J Technol Transfer (2008) 33:23–43
DOI 10.1007/s10961-006-9010-2

How scientists commercialise new knowledge via entrepreneurship

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Published online: 12 December 2006

Abstract In this paper, we explore how university-based scientists overcome the barriers to appropriating the returns from new knowledge via entrepreneurship; and we examine how a university-based technology transfer office (TTO), with an incubation facility, can assist scientists in the commercialisation process. We identify how scientists overcome three barriers to commercialisation. First, we find that scientists take account of traditional academic rewards when considering the pay-offs of commercialisation activity. Second, scientists recognise the commercial value of new knowledge when market-related knowledge is embedded in their research context, and/or when they develop external contacts with those with market knowledge. Third, the deliberate efforts of scientists to acquire market information results in individuals or organisations with market knowledge learning of the new knowledge developed by the scientists; and intermediaries can help individuals or organisations with resources learn of new knowledge developed by scientists. We find that the TTO, principally through an enterprise development programme (CCDP), played an important role in the commercialisation process. The principal benefit of the TTO is in the domain of putting external resource providers in contact with scientists committed to commercialisation. Our findings have important implications for scientists and for those interested in promoting commercialisation via entrepreneurship.

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Keywords Knowledge spillovers · TTO · Incubators · Scientists · Commercialisation · Academic spinoffs

JEL Classifications O31 · O32

1 Introduction

The creation and exploitation of knowledge is an important determinant of regional economic performance (Audretsch & Lehmann, 2005; Audretsch, 1995). Scientists and researchers in public research institutes (PRIs) such as universities are important creators of knowledge. For the economic benefit of this knowledge to be realised, the knowledge must spill-over. Knowledge flows from universities in a number of ways, such as licensing activity and spin-offs (Rothaermel & Thursby, 2005). According to the Knowledge Spillover Theory of Entrepreneurship advanced by Acs, Audretsch, Braunerhjelm, & Carlsson (2004) entrepreneurship serves as a key mechanism by which knowledge created in one organisation becomes commercialised in a new organisation. Entrepreneurship is one way that the 'economic agent with a given endowment of new knowledge' can best appropriate the returns from that knowledge (Audretsch, 2004, p.172).

While scientists who develop new knowledge may choose to appropriate the returns via entrepreneurship, most universities report very low levels of commercialisation via entrepreneurship (O'Shea, Allen, Chevalier, & Roche, 2005). Low levels of commercialisation activity have been explained in terms of attributes of the scientist; the resources of the university, and in particular the nature and level of the research funding and the research intensity of faculty; university reward systems; university culture; and attributes of the local region in which the university is located, such as the local demand opportunities and the availability of venture capital (O'Shea, Allen, O'Gorman, & Roche, 2004).

Scientists face difficulties in seeking to appropriate the returns from the knowledge they have created. Extant empirical evidence suggests that scientists' typically lack market knowledge and they lack resources. Some market knowledge may be a prerequisite to the scientist's ability to recognise the commercial value of new knowledge and therefore to engage in technology transfer (Vohora, Wright, & Lockett, 2004). The ability to recognise, value and assimilate new external information is a key challenge in emerging technology firms (Rothaermel & Thursby, 2005). New firms created by scientists may lack critical resources such as technological resources, human capital and finance (Lockett, Siegel, Wright, & Ensley, 2005). One reason firms created by scientists may find it difficult to attract external investment is the composition of the founding team; which typically lacks industry experience and is homogenous in terms of prior knowledge and experiences (Clarysse & Moray, 2005).

Vohora et al. (2004) suggest that the barriers that scientists face in appropriating the returns from new knowledge can be classified in terms of the resources and capabilities required for firm creation. They suggest four phases of development, each of which results in a 'critical juncture', which in turn, requires the firm to develop or acquire new resources and capabilities. Their resulting framework explains success and failure at commercialisation in terms of factors such as, amongst

other, a lack of prior knowledge; university incentive structures; personality traits of the founding scientists; social, academic, commercial and industrial networks; resources; commercial viability; and top management team composition.

The Knowledge Spillover Theory of Entrepreneurship suggests a more parsimonious explanation for the failure of scientists to commercialise new knowledge via entrepreneurship. It suggests the following reasons: first, scientists with new knowledge might under invest in commercialisation activity as do not see the benefits of commercialisation; second, those with new knowledge may not recognise the commercial potential of the knowledge, or fail in their attempts to commercialise the new knowledge, due to a lack of market knowledge; and third, those individuals or organisations with market knowledge or with resources might not know of the new knowledge, and therefore fail to invest, or under-invest, in the knowledge or in new firms created by university scientists seeking to exploit the knowledge. Based on this theory we identify three research questions:

1. Why do scientists choose to appropriate returns to new knowledge via entrepreneurship?
2. How do scientists recognise the market potential of their new knowledge?
3. If, and how, individuals or organisations with market knowledge or with resources learn of new knowledge and/or invest in the commercialisation process?

To encourage scientists to consider commercialisation and to support them through the process many universities develop technology transfer offices (TTOs) and offer scientists incubation facilities. A key rationale for developing TTOs and technological incubators that are closely linked to universities is that they 'make it easier for academic personnel to exploit knowledge-based business ideas, thus lowering the barriers that inhibit direct commercial application of the results of university research' (Colombo & Delmastro, 2002, p.1105). While there is ample evidence to demonstrate that there is significant variation in the use of, and perceived value of, supports offered by TTOs and incubation centres (Mian, 1996; Hackett and Dills, 2004), prior research has suggested that TTOs and incubators can play a critical role in helping firms overcome gaps in knowledge, competencies and resources (Peters, Rice, & Sundararajan, 2004; Rice, 2002). This leads us to ask a fourth research question:

4. What role do university TTOs play in facilitating the commercialisation process?

The structure of the paper is as follows. In Section 1 we explain our rationale for using a case method and our method of case analysis. In Section 2 we briefly describe the university, the TTO, State policy and State funding agencies, support programmes, and the case firms. In Section 3 we present and discuss case evidence for the four research questions outlined above. We conclude by discussing policy implications.

