software company

Development companies. In cases 1 and 2 (Table 3) a promising invention originated from the science base. Although commercial potential was soon detected, recognition of a specific productive opportunity was particularly difficult because of the generic nature of the technology and lack of contact with possible users. However, the potential for creating economic value was identified. Resources were mobilised for research and development, covering patent costs and designing a commercialisation strategy.

In case 1, the scientist-entrepreneur went through a lengthy process of opportunity identification alongside technology development. The optical device developed offered the advantage of being generic and innovative, thus opening many applications and being easy to protect. However to find a route to market it was necessary to identify specific applications that would create value for a new company, which proved difficult: potential users could not see an application for this early stage technology and scientists' prior knowledge and experience of the sectors in which the technology could be applied were limited. Resources were accessed within the university to offset these disadvantages: students, departmental business managers assisted with market research. The advisor from the AEN mentoring scheme provided strategic advice. Connections were critical: the contacts within the Cambridge-based investment community developed by the entrepreneurial group leader allowed the scientists to obtain feedback on his project from venture capitalists. Raising funding before development work reached a market-focused stage proved impossible. Public research resources were insufficient to cover development costs and the project progressed slowly. These strains led to internal conflict. Eventually, the scientist, who had left his department, could not secure a license on the original patents of the technology. The company was closed down.

Case 2, the development of a novel type of antenna, is currently still at the research stage, with experimental work being carried out by partners in Oxford University. Further progress along the route to market will depend upon the experimental results attained. A research grant was first awarded by a Research Council to a research group in Oxford to test the theory developed by the Cambridge scientist. This was later complemented by an Oxford University Challenge Fund Investment. If experimental work is successful, specific applications, in particular in the scientific market, could be readily commercialised. A company was formed, pulling together initial IPR, and to which future IPR would be added on the basis of experimental developments. This case illustrates both the high potential for value creation and the uncertain development trajectory of a radically new technology of which the basic principles still need to be proven.

In both cases, given the early stage of the technologies, resource creation and opportunity recognition were interdependent: the recognition of a particular opportunity partly directed research and development, while the technology path taken and the exploration of various technological options also dictated what opportunities were achievable. Resources were mobilised in the proximate environment: the university for technical and financial support;

the local environment for exploring sources of funding (venture capitalists). Personal connections were a valuable resource (research group in Oxford in case 2).

In cases 3 and 4 (see Table 3), costly resource requirements delayed the creation of value, and hence returns. The scientists had direct industrial experience and industrial contacts, which triggered the recognition of a specific commercial opportunity. But it was clear that the resources required to develop the technology to the point where it could provide a productive base would be considerable. Raising commercial funds was necessary where research grants were unavailable for this purpose. This is a role now undertaken by the government's Challenge Fund, in the light of reluctance of venture capitalists to fund such work..

Both technologies required heavy patent protection and regulatory approval was needed for medical devices. The scientists subsequently undertook further R&D within the university to develop the technology as required in order to pursue this opportunity. In case 4, grants from various charities and organisations provided a regular stream of research funding but mobilising resources for commercialisation required a clearer view of the appropriate route to market. In case 3, which aimed to develop an anaesthetic technique for laser surgery, self-funding ensured early development but did not suffice to carry the technology through clinical trials. The team engaged in a lengthy process exploring various commercialisation options, including licensing, outsourcing development, and starting a VC-backed company.

Resource mobilisation was all the more difficult when selection of the route to market was not straightforward. Both teams eventually opted to set up a development company, incubated within the university by the research group and associates with relevant technical skills. A development company is created specifically to advance a technology that has commercial potential, and must attract investors or partners by offering them a stake in eventual returns. In case 3, seed funding from Catalyst Biomedica secured funding, while in case 4, a University Challenge Fund investment eventually provided finance needed for R&D and patenting costs. Prior industrial knowledge, useful connections and the market focus of the technology aided progress for this type of enterprise. The lengthy development period, the difficulty of creating a productive base and the extent of financial resources required explain why these projects did not result in value creation as quickly as the three cases analysed below.

Product companies. In three cases, the recognition of an opportunity built directly on the scientists' prior knowledge and connections (cases 5, 6 and 7). The technologies had been developed as research tools and commercial and the scientific activities were complementary. Development of the technology for own use and the connections formed during research with suppliers and users of the technology resulted in the early identification of a market opportunity. Products could be sold into technical markets alongside a service relying on the expert knowledge of the scientists. The scientists could leverage their links to the academic, governmental, and corporate scientific communities to access customers. Resources required to reach a niche market were accessible. In case 5 and 7, the scientists started a product-oriented company, following an organic development path, relying mostly on self-financing after initial seed funding was provided by friends and family support, a SMART award, or research grants. Since the scientists' expertise could generate returns with relatively low resource requirements, these product-oriented ventures delivered value relatively early and could potentially secure returns soon.

Case 6 stands in contrast with the early progress of case 5 and 7. Although a productive opportunity was identified and involved developing a motion capture system and software for the sport and medical markets, the potential for value-creation and returns was soon found to be too low in relation to costs, once further development of the technology had been undertaken. The mobilisation of resources was problematic because the technology was in the public domain and intellectual property rights were unavailable. Private investors were only prepared to invest a small amount, judged insufficient by the scientist-entrepreneurs to carry out development and commercialisation on a scalable basis. Although the scientists decided not to proceed with commercialisation, further research was carried out on the technology for which applications were found in various settings. Thus some economic value was created in technology developed for experimental medical and sports applications, but no financial return was generated for the originators.

