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Research and Technology Commercialization

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ABSTRACT This paper introduces the special themed section on organizational interactions involving universities and firms that result in the commercialization of research and technology. Our objective is to shed light on some of the most vexing, yet under-researched predicaments research institutions encounter, despite their best efforts to advance commercialization. First, we synthesize and extend recent studies, including the papers in the special themed section. Next, we develop a taxonomy of modes of commercialization. Specifically, we consider internal approaches, quasi-internal approaches (e.g. incubators), university research parks, regional clusters, academic spin-offs and start-ups, licensing, contract research and consultancy, corporate venture capital, and open science and innovation. We also identify areas for further research at the individual (e.g. heterogeneity of entrepreneurial teams and experience; incentives), organizational and intra-university (e.g. corporate governance; nature of growth strategies; relationships with trading partners; boundary spanning activities) and technology levels (e.g. institutional context; reconfiguration of technology; valuation of technology).

INTRODUCTION

The rates of research and technology development and appropriation are accelerating because widely distributed knowledge reduces costs related to organizing. For example, advances in computer science and information technology reduce search and collaboration costs. A key implication of this trend is that organizations (both for-profit and non-profit organizations) no longer rely solely on their *internal* R&D capacity. No organization has sufficient human talent inside its boundaries; no single institution can cover all the science disciplines that contribute to its product offerings; and large firms often cannot control their end-to-end production processes. Instead, firms are compelled to augment their R&D capacity by collaborating and *sourcing-in* (i.e. purchase, license, and co-develop) discoveries, inventions, and innovations from other players and institutions (Chesbrough, 2003). This trend has stimulated the growth of open innovation networks,

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such as Yet2.com, InnoCentive and TekScout, which connect industry, academic institutions, public and non-profit organizations with a global network of scientists to manage intellectual property (IP) and solve vexing problems in engineering, computer science, maths, chemistry, life sciences, physics, and business. Yet2.com connects buyers and sellers of technologies, whereas InnoCentive's or TekScout's clients post their challenges on a portal website, and those who solve the problems receive monetary awards.

Increasingly, private, public, and even non-profit organizations are also mobilizing their idle, unexploited, and underutilized discoveries, inventions, and innovations into the open market. Indeed, the commercialization of new knowledge – basic and applied research, technology breakthroughs, scientific developments – is an ecosystem of *research* and *technology commercialization*, which is the focus of this themed section. This ecosystem is essentially a market that includes research joint ventures, strategic alliances, and licensing agreements involving universities, research parks, and firms, as well as the formation of start-up companies that focus on science and technology. Put differently, we are witnessing the emergence of new organizational forms and functions that promote research, knowledge, and technology commercialization, such as technology transfer offices (within for-profit and non-profit organizations), science parks, incubators, and industry–university research centres.

Besides the trends noted above, this special themed section is motivated by two additional trends. The first is the rise in technology commercialization at research universities, which was stimulated by key legislation designed to promote more rapid diffusion of technologies from universities to firms (e.g. the US Bayh-Dole Act of 1980 in the USA, and similar legislation in Europe, e.g. OECD, 2003), as well as an expansion of public-private partnerships by national governments (e.g. the US Commerce Department's Advanced Technology Program and the UK Small Firms Merit Award for Research and Technology Programme). A second trend is the rise of public–private research partnerships (e.g. science parks) and public investment in programmes that support research and commercial interactions involving universities and firms. While these developments are more prominent in the USA, the rate of investment in such activities is actually higher outside the USA (Phan et al., 2005).

These developments raise important managerial and policy issues because they triggered changes that have affected universities, corporations, and government. For universities and public research institutions, the trend towards commercialization reflects pressures to maximize the social return on public investment in research and effort to enhance universities' self sustenance. Because idle discoveries are underutilized opportunities, the desire for greater commercialization grows stronger in periods of budgetary cutbacks. What is less clear, however, is how university–industry interactions actually shape processes and outcomes related to research and technology commercialization. Also, while there is a burgeoning literature on innovation via patenting, licensing, corporate venturing, joint ventures, and strategic alliances (Becerra et al., 2008; Keil, 2004; Walter et al., 2008), we have insufficient theoretical and empirical evidence on the underlying processes that govern the commercialization of research and technology across institution types. For instance, commercialization is sometimes interpreted differently by for-profit and non-profit organizations and by micro and macro researchers, yet the issues involved are salient to both sets of scholars.