2 Research method

Studying the commercialisation activity of scientists via entrepreneurship is an important research context for those interested in understanding the phenomena of

knowledge spillovers, university based spinouts (USOs), incubators, TTOs, and the entrepreneurial university. By focussing on the scientist as the unit of analysis we can explore the early stages of the commercialisation process, an area that Lockett et al. (2005) and Hackett and Dills (2004) identify as requiring further study. By choosing a public university in Ireland we are studying scientists in a context where we expect there to be barriers to commercialisation. The university we studied was not characterised by the policies, procedures, resources, and organisational culture that are associated with more entrepreneurial universities.

We study the decision and processes surrounding the appropriation of the returns to new knowledge via entrepreneurship by scientists through the case method. These decisions and processes are characterised by high degrees of uncertainty and occur in multiple organisational settings: the *university* in which the scientist works and in which the new knowledge is created; the *new firm* created by the scientist; and the *TTO* and the *incubator*. The cases allow us to identify the events that occurred during the commercialisation process and to explore how the TTO influenced the emergent processes of commercialisation.

Our sample is two scientists who independently developed new knowledge within research projects and sought to commercialise this knowledge by creating a new firm with the assistance of a TTO with incubation facilities. We identified the scientist/firms with the help of the TTO manager. For each firm we conducted four interviews with the scientists and members of the management team over an 8-month period in 2003/2004. Additionally the TTO manager was interviewed four times over the same period. Interviews with the scientists focused on our four research questions. We structured the interviews around a discussion of the emergence of the new firm, and the scientists' experiences of commercialisation, the TTO and incubation. We covered issues concerning their initial business ideas, how the business idea evolved since efforts at commercialisation were initiated, and the impact of the TTO on the new firm. We also sought information on the TTO services offered to, and used by, the scientists. All the interviews were at least one hour long, and typically they were one and a half hours; were recorded; and were transcribed.

Over the course of the interviews 'sequence analysis' was used as a way of organising the information (Eisenhardt, 1989). We created chronological accounts of the firms by writing detailed case histories for each firm and by producing detailed 'timelines' for each of the firms. These were based on the narratives recounting the emergence of the firm and the identification by the scientists of the events that described how and why they started these firms. We identified, from our four research questions, the following questions to organise and interpret the case data: why did these scientists choose to start new firms? How did the scientists recognise the market potential in their new knowledge? How did the scientists acquire market knowledge and develop initial customers? How did the scientists finance their commercialisation efforts? What was the role of the TTO in the facilitating these scientists in the commercialisation process? In exploring the role of the TTO we asked: What benefits did the scientists explicitly identify from their experiences of the TTO and of incubation? How did the TTO assist the scientist in acquiring market specific knowledge? How did the TTO assist the scientists in acquiring resources? These questions allow us to identify the role of the TTO and of incubation in firm emergence, while allowing for the possibility that the TTO and incubation may not have been important to many or any aspects of firm emergence.

3 Research context

3.1 The university

UCD Dublin, Ireland's largest public university is located in Dublin city, the principal city in Ireland. At the time of our study the university was organised in to faculties and departments, across a full range of disciplines, with about 20,000 students and 2,000 administrative and academic staff.[1] Academics typically perform both teaching and research roles. Reviews of the university have identified factors that have constrained its development, including a chronic under-investment by the State in higher education and in research; and a disconnect between academic and administrative systems that has lead to an excess administrative burden carried by academic staff.

3.2 The TTO and the incubator

The technology transfer office is called NovaUCD. It is a university-based 'Innovation and Technology Transfer Centre', located on the site of the university. The centre lists it objectives as: (1) identifying, protecting and exploiting intellectual property arising from university research; (2) supporting entrepreneurs, campus companies and other knowledge-based ventures; (3) promoting a culture of innovation and entrepreneurship; and (4) promoting contract research and other forms of university-industry co-operation. The university has operated an incubation facility on campus since 1988,[2] with space for approximately 15 companies. During the 1990s these companies were predominately external to the university in origin, reflecting the very low levels of commercialisation activity from within the university. The centre seeks to attract knowledge intensive start-ups that are associated with, or willing to become associated with, the university.

NovaUCD provides a part-time structured enterprise development training programme for university academics, the Campus Company Development Programme (CCDP). The format of the programme has evolved from one half-day session every 3 weeks for a period of 3 months to one half-day session once a month for 9 months. Typically academics attend the CCDP prior to locating in the incubator. This programme provides participants with practical advice on starting a new venture and access to a mentor. On an on-going basis the TTO runs workshops and one-to-one clinics for tenants in areas such as IP protection and raising finance.

Prior to 2003 NovaUCD invested directly in some businesses. Since then the centre does not invest in companies though it takes an equity stake in the businesses (approximately 6% in external businesses and 15% for university related businesses, depending on negotiations). This equity stake is in return for any Intellectual Property rights or claims the university may have. The centre has 9 fulltime staff, with a further 5 part-time staff. The state agency Enterprise Ireland (see below) have located, on a part-time basis, two members of their own staff with expertise in ICT,

[1] In 2004 the university appointed a new president. Since then the university has restructured itself into a smaller number of Colleges and Schools.

[2] The current centre is a purpose built incubator that opened in 2003. This new centre was a public-private partnership, in that it was co-sponsored by UCD Dublin, six external groups and Enterprise Ireland.

Life Sciences and Biotechnology in the centre to act as initial 'points of contact' for scientists.

3.3 State policy and State funding agencies

Irish state industrial development policy emphasises both the attraction of inward investment by overseas multinational firms, and the development of indigenous firms with the potential to export. More recently, the State has emphasised the development of a 'knowledge based' economy, and the role universities can play in the creation and exploitation of new knowledge. Enterprise Ireland is a government operated business development agency that supports 'high potential start-ups' (HPSUs)[3] and the commercialisation of research from third level educational institutions. Its activities include funding the development of incubators; co-funding programmes such as CORD (described below); and providing supports such as equity investment, mentors, and export assistance to new and established firms with export aspirations in the manufacturing and internationally traded services sectors. Enterprise Ireland supports approximately seventy 'high potential' start-ups each year, approximately 10% of which are new businesses originating from third level educational institutions.

3.4 Support programmes

Commercialisation of Research and Development (CORD) grants assist academics to bring a new product idea or business venture from a third-level educational institution to market. To receive a CORD grant the academic must demonstrate that their business idea is (1) an innovative technology or a unique application of an existing technology, and (2) that the business will be an internationally traded service that can be developed into a HPSU. Funding can be used to support salaries and activities such as market research, product trials, developing links with potential strategic partners. Maximum funding available is 50% of eligible costs, to a maximum of €38,000.