In case 8, robotic equipment for the biotechnology research market was developed within a university department. A productive opportunity was recognised by the entrepreneurs through their contacts with geneticists. This enabled them to identify a market for low cost, compact automation equipment for biotech labs. Though there were many difficulties in developing the product to a high standard of quality and reliability (as shown by the failure of a rival project at the MRC using the same initial IP to achieve this), the precision engineering and software technology of the newly created productive base was state of the art rather than immature. Early development costs were covered by another university department as customer. The funds available in this customer department resulted from earlier academic enterprise by the customer scientist, who had acted as distributor of equipment for genetic research. His simple retailing ‘productive base’ had generated revenues which subsidised the development of the more extensive productive base required for scientific instrument production. The entrepreneurs who founded the lab equipment company avoided external funding because they wanted to retain control over their company. These entrepreneurs were new to the product and market, but were experienced engineers with business knowledge. Their new product stream and impressive trading performance attracted a US company that acquired the venture in 2000, realising very high returns to the entrepreneurs.

Product companies progressed faster than the development companies because fewer resources were required and the opportunity had a clear focus early on. Business and commercial activities were complementary.

Software. Voice recognition software had been developed by the entrepreneur in case 9 and was being further refined in order to apply a generic technology to more specific market needs. Shortly after the venture was founded, an attractive acquisition offer was received. The academic left his post and his venture was incorporated into a successful global Internet company, itself a university spin-out. The focused opportunity and advanced development of the technological resource made the software venture an attractive target. Corporate acquisition allowed the entrepreneur to access finance to take his technology to market and develop new products.

5 Concluding discussion

This analysis of spin-outs in Cambridge using database and case study evidence has shown the extent of their diversity. Although our initial typology was valid (consultancy, development company, software, product-based company, infrastructure creation), it conflated important sub-sectors as revealed in the empirical analysis and outlined in Figure 2.

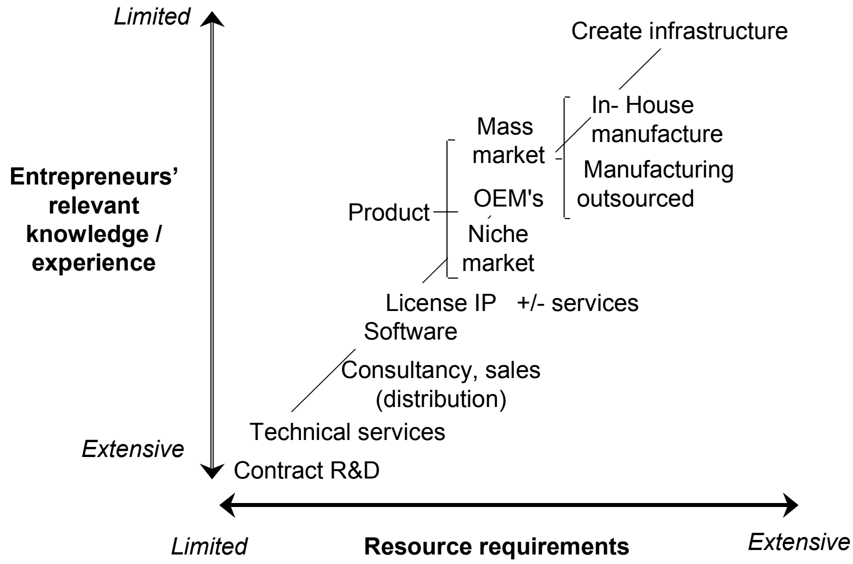

Figure 2: Refined categories of academic spin-outs activities

The case studies show that the business models of new ventures are altered as entrepreneurs improve their knowledge of resources and opportunities. In the case of development companies, these may initially be set up to commercialise 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. Although in the previous section we classed case studies between types of activity, there was some shift in categories as business models evolved. In case 3 for instance, although the scientists initially aimed at licensing their early-stage technology, they eventually set up a development company to move the technology closer to market while redefining their business model and examining various options including production. In case 6, from a purely product-oriented company, the emphasis shifted to the combined supply of a product and service. Further exploration of the market had shown that targeting niche markets for specific applications and providing a customised offer were the only viable way of capturing returns for the inventors. However, this model did not match the scientists' expectations and interests and direct commercialisation was abandoned.

It is also apparent that our two-dimensional axes over-simplify the dimensions that interact in the emergence of academic spin-off companies and influence the adoption of specific business models. Elsewhere (Druilhe and Garnsey 2001), we have shown that the characteristics of the productive opportunity are influenced by:

- Market specificity
- Market size
- Competitive intensity
- Maturity of the technology

These factors interact with features of the venture's productive and commercial resources which include:

- Initial resource endowment
- Resource intensity
- Resource availability
- Type of technology
- Maturity of the (technological) resources of the venture

This discussion brings to the fore the complexity of the issues that academic entrepreneurs face and need to resolve when they start an academic enterprise. These are among the factors that affect the viability of the business model selected. The difficulty for scientist-entrepreneurs is that they may act pragmatically in opting for a specific business model on the basis of resource endowments but this business model may not be a good fit with the emerging market opportunity, leading either to failure of the company or lower returns. The productive opportunity of an academic venture can only be realised, with a limited initial resource base, if the venture can set up appropriate partnerships and collaborations. Since partnerships are essential to success, support schemes should be based on improved understanding of collaboration strategies and of the factors cited above.

These findings have theoretical and practical implications, calling for further investigation. We need to recognise the heterogeneity of spin-outs to avoid simplistic measurements and assumptions about science-based enterprise. It is necessary to develop more rigorous metrics to assess commercialisation activities and their success. Recognising the heterogeneity of spin-outs will improve our theoretical understanding of academic entrepreneurship. It will also open scope for policy-makers to provide appropriate support, recognising that different types of spin-outs have very different needs and resource requirements.

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