Research at multiple levels can benefit from this timely focus on processes. For example, creativity studies have emphasized learning, search, and discovery, but leave unanswered questions regarding their link to value creation. By the same token, the literature on knowledge and innovation as a source of competitive advantage has emphasized proprietary control and appropriation, but overlooked questions regarding organizational processes driving these activities, especially collaboration and co-creation. Similarly, the technology strategy literature has emphasized new product development and how to identify underserved markets for disruptive technologies (e.g. Veryzer, 1998; Zahra, 1996), but also underscores models on how research and technology are appropriated, transferred, and commercialized across organizations. While numerous studies on agglomeration, clustering, embeddedness, and boundary spanning imply that joint ventures, alliances, and spin-offs constitute useful mechanisms for transferring technology between non-profit institutions and corporations, this body of work does not address critical issues regarding scope and factors underlying these processes (cf. Siegel, 2003).

Consequently, the time is ripe for a special themed section on organizational interactions related to the commercialization of research and technology. It is also useful to explore how these organizations manage and allocate resources to commercialize activities. Studying research and technology commercialization is especially important because such analysis provides important evidence for policymakers and managers. Indeed, the topic has moved beyond a niche field and is now a scholarly subject matter that is published in premier academic journals (Rothaermel et al., 2007). Advancing research, practice, and theory on this topic is also critical because IP commercialization is a widening practice among for-profit and non-profit institutions. The papers in this special themed section shed light on some of the most vexing, yet under-researched predicaments (for-profit and non-profit) organizations face despite their best effort to commercialize their research and technology.

In the following section, we review and extend recent studies, including papers in this issue. The concluding section synthesizes the findings and outlines an agenda for additional theoretical and empirical research on this topic.

MODES OF RESEARCH AND TECHNOLOGY COMMERCIALIZATION

To better understand the organizational implications of research and technological commercialization, we issued an open call for papers on the Academy of Management website and other venues. We received 34 manuscripts, which were reviewed according to *JMS* standards. Seven papers were then selected for presentation at a Special Themed Section Workshop, held in conjunction with the 2007 Technology Transfer Society Meetings at the UC-Riverside Palm Desert Graduate Center in Palm Desert, California. Authors were given an opportunity to revise their papers before the workshop. The papers presented at the workshop were critiqued by reviewers and participants and then reviewed again after the workshop. From these revised manuscripts, we selected the four best manuscripts for publication in the special themed section. Table I contains a summary of these articles.

For each paper, Table I lists a key research question, theoretical framework, data and analytical methods and critical findings. Note that a variety of theoretical frameworks are

Table I. Summary of papers in the special themed section

Authors	*Key research question*	*Theory*	*Data/analytical methods*	*Key findings*
Ambos, Mäkelä, Birkinshaw and D'Este	What is the role of ambidexterity in the commercialization of university research?	Ambidextrous organizations	Longitudinal project-level data/binary logistic regression	Tension between academic and commercial demands more salient at individual researcher level than at organizational level; universities manage tensions by creating dual structures; star scientists better able to be ambidextrous but this is a minority; academic scientists' motivation important
George, Kotha, and Zheng	How does a firm's knowledge structure across technology domains influence the impact it has by entering an insular domain?	Organizational learning theory; dynamic capabilities	Patent and other archival data from 128 biotechnology firms; fixed effects negative binomial regression	Depth of the firm's technological capabilities is necessary but not sufficient for high impact innovation when they enter insular domains; firms whose knowledge is spread over disparate domains have negative returns from entering insular domains
Keil, Autio, and George	Which learning processes do firms adopt to engender capability development needs and what factors influence the internalization of these capabilities?	Dynamic capabilities; social learning; cognition	Longitudinal case studies of corporate venture capital (CVC) in information and communications technology (5 firms); grounded theory	Disembodied experimentation through CVC investments facilitates deliberate investments in capability development through greater awareness of the benefits of engaging in such activity; influential CVC managers recruit members with high internal social capital, and members with strong functional experience and seek out network endorsement by accessing non-traditional networks
West	How is open science commercialized?	Knowledge spillover theory	Primary and secondary data from multiple sources over 25 year period; exploratory research	Commercialization delayed by scarcity of 'know-why' among top researchers; scientific research elaborating the superior trajectory was publicly funded and concentrated at one institution and despite open dissemination was commercialized by researchers with strong ties to that university; important for star researchers to commercialize their own research and to directly link basic and applied R&D