3.5 The case firms

The two case firms are profiled in Table 1.[4] Both firms were founded by scientists seeking to exploit knowledge and expertise they developed as part of their research work in the university. Both firms are at an early stage of development in that the scientists have completed business plans, raised some form of external finance, incorporated as a legal entity, and hired some staff. By the end of the research Geovera had just completed 'beta-site' tests and had made its first sale; and H&STech was conducting 'beta-site' tests with a client, and as such had yet to make a sale.

[3] Enterprise Ireland defines a 'high potential start up' as a company which is based on technological innovation; likely to achieve significant growth in 3 years (sales of €1.0m per annum and employment of 10 or more); is export oriented; and ideally, led by an experienced team, with a mixture of technical and commercial competencies. This definition includes early stage, product led R&D companies, with equivalent sales and employment potential, following successful completion of a defined pre-commercialisation phase.

[4] Names are disguised to protect the commercial interests of the firms.

Table 1 Descriptive data

Founders	Declan Daly	Ken Browne David O'Reilly
Firm	Geovera	H&STech
Year of founding	2001	2002
Sector	Microchip manufacturer	Software development
Product/Service	Mirco-processors to accelerate simulation tools used by the microelectronics design market	Information systems and tools for the Health and Safety Industry
Relationship of the founders to the university	Assistant professor in Computer Science	Assistant professors in Computer Science
Relationship of the 'knowledge' to the university	PhD research topic and research specialism of the founder	Funded research project leads to expertise in the technology University acts as Beta-site
Enterprise Development Programme	Daly attends CCDP over a three month period in 2000	Browne and O'Reilly attend CCDP in 2002
Locates in incubator	2001	2003

3.6 Geovera

Geovera designs and manufactures speciality microprocessors that reduce the time manufacturers of chips devote to testing microprocessor chips during the manufacturing process. Testing is a significant cost in the production of speciality microprocessors, so a saving in the time required to test reduces overall costs of manufacture and allows faster delivery of product to customers. Dr Declan Daly, an Assistant Professor in Computer Science, founded the company in 2001. The company employs 10 staff, has raised external funding from Enterprise Ireland and from a venture capitalist, and recently completed the first sale of its product. In the early 1990s, while working as a laboratory technician in the university, Daly identified a way of improving microelectronic devices that he considered had commercial application. He considered starting a company but failed to interest potential investors. Having completed his PhD in 1999 he sought to raise research funds. However, his failure to raise funds lead him to consider once again commercialising his research. Daly joined the CCDP in 2000. During this time he began negotiating with a UK company, to involve them in his research; however this failed to materialise late in 2000. On the CCDP he met Sean Molloy who subsequently introduced Daly to the financial community. Daly incorporated his new firm and he got funding from private investors, and subsequently from Enterprise Ireland, amounting in total to approximately €900,000. In 2001 Geovera partnered with a research institute in Austria. In 2002 a microelectronic expert, Delmar Kandag, who had extensive industry experience joined Geovera as Engineering Director. Geovera then took space in the university incubator. In 2003 Geovera raised funds from Enterprise Ireland. In 2004 Geovera made its first sale to Phillips Electronics in Austria. By the end of the case Geovera is seeking a significant venture capital investment (circa three million euros) to 'roll-out' its product to the market.

3.7 Health & Safety Technology

Health & Safety Technology (H&STech) is a software development company founded in 2002. It has developed specialised information systems and information management tools for the Health and Safety Industry. The business model of H&STech is a computer software system that records both incidents and accidents. An incident is an event that might lead to an accident. The software can analyse incidents and accident records to identify where and why accidents might happen in the future. Ken Browne and David O'Reilly, two university professors from the university Computer Science School, founded H&STech. The idea emerged from a research group in the university funded by Enterprise Ireland and a state-funded research grant awarding body. Following a suggestion by an information retrieval expert to apply their technology to the health and safety industry, Browne and O'Reilly decided to pursue the opportunity. Mary Quinn, Head of Health and Safety in the university joined them as a partner in the project. The company has been funded by research grants and by the promoter's own personal investments in the company. Currently there is one full-time and one part-time member of staff. H&STech's product has been involved in much testing in house but has not yet gone 'live' on the university campus. At the end of the case the founders are unsure as to whether or not they will continue the project.

4 Why do scientists choose to appropriate returns to new knowledge via entrepreneurship?

The scientists in this study could be described as reluctant or accidental entrepreneurs. For Daly (Geovera) and Browne and O'Reilly (H&STech) the case evidence suggests that the availability and nature of the external funding of their academic research played a critical role in shaping their research agenda and in their involvement in commercialisation activity. The experiences differ, in that Daly found it difficult to raise research funds, and this drove him to seek commercial support for his research, while Browne and O'Reilly were able to raise research funds from a state agency, with these funds encouraging and promoting commercialisation activity. The scientists were not driven by the desire to appropriate additional returns to their knowledge, but rather by the desire to further their own research activity, in terms of increased funding, but also in terms of demonstrating the value of their research work. Daly said:

> I didn't really want to start a company, but it was only through necessity of wanting to take it forward that circumstances forced me to commit to this as being the only way forward. And had I got [research] funding I probably would have had a PhD student or two do the research, publish a few papers, and then just put it on the shelf and moved on to something else. So it's quite serendipitous the way things happened.

Daly cited his failure at raising research funds as his motivation to seek commercial funding to support his research, and this lead him to participate on the CCDP and then subsequently to changing from a fulltime to a part-time employee of the university. Daly also suggested that there was a lack of support from the university,

saying, for example, 'we had a big battle with the university because they wanted to own the IP'. He said that the university promotion structures failed to recognise commercial activity, which effectively penalised him in any promotion competitions: 'the university does not reward commercialised research that employs, creates money and competes with companies in Silicon Valley and across the world, but instead would merit the publication of a number of papers'.[5]

For Browne and O'Reilly it was the realisation that there might be a market opportunity for their software that crystallised their desire to start a new firm. Browne said:

> We had no idea of setting up a company at all before we meet him [world expert in accident analysis], we were just doing research on information retrieval systems, and we thought of setting up a company but we didn't know of any niche areas to do that in and then meeting him [the expert] and seeing the application we said: 'yes- here's a niche area for information retrieval software that we could set up a new software company in'.

On recognising the opportunity, Browne and O'Reilly were able to raise commercialisation funding from Enterprise Ireland to develop the software and to develop a commercial prototype. The two then joined the CCDP. This exposed Browne and O'Reilly to aspects of new venture creation, and was critical in the development of the new firm, as Browne stated: 'we decided to follow up on it and we decided to set up a company'.

For the scientist choosing commercialisation activity there is a tension between the demands that commercialisation activity place on the scientist's time and the contribution that the scientist will make to the academic activities of the university, which presumably is a concern of the university. In the case of Browne and O'Reilly, they continued working as university professors, however this significantly restricted the time they have been able to, or are prepared to, devote to the firm. One of them commented: 'no time allowances were made to staff from our department to facilitate this new endeavour. We found it difficult to spend time on company business, even in the early days, because of our professional commitments'. They acknowledged that 'we were aware of the importance of someone in the firm forfeiting their career, yet no-one was prepared to make that move'. For Daly the impact on his career of starting a business was that he had to change from fulltime to part-time employment, with a consequent cut in salary, as a means of ensuring that his firm would own the IP rights of his research. However initially he received no reduction in lecturing duties, meaning that he continued to contribute to the teaching and research activities of his department.

The benefits of commercialisation activity to the scientists in our cases related to benefits that are best understood in terms of the scientists as academics. The scientists had the preference to be involved in traditional academic roles and structures, seeking recognition through traditional academic reward structures such as 'peer recognition' and the university reward structures. It would appear that the potential

[5] Since this case was completed the University has undergone a major restructuring under a new president. One effect of this is that the university promotion system now explicitly recognises commercialisation activity.

monetary value that might be embedded in the new knowledge was not of central importance to the academics.

More generally there may be a disconnection between the common personal goals and motives of scientists and the benefits that commercialisation activity offers. Therefore if university reward and resource allocation systems are changed to include and recognise commercialisation activity, some academics may choose to engage in the behaviour. We argue that *in assessing the pay-offs of commercialisation activity of new knowledge, via entrepreneurship, scientists take account of traditional academic rewards such as access to research funding and promotion opportunities*.

5 How do scientists recognise the market potential of their new knowledge?

Recognition of commercial opportunity occurred as a result of the scientists efforts to develop or acquire market-related knowledge (Table 2). While the origin of these businesses reflects the prior knowledge of the scientists that flowed from their research activities, the scientists did not have the contacts that would allow them fully assess the commercial potential of their innovations, and therefore they had to seek new market knowledge from external sources.

In the case of Daly, his understanding of the research in his domain, from published papers, highlighted the commercial application for a product that could 'accelerate a simulation engine'. He specifically set out to develop commercial linkages to fund his research. To that end he attended conferences to 'publish what I had, but also to identify companies who where sponsoring or supporting these conferences to see if they were interested in what I was doing'.

For Browne and O'Reilly it was a chance encounter with an outside expert that allowed them identify a niche opportunity for exploiting their expertise in information retrieval software. Browne and O'Reilly were aware that there were commercial applications of their knowledge: 'one of the classic ways information retrieval software is used is in Google, and who wants to compete with Google'; though they did not have any market experience that enabled them identify niche applications for information retrieval software. To assess the potential for the software to work in the Health and Safety environment Browne and O'Reilly approached the university Health and Safety Officer (Quinn). She provided positive feedback, and joined with the two academics to commercialise the product (though remained in her existing role within the University). Quinn then used her industry contacts to arrange for the three to have a number of site visits to industry colleagues in industries such as pharmaceuticals, supermarkets, and insurance. The three concluded that there was a commercialisation opportunity in the Health & Safety Sector for a product that would exploit Browne's and O'Reilly's information retrieval expertise. They subsequently engaged the assistance of post-graduate students to prepare a market research study of the Health & Safety sector in Ireland.

Recognition of the commercial potential occurred as a result of the acquisition of market-related knowledge. The initial 'recognition' of commercial potential was followed by an ongoing process of developing further market-related knowledge in attempts to assess the extent of the commercialisation opportunities. The process of recognising opportunities is referred to as the 'discovery' process (Kirzner, 1997).

Table 2 Recognising commercialisation opportunities

	Daly (Geovera)	Browne and O'Reilly (H&STech)
Opportunity recognition:	While working as a technician in a university laboratory Daly designs new method for testing microprocessors.	O'Reilly participates in Health & Safety course in university, making contacts with staff in that School.
	His understanding of the research in this domain, from published papers, highlights the commercial application for a product that could 'accelerate a simulation engine'.	Browne and O'Reilly developed expertise in the area of information intelligence and retrieval as part of their research work in the university. This work receives Enterprise Ireland funding that supports work on Information Retrieval Software.
	He develops product expertise and knowledge of commercial applications as his PhD and subsequent publications relate to the process (though publishing opportunities are limited as Daly seeks to protect his knowledge).	In 2000 Browne and O'Reilly meet the husband of one of their post-graduate students at an international conference. He has expertise and experience in information retrieval and suggested that Browne and O'Reilly apply their technology to the Health and Safety industry, as there were industry openings for that type of work and opportunities for research funding.
	He attends conferences to 'publish what I had, but also to identify companies who where sponsoring or supporting these conferences to see if they were interested in what I was doing'.	To assess the potential for the software to work in the Health and Safety environment Browne and O'Reilly approached the university Health and Safety Officer (Quinn). She provided positive feedback, and joined with the two academics to commercialise the product (though remained in her existing role within the University).
The commercialisation decision:	He concludes there are commercial applications for his knowledge.	Quinn used her industry contacts to arrange for the three to have a number of site visits to industry colleagues in industries such as pharmaceuticals, supermarkets, and insurance.
		The three conclude there is a commercialisation opportunity in the Health & Safety Sector for a product based on their Information Retrieval Software

Kirzner's articulation of the 'discovery' process centres on the 'alertness' of the individual; while Shane (2000) has emphasised the importance of prior knowledge to this process. Having 'discovered' an opportunity an entrepreneur must test the entrepreneurial discovery by engaging in market-making activities (Casson, 2003). The forming of an entrepreneurial judgement requires knowledge generation and acquisition. According to Casson (2003), such activity is the essence of the entrepreneurial process.