used and that most of these studies employ 'mixed methods', combining quantitative and qualitative techniques. The papers are based on a wide range of management theories, including organizational learning, social network theory, dynamic capabilities, cognition, and ambidexterity theory. Several authors also combine 'micro' and 'macro' data, presenting results at multiple levels of analysis. Importantly, the studies show that longitudinal research designs and inductive theory building are central to a more nuanced understanding of research and technology commercialization. Consistent with the extant literature, the papers identify three modes of research and technology commercialization: (1) internal approaches; (2) quasi-internal approaches; and (3) externalization approaches.

Internal Approaches

We focus our analysis on the internal activities of two key institutions: universities and firms. Universities, more than companies, are faced with the problem of pacifying conflicting demands from their stakeholders in technology commercialization: academic scientists, university administrators, and firms/entrepreneurs (Siegel et al., 2003a). The key agents involved in addressing these conflicts are university technology managers (sometimes called technology licensing or technology transfer officers), who are typically employed in a technology transfer office (henceforth, TTO). These managers serve as boundary spanners, acting as a bridge between 'customers' (entrepreneurs/firms) and 'suppliers' (academic scientists), who operate in distinctly different environments and have different norms, standards, and values.

In addition to their boundary-spanning capability the *organizational structure* within which TTO managers work is also crucial to the effectiveness of commercialization. For example, Bercovitz et al. (2001) identified four organizational forms in universities: the functional or unitary form (U-form), the multidivisional (M-form), the holding company (H-form), and the matrix form (MX-form). In a similar vein, Markman, Gianiodis and Phan (in press) classified university TTOs according to autonomy levels – *traditional structure*, *non-profit research foundation*, and a *for-profit private extension*. This line of research shows that these structure differences are associated with variations in technology transfer performance in terms of transaction output, the ability to coordinate licensing and sponsored research activities, and incentive alignment capability.

Ambidexterity theory suggests that organizations modify their structures to deal with conflicting objectives (Duncan, 1976; Tushman and O'Reilly, 1996). In this context, ambidexterity entails a senior leadership team with the clout to align structures and advance a culture that promotes basic science and research while enhancing IP exploitation. In universities, dual structures include the creation of a TTO and the introduction of different career paths for those involved in technology commercialization and for the more traditional academic activities of research and teaching. In the special themed section of this issue, Ambos et al. (2008) compare projects that generate commercial outcomes (patents, licenses, or spin-outs) with those that do not, at the point of the decision about whether to commercialize or not. Consistent with ambidexterity theory, the authors find that universities manage the tensions between academic and commercial demands by setting dual structures.

Besides internal organizational issues, the nature of knowledge structuration and scope of technological capabilities may have a central role to play for firms, such as those in the biotech sector, seeking to enter new markets. George et al. (2008) (this issue) show that when a firm enters an insular domain – where innovations draw heavily on knowledge embedded within a particular technology corridor or domain – the depth of technological capabilities is necessary but insufficient for high-impact innovation. The authors suggest that when firms develop deep capabilities in an insular domain they are better equipped to venture into new domains; firms holding broad knowledge that is spread over disparate domains have negative returns from entering insular domains.

Quasi-Internal Approaches

Corporations and universities also rely on 'quasi-internal' activities to stimulate technology commercialization. A key facilitator of such activity is the business incubator, defined as a property-based organization focused on accelerating the growth and success of entrepreneurial companies through the provision of business support, resources, and services. Business incubators have four main objectives: (1) economic development (especially, job creation and diversification of a regional economy); (2) technology commercialization; (3) real estate development; and (4) entrepreneurship. Many universities have established incubators to foster the creation of start-up companies based on university-owned (or licensed) technologies.

According to Phan and Siegel (2006), incubators appear to work best when there is a complementary innovation system at the university, i.e. an 'entrepreneurial university'. This 'innovation system' includes incubators, science parks, angel networks, academic entrepreneurs, surrogate entrepreneurs (i.e. individuals with commercial experience who take on the role of entrepreneur from the academic scientist; see Franklin et al., 2001), graduate students, and post-docs. According to the authors, this innovation system works best when venture capitalists and other individuals who have strong industry ties are involved in designing and operating the incubator, a complementary education system is in place, and the incubator managers are working with real estate developers.