Recognising that the career paths of academics in many traditional university settings are predominately within the university setting, and therefore do not include private sector work experience, academic scientists are unlikely to acquire market knowledge through prior work experience. However, as market knowledge is important to opportunity recognition or discovery, academic scientists will need to

acquire such knowledge through other channels. To recognise the commercial value of new knowledge scientists must possess market-related knowledge. We argue that *such knowledge will be embedded in their research context and/or will be developed as a result of the scientist's external contacts with those with market knowledge.*

6 If, and how, individuals or organisations with market knowledge or with resources learn of new knowledge and/or invest in the commercialisation process?

Like all entrepreneurs, scientists face barriers in accessing resources, including customers. Scientists lack resources because those with knowledge of markets or with resources may be unaware of the technological innovations and the benefits of the innovations, and therefore might fail to invest or might under-invest in such firms. As scientists engage in commercialisation activity, they must engage with individuals and organisations with resources and persuade them to support the emerging firm and its technology/product. We now describe the commercialisation process in terms of the external individuals and organisations that helped in the scientists' acquisition of resources. We summarise these activities in terms of five elements of the commercialisation process: Business Planning and Developing Customer Links (Table 3), Financing Commercialisation (Table 4), and Product Development and Team/Management Development (Table 5).

For Daly (Geovera) external contacts with the Austrian researcher, with Molloy, with Kandag, and with Enterprise Ireland proved important. Daly came into contact with Molloy and Kandag through the CCDP. These two subsequently joined Geovera, they helped Daly develop a business plan, raise finance and develop external commercial links (Table 5).

Table 3 illustrates how Daly developed his Business Plan with the assistance of Molloy while he was participating on the CCDP; though later Kandag, who brought commercial experience to the venture, helped 'focus' Daly's research in terms of the commercial applicability of the product. Daly reflected: 'we looked at the business and designed a plan to align ourselves with customers'. Daly developed customers through his efforts to develop market knowledge in that he developed contacts with local customers, who he was able to use to beta-test his product; and he developed his links with his first customer, Phillips, through his efforts to develop and promote his research with other research groups (Table 3).

Table 4 illustrates how Molloy was instrumental in introducing Daly to private external 'angel' investors. Prior to meeting Molloy, Daly self-financed his own participation in conferences; he supported product development and testing through the use of PhD students (Table 5). Molloy introduced Daly to private angel investors who invested in the business. This money allowed Geovera access commercialisation grants during the period of 2002–2004 from Enterprise Ireland, as such grants required 'matched' investment from other investors. The linkages with Enterprise Ireland were developed through the association with the TTO (two Enterprise Ireland staff are dedicated to supporting the firms in the incubator). The 'stamp of approval' of state investment can be important in attracting external finance.

For Browne and O'Reilly (H&STech) important external contacts in the commercialisation process were the expert in Health & Safety, the University Safety

Table 3 The commercialisation process: business planning and market penetration

	Daly (Geovera)	Browne and O'Reilly (H&STech)
Preparation of a business plan	Daly meets Molloy on CCDP. Molloy helps Daly 'fine-tune' his business plan. In 2001, Daly, Molloy and Kandag 'looked at the business and designed a plan to align ourselves with customers'.	Browne and O'Reilly complete a business plan while attending the training programme. They decide to focus on university market. H&STech commissioned post-graduate students (identified while on the incubator University Training Programme) in an applied 'market development' masters to research the Health & Safety market. The report suggested that the product would be a 'hard sell' as it was not a 'must have' product for either companies or universities. Furthermore, the product cost would be prohibitive for small companies and the larger companies in Ireland that tended to be interested were US multinationals located in Ireland- but they typically have 'advanced' procedures in place.
Customer links	While attending a conference in 2001 Daly meets an Austrian professor who later introduces Geovera's product to Phillips.	Quinn negotiates for University Health & Safety Office to be beta-site for H&STech. (This process involved the University IT Department testing the software to ensure that it could operate on the university IT system; and the Health and Safety Office modifying existing procedures).
	In 2001, Geovera approaches companies in Ireland to ask them to try the product. Three beta-sites negotiated. One is in an industrial park in the same locality as the university. A year after first meeting the professor from Austria, he visits Daly at his university and the two groups agree a partnership and begin collaborating in research in mirco-processors.	On-going beta-site in University Health & Safety Office, project not yet completed (as of 2004). Due to 'lack of time' in the IT Department, approval for H&STech to use college computer network (necessary for beta-site test) delayed. IT Department approves H&STech, though further delays in implementation of system by Health & Safety Office due to a 'lack of time' in the Health & Safety Office.
	Austrian research group establish link with Phillips. Phillips meets Geovera and agrees to be a partner in the research project and to invest in Geovera's technology. In the spring of 2004 Phillips become first customer of Geovera's product. US contact interested in promoting the product to companies in Silicon Valley. Geovera management plan to begin selling directly in Ireland.	H&STech organise and host an 'Incident Management' conference in late 2003 to promote the product. Develop a number of contracts through this event.

Table 4 The commercialisation process: finance

Daly (Geovera)	Browne and O'Reilly (H&STech)
Stage: Pre-Incubation *Failed Research Grant Submissions*: Daly fails to raise Government research funds for his research (he cites his lack of an identifiable research group as a barrier to such funding). *Own-funds*: Daly funds his own conference attendance (circa €45,000 pre 2001).	*Stage: Pre-Incubation* *Research Grant* (2000): from Enterprise Ireland to support basic research in information retrieval. *CORD Research Funding* (2002): though the money has yet to be 'drawn down'
Failed Co-development Project: A supplier company from the UK was, 'purely by chance', interested in expanding into research and development in Ireland. Daly negotiates with the company to co-develop product and for the UK company to provide funding. Deal falls through as UK company undergo period of consolidation: 'that was disconcerting to say the least'. *PhD students*: Daly uses PhD students to develop a prototype.	*Stage: 'Campus Company Development Programme'* *Research Grant* (2 year): Enterprise Ireland provide grant to develop a commercial prototype- though this money had yet to be 'drawn-down' as H&STech had yet to submit accounts signed-off by an account. *Graduate Employee Grant*: Enterprise Ireland fund the cost of a fulltime graduate employee (used to develop the product).
Stage: 'Campus Company Development Programme' *Business Angel Investment*: Molloy introduces Daly to the financial community and helps him raise 'angel' investment through a Government scheme that encourages risk capital investment (such investments can be written-off against income tax). *Cheaper Supplier:* Geovera working with UK supplier to develop prototype board, but due to high costs, look for new supplier in 2002. Supplier found in US, and Geovera meet them at a Trade Fair in Germany. *Enterprise Ireland Investments:* During 2002 to 2004 Enterprise Ireland invests in Geovera, providing both grants (requiring matched-funding) for Research and Development and commercial funding. *Customer Finance- Phillips:* In 2004 Phillips joins research collaboration, providing research funding.	*Stage: Incubator tenant* *Bank Overdraft*: Use H&STech overdraft to fund research project and to pay staff, while research funding is negotiated. *Consultancy Project:* H&STech accept consultancy project for systems development in a University Department. This system required information retrieval but not in the domain of Health & Safety. They employ a post-graduate student to work on the system design.