Clarysse et al. (2005) identify three types of university incubation approaches; each comprises different resource-capability commitments. The first approach seeks to support a small number of high-potential start-ups aiming to become global businesses generating significant capital gains. The second incubation approach focuses on businesses that already generate revenue streams, whereas the third approach focuses on a larger number of smaller consultancy and service businesses that generate local employment. They also identify sub-optimal cases where university TTOs either attempt to undertake commercialization activities beyond their resource-capability mix or where they fail to develop the competences needed to achieve commercialization objectives. Hence, universities should match their commercialization and spin-off objectives with appropriate resource-capability mixes and with a realistic perspective given their science and technology base. The considerable heterogeneity in organizational arrangements regarding incubation of spin-offs stems from the fact that some universities adopt ambidexterity to reconcile and synergize organizational missions, such as research, teaching, and commercialization. Indeed, one message advocated by the papers featured here is that TTOs need to adopt a more customized approach to the incubation of different types of spin-offs. For instance, some universities should follow a narrower strategy focusing on world-class innovations with global potential (Thornhill and White, 2007), whereas other institutions should pursue a more modest approach developing broader, more incremental, or generic innovations that have local and regional potential (Clarysse et al., 2005). In short, a multi-dexterity approach helps some universities pacify diverse stakeholders and objectives – teaching, research, commercialization – at multiple levels (local, regional, national, international).

An additional option is to rely on intermediaries by outsourcing the commercialization to specialists; hybrid public–private companies (e.g. the IP Group in the UK and UTEK in the USA) that sign long-term, and even exclusive contracts with universities to commercialize their IP. These hybrid companies provide support that covers expertise in identifying IP with commercial potential, accessing early stage finance and strategic partners to accelerate ventures development. This option enables universities to compress learning and fill skills gaps that TTOs with limited expertise are yet to provide effectively (Wright and Filatotchev, 2008).

(Clarysse et al., 2005) find that university incubators that focus on developing a small number of high value spin-offs frequently establish their own venture capital fund and/or develop access to external venture capital provision. This approach has similarities with corporate venture capital (CVC) in the commercial sector and also raises associated issues concerning the presence of appropriate capabilities to develop ventures alongside the provision of finance (Keil, 2004). The paper in the special themed section of this issue by Keil et al. (2008) employs a grounded-theory approach to address an important research question on CVC. Specifically, the authors wish to: (a) determine which learning processes firms adopt to engender new capabilities; and (b) identify the factors that influence the internalization of these capabilities. Based on longitudinal case studies, they find that disembodied experimentations facilitate capability development. The authors also report that influential CVC managers recruit members with high social capital and strong functional experience. CVC managers also seek out network endorsement by accessing non-traditional networks. A key implication of their study is that social and network factors play a significant role in technology commercialization, a result that has also been found in the university context (e.g. Zucker and Darby, 1996).

Externalization Approaches

This final mode of research and technology commercialization entails university research parks, regional cluster, academic spin-offs and start-ups, licensing, contract research and consultancy, joint venture spin-offs, alliances and collaborations, corporate venture capital, and open science and innovation.

University research parks. Science parks and incubators are property-based organizations whose aim is business acceleration through knowledge agglomeration and resource sharing (Phan et al., 2005). Unlike incubators, which offer business assistance services to start-ups, research parks are not dedicated to start-up, early-stage companies, or business development services. Instead, research parks are typically large-scale projects that house a spectrum of entities, including corporate units, government labs, and medium and small firms. However, these institutions yield positive externalities and network benefits from being co-located with other high-tech firms and important players, such as venture capital providers. Open innovation platforms, virtual networks, and online marketplaces reduce search and collaboration costs, so collectively, they may substitute at least some of the network benefits of science parks and incubators. There is thus some debate about whether and to what extent science parks and incubators enhance the performance of the businesses located on them, as well as the associated universities and economics regions (Siegel et al., 2003b). A major problem arises in defining the appropriate measure(s) of performance for the park or for companies located on these facilities, particularly with respect to survival, wealth creation, and employment growth.