Table 5 The commercialisation process: product development and team development

	Daly (Geovera)	Browne and O'Reilly (H&STech)
Product Development	Initially PhD students work on development of a prototype (focusing on PCs, and not Mainframes, as the initial choice of platform). Geovera begin patenting their IP in 2002. Research collaboration agreed with Austrian University.	Product development funded through research grants. A graduate is employed fulltime to develop the product (funded by EI); and later a post-graduate student is employed to work on the system design for consultancy project.
Team Development	On the CCDP Daly meets Kandag and Molloy. Kandag has microelectronic industry experience and is interested in working with new firms. Molloy has finance experience. Molloy becomes CEO of Geovera (2002). Kandag joins Geovera as Engineering Director (November, 2002).	Mary Quinn, The University Safety Officer joined with the two academics to commercialise the product (though remained in her existing role within the University).

Officer (Quinn), and Enterprise Ireland. Table 3 illustrates how subsequent to the identification of the Health & Safety market niche, Browne and O'Reilly commissioned a market research study; how Browne and O'Reilly developed a number of contacts by organising and hosting a conference on Health and Safety; how the University Safety Officer, Quinn, played a role in helping Browne and O'Reilly shape their assessment of the commercialisation opportunity by arranging for them to meet Health & Safety Officers in industry; and how she negotiated with the University to become a test customer during the beta-testing phase of development. While Quinn joined Browne and O'Reilly as a co-promoter of H&STech, she remained in her University job (Table 5).

Table 4 illustrates the role of outsiders in the financing of H&STech. Browne and O'Reilly financed H&STech with government grants targeted at research and grants aimed at supporting the commercialisation of research; a bank overdraft; and the undertaking of a consultancy project. Additionally, Browne and O'Reilly continued to work in their university professor jobs. Participation on the CCDP assisted them in successfully applying for commercialisation funds (a 2 year grant) from Enterprise Ireland, though they had yet to 'draw down' these funds, and they used a bank overdraft to cover staff and related costs. H&STech also received a grant from Enterprise Ireland to employ a graduate. At the end of the study, H&STech had undertaken a consultancy project that would generate revenues for the firm. This funding allowed Browne and O'Reilly to fund continued product development.

How do individuals or organisations with market knowledge or with resources learn of new knowledge developed by scientists? The scientists had to seek contacts with external parties with market knowledge, rather than external parties seeking access to the new knowledge within the university. The scientists in our cases demonstrated deliberate, pro-active, efforts to make contacts with external parities with market knowledge. In terms of acquiring resources such as finance or personnel, there is evidence that this process occurred as a result of intermediaries such as mentors from the CCDP. The TTO provided a mechanism for external parties to

Table 6 Impact of TTO cited by the scientists

	Daly (Geovera)	Browne and O'Reilly (H&STech)
The Campus Company Development Programme (pre-incubation)	'The CCDP was an area where you were interacting with people who have funds of various shapes and sizes and eventually you find someone who is interested in what you are doing'	'The CCDP made us think the company through, what our expectations and hopes were'
	'There were some guys who were successful in business giving us some mentoring and that was very useful'	'The experience was very beneficial. Each of the modules was of great value as none of H&STech's members had any business experience prior to the CCDP.
Advice	'We use the Enterprise Ireland staff located in the incubator'	'There is someone (at the centre) you can go and ask and they would help sort you out'
Prestige of the university linkage	'University presence important for building research linkages'	'A nice prestigious address'
The convenient location of the center	'Convenience of location'	'Bilocate' in the incubator and university department office''. 'Physical place that's there: it's a warm and secure comfortable environment for someone to work'. 'It gives you time and space to focus'
		'Clarity about IP'
Low cost/flexible rents	'Low cost rents- when cashflows were tight allowances were made. Outside you probably wouldn't get as much latitude'.	
Use of college resources	'Access to college facilitates, in particular to the college computer network'	'Access to the college resources'
The decision to start a new firm	'I didn't really want to start a company'	'I don't think we would have gone ahead with the project had it not been for the centre'

contact the firms and the mentor identified potential investors interested in 'high risk' investment opportunities. In our cases these intermediaries were important to building the entrepreneurial team, in accessing external investment, and in learning about the processes associated with new firm creation. The TTO in our cases had, through its own activities, built bridges to external networks. Therefore, we argue that *individuals or organisations with market knowledge learn of new knowledge developed by scientists, through the deliberate efforts of scientists to acquire market information;* and that *intermediaries, such as technology transfer officers and incubator managers, can help individuals or organisations with resources learn of new knowledge developed by scientists.*

7 What role do TTOs play in facilitating the commercialisation process?

How did the TTO impact on the emergence of these firms? Table 6 summaries the benefits that the scientists received from using the TTO and the incubator (in

Table 7 Cited incubation events

	Daly Geovera	Browne and O'Reilly H&STech
	Stage: 'Campus Company Development Programme'	*Stage: 'Campus Company Development Programme'*
Business planning	Advice and assistance with business plan from mentors accessed through training programme.	Assistance with preparation of business plan: 'by the end of the programme we had developed a business plan that mapped out the future for us'.
Finance	Met Molloy- He helped secure external finance (Molloy subsequently became CEO); Mentor invested in the business.	
Expert advice		The in-house expert on patent advice; Used solicitors and accountants recommended during programme.
	Stage: Incubator tenant	*Stage: Incubator tenant*
Office space	Office space.	Office space.
Access finance and other resources		Use of EI expert for advice in accessing state funding.
		Incubator manager puts them in contact with post-graduate research students who conduct market research project.
Expert advice	Use of EI expert for advice in accessing state funding.	Incubator manager offers advice on selection of professional accountancy advisor.

response to a question during the data collection). Table 7 summarises the specific elements of the case histories that involved references to the TTO and the incubation experience. In response to a question, the scientists identified benefits such as the CCDP, including advice on business planning; access to advice; the status of association with the university; the convenient location of the centre; low cost and flexible term rents; and access to university resources, notably the computer network (Table 6). In terms of events in the emergence of these firms that referred to the TTO, we identified events relating to the CCDP and to the physical incubation space. In terms of the CCDP, the impacts are classified into three distinct areas: business planning, access to finance, and expert advice; while the episodes in the case histories that relate to the time in the incubator related to the decision to locate in the incubator, access to finance and other resources, and expert advice (Table 7).

While the scientists made reference to similar benefits, the nature of the benefits perceived by the scientists may differ from that anticipated by the provider. For example, for Daly the benefit of the CCDP was that it provided access to external parties, principally to the unfamiliar world of venture financing; in contrast, for Browne and O'Reilly, the programme was 'useful as it was the first major step in the decision to found a firm'. Furthermore, while both scientists received advice on how to prepare a business plan; the benefit they perceived was not 'information' on how to plan, but rather the source of the advice (the mentors that were associated with the CCDP) and how they used the plan. For Daly the references to advice on business planning were in the context of his attempts to raise external finance; in contrast, Browne (H&STech) referred to completing a plan that 'mapped out the future for us', with no reference to seeking external finance.

Reflecting on the case histories suggests that the scientists in our study had only sporadic interactions with the technology transfer officer or the incubator manager and only limited use of formal supports such as 'business development' clinics. The scientists used the assistance of the TTO the most during their early stages of start-up, and typically while attending the CCDP. While use of the services and supports offered by the TTO and the incubator was sporadic, it was occasionally in an intensive manner. As the companies developed, or as time elapsed, the scientists made less use of the direct supports of the TTO. Explaining the decreased usage overtime of the support offered by the TTO, Browne commented: 'if you are going to build a company that will stand on its own two feet you need to be weaned off all the other support'. The sporadic, though often intensive use, of the services offered by the TTO that we observed may partially explain why prior cross-sectional studies of firms in incubators report limited use of many services offered by incubators and lead researchers to question the value of incubation services.

7.1 The impact of the TTO on the barriers to commercialisation

Did the TTO play a key role in the scientists' ability to overcome the three barriers to commercialisation activity? First, did the TTO influence the scientists' perceptions of the commercialisation process? The CCDP did play a role highlighting the potential benefits of commercialisation activity to the scientists. The TTO appears to have been instrumental in the decision to start a new firm, and in a way acted as a counter-balance to the university's incentives and procedures that worked, from the perspective of the scientists, against efforts at commercialisation. For Browne and O'Reilly it was as simple as 'I don't think we would have gone ahead with the project had it not been for the centre'. Referring to the TTO Daly suggested: 'we wouldn't be here if it wasn't for this initiative'.

Second, did the TTO influence how the scientists recognised the commercial value of the knowledge they possessed? As outlined above, it would appear that the scientists had initially recognised the commercialisation potential prior to engagement with the TTO. So, overall, it appears that the TTO's role in this stage of the commercialisation process is quite limited.

Third, did the TTO play a role in connecting individuals or organisations with market knowledge or with resources to the scientists? Yes, it would appear from the cases that the TTO was important in this regard. In terms of the development of further market-related knowledge, and the on-going testing of the entrepreneurial judgement, the CCDP played a role in the two cases. For example, Kandag identified Geovera through its presence in the incubator; and Browne and O'Reilly considered that the planning process they engaged in during the CCDP helped them 'map out a future' and the incubator manager put them in contact with students who carried out market research. In the case of Daly crucial contacts with resource providers resulted from Daly's participation on the CCDP. For Browne and O'Reilly the TTO provided few contacts with external parties, with the exception of the Enterprise Ireland staff, who were important in providing funds for H&Stech.[6]

[6] Participation by the scientists from both firms on the CCDP and the subsequent location of their firms in the incubator may have been an important signal to the funding agency, Enterprise Ireland, of the entrepreneurs' commitment to commercialisation, and therefore their success in accessing the funds.

Overall this suggests that the impact that the TTO had on the emergence of these firms was principally in terms of social network extension and secondly in terms of access to resources. The value-added of the TTO was primarily the contacts that the scientists developed while attending the CCDP. We found little evidence for 'community of practice' benefits of incubation (Peters, Rice, & Sundararajan, 2004). The lack of evidence for 'community of practice' benefits may be explained in terms of the part-time approach of the scientists to entrepreneurship—with each remaining within their own pre-existing academic 'communities of practice'.

8 Concluding remarks

The Knowledge Spillover Theory of Entrepreneurship (Acs et al., 2004) suggests that commercialisation of new knowledge via entrepreneurship will occur when (1) scientists recognise personal benefits to commercialisation; (2) when scientists recognise the commercial value of new knowledge; and (3) when 'outsiders' with resources, including those with market knowledge, invest in the new knowledge. However, for most scientists working in public research institutes these conditions will not be met as most universities are typically not characterised by the policies, procedures, resources, and organisational culture that are associated with entrepreneurial universities. Therefore the scientist will face barriers to commercialisation activity.

How do they overcome these barriers; and what role does a TTO with incubation space play in facilitating the commercialisation process? We conclude the following. First, scientists take account of traditional academic rewards such as access to research funding and promotion opportunities when considering the pay-offs of commercialisation activity. Second the market-related knowledge that allows scientists recognise the commercial value of new knowledge will be embedded in their research context and/or will be the result of the scientist's external contacts with those with market knowledge. Third, that individuals or organisations with market knowledge learn of new knowledge developed by scientists, through the deliberate efforts of the scientists to acquire market information; and that intermediaries can help individuals or organisations with resources learn of new knowledge developed by scientists.

Fourth, the provision of a TTO and university-based incubation space and supports can help scientists overcome the barriers to commercialisation via entrepreneurship. The principal benefit of the TTO is in the domain of putting external resource providers in contact with scientists committed to commercialisation, and this reflects the external contacts of the TTO. In our cases most of the benefits of the TTO occurred in the context of the CCDP, rather than benefits resulting from locating in the incubator. Overall, our case evidence suggests that universities can influence the decision by scientists to engage in commercialisation via entrepreneurship. Universities can increase the perceived benefits of commercialisation by tying research funding to commercialisation activity; by facilitating scientists to engage in markets; and by developing the scientist's access to external providers of resources.

An important limitation of our study is that it is based on case material that may not generalise to other contexts (both other universities and other fields of research). A second limitation of our study is that we do not know the impact of

commercialisation activity on the teaching and research roles performed by the scientists—did these commercialisation efforts occur at the expense of other activities or did they enhance the academic activities of the scientists. A further limitation of our work is that it does not provide evidence of the effectiveness of university TTOs and incubation centres as a policy intervention, though we do provide a theoretical rationale for how a TTO might be expected to influence the commercialisation of new knowledge. While the firms in our study benefited from the TTO this is, in and of itself, insufficient evidence as to the effectiveness of TTOs as a policy tool, as we do not measure the costs of the policy or whether these scientists might have achieved the same ends through alternative means.

Our findings have important implications for scientists and for those interested in promoting commercialisation via entrepreneurship, such as university managers, managers in Public Research Institutes, TTOs, incubator managers, and regional and national policy makers. These are as follows.

1. Small modifications to traditional university reward structures may create incentives for scientists to engage in commercialisation activity.
2. In general, university-based scientists may be disadvantaged compared to other entrepreneurs in that they will typically possess less prior market knowledge. While the individual scientist must play a key role in developing such market knowledge our case evidence suggests that university managers may be able to assist the scientist. For example, university managers might seek to find ways of attracting individuals with the capacity to bring the new knowledge to market into the university setting, through, for example, efforts at industry co-funding of research projects. University managers need to ensure that opportunities for acquiring market knowledge occur through out the scientist's career, as it is impossible, ex-ante, to know what market knowledge might lead to the formation of an entrepreneurial judgement about a new market opportunity.
3. TTOs can assist scientists in commercialising new knowledge. However, the commercialisation process is dependent on the ability of the scientist to engage in the entrepreneurial function of market making, which will necessitate interactions with those in the market. TTOs will typically be disadvantaged in directly assisting the scientist in this role as they are unlikely to have the market knowledge and experience across the broad spectrum of research activity within the university. In contrast, the TTO may play an important role in putting scientists in contact with those with access to resources, such as finance and potential members of the entrepreneurial team. This suggests that the ability of the incubator manager to develop external networks for the incubator that can be transferred to the firms will be an important determinant of incubator effectiveness.
4. When considering developing a TTO and investing in incubation space we suggest that university managers and policy makers should note that it may be possible to deliver many of the benefits of incubation without investing in a physical incubator; and that efforts to increase commercialisation activity will necessitate broader based policies than the merely provision of incubation space. The virtual incubator may be practical in a university context where it is possible for scientists to maintain links with the university. So resource constrained universities may have a low cost mechanism for encouraging and facilitating

scientists in overcoming the barriers to the commercialisation of new knowledge, via entrepreneurship.

Acknowledgements Financial support for this research was provided by Irish Government under the Technological Sector Strand 1 Research Programme.

References

Acs, Z., Audretsch, D., Braunerhjelm, P., & Carlsson, B. (2004). The knowledge spillover theory of entrepreneurship. Working Paper, Max Planck Institute and CERP.

Audretsch, D. (1995). *Innovation and industry evolution*. Cambridge/Mass. MIT Press.

Audretsch, D. (2004). Sustaining innovation and growth: Public policy support for entrepreneurship. *Industry and Innovation, 11*(3), 167–191.

Audretsch, D., & Lehmann E. (2005). Does the knowledge spill-over theory of entrepreneurship hold for regions? *Research Policy, 34*(8), 1191–1202.

Casson, M. (2003). *The entrepreneur: An economic theory*. Oxford: Robertson & Co.

Clarysse, B., & Moray N. (2004). A process study of entrepreneurial team formation: The case of a research-based spin-off. *Journal of Business Venturing, 19*(1), 55–79.

Colombo, M., & Delmastro M. (2002). How effective are technology incubators? Evidence from Italy. *Research Policy, 31*(7), 1103–1122.

Eisenhardt, K. (1989). Building theories from case study research. *The Academy of Management Review, 14*(4), 532–551.

Hackett, S., & Dills D. (2004). A systematic review of business incubation research. *Journal of Technology Transfer, 29*(1), 55–82.

Kirzner, I. (1997). Entrepreneurial discovery and the competitive market process: An Austrian approach. *Journal of Economic Literature, XXXV*(March), 60–85.

Lockett, A., Siegel, D., Wright, M., & Ensley M. (2005). The creation of spin-off firms at public research institutions: Managerial and policy implications. *Research Policy, 34*(7), 981–993.

Mian, S. (1996). Assessing value-added contributions of university technology business incubators to tenant firms. *Research Policy, 25*(3), 325–335.

O'Shea, R., Allen, T., Chevalier, A., & Roche F. (2005). Entrepreneurial orientation, technology transfer and spinoff performance of U.S. universities. *Research Policy, 34*(7), 994–1009.

O'Shea, R., Allen, T., O'Gorman, C., & Roche F. (2004). Universities and technology transfer: A review of the academic entrepreneurship literature. *Irish Journal of Management Studies, 25*(2), 11–29.

Rice, M. (2002), Co-production of business assistance in business incubators: An exploratory study. *Journal of Business Venturing, 17*(2), 163–187.

Rothaermel, F., & Thursby M. (2005). University-incubator firm knowledge flows: assessing their impact on incubator firm performance. *Research Policy, 34*(7), 305–320.

Peters, L., Rice, M., & Sundararajan M. (2004). The role of incubators in the entrepreneurial process. *Journal of Technology Transfer, 29*(1), 83–91.

Shane, S. (2000). Prior knowledge and the discovery of entrepreneurial opportunities. *Organization Science, 11*(4), 448–469.

Vohora, A., Wright, M., & Lockett A. (2004). Critical junctures in the development of university high-tech spinout companies. *Research Policy, 33*(1), 147–175.