Regional clusters. The scope and depth of research across the spectrum of academic disciplines have important implications for universities' ability to commercialize research and technology (Wright et al., 2004a). For example, many mid-range universities, typically located away from major metropolitan areas, lack the resources to be world-class players in all research areas, hence the development of regional clusters is a mechanism some universities use to overcome restricted resource endowments and improve scale economy. Indeed, evidence shows that technology transfer is more efficient in larger metropolitans and regions with high R&D levels (Siegel et al., in press). While regional clusters are not as vibrant and efficient as metropolitans, they do facilitate collaborations between universities and industry: they create critical mass in TTOs' discipline-specific skills and involve development agencies, public research labs, intermediary organizations, local corporations, and occasionally, venture capital funds.

Academic spin-offs and start-ups. Strictly defined, spin-offs are new ventures that are dependent upon licensing or assignment of a university or corporation's IP for initiation. A corporation or university may own equity in the spin-off in exchange for patent rights it has assigned or in lieu of licence for fees (Wright et al., 2007). The institutional context may determine whether universities and indeed academics can take equity stakes in these firms. In our view, a narrow definition of a spin-off – at least at this early conceptual state of the field of technology commercialization – would miss substantial venture variations. For example, many spin-off ventures do not build upon formal, codified knowledge embodied in patents but instead, draw on non-IP or tacit knowledge of scientists who work in academic or corporate settings. Also, despite the ground-breaking technology they embody, only a few university spin-offs have created new markets (e.g. Google). Most spin-offs are unlikely to serve national markets, yet taken as a whole, university ventures do have significant implications for local employment creation and revenue generation (Clarysse et al., 2005). Having well-defined strategies and policies are central to the number of spin-offs that universities create, which includes having the necessary business development capabilities among TTOs (Lockett and Wright, 2005; O'Shea et al., 2005). Naturally, it is equally important to have a critical mass of faculty generating world-class research (Di Gregorio and Shane, 2003).

Our review of the literature suggests that world-class research and star scientists have considerable leverage in persuading TTOs to create ventures, particularly when licensing is the more obvious alternative (Lockett et al., 2005; Markman et al., 2005). Additional determinants of successful academic spin-offs and start-ups include enticing equity incentives for faculty who create businesses (Markman et al., 2005) and strong network ties between TTOs, venture capitalists, business angels, IP specialists (e.g. law firms), and entrepreneurs (Franklin et al., 2001; Wright et al., 2006). The bulk of research on the commercialization of research and technology, especially that emanating from universities, has focused on firm creation with less emphasis on understanding what is required to grow these ventures (Mustar et al., 2006). There is also a paucity of research on more informal commercialization mechanisms, including instances where scientists bypass their TTO when they privately sell, license, or use discoveries made while working in university labs (Markman et al., 2008).

Licensing. Companies license inventions for many reasons. These include harnessing external ideas and talent, keeping up with science and technology, reducing the risks associated with R&D, and enhancing dominance over technology corridors. Thus, firms pursue licensing strategies to increase the speed, scope, odds, and impact of their innovation. An increasing number of universities license their inventions, but because universities are accountable to a broad range of stakeholders, their licensing goals are typically more complex than those of firms. Public universities typically have even less flexible policies than private universities regarding patenting, licensing, start-up formation, and interactions with industry (Siegel et al., 2003a). Furthermore, historically, public universities were less focused on technology transfer and commercialization as a source of revenue than private universities. In addition, public universities may have objectives relating to the promotion of local and regional development through IP spillovers. This latter objective and a preference for licensing agreements to smaller, local firms, tends to yield less income. Hence, public universities are more constrained by political pressures, whereas private universities are more agile, adapting faster faculty royalty incentives to promote licensing and entrepreneurial activity.

Following their review of the literature, Siegel et al. (2007) conclude that returns to licensing are generally low and highly skewed towards a small number of licenses in small number of universities. The main impediments to effective technology commercialization through licensing are organizational ones – discordant cultures between universities and firms; misaligned incentive systems (e.g. insufficient credit towards tenure and promotion); and inappropriate staffing and compensation practices of the TTO itself (Siegel et al., 2003a,c). Collectively, these impediments explain the fact that as scientists make more valuable discoveries, they are more likely to divert their discoveries to the marketplace by sidestepping their TTOs (Link et al., 2007; Markman et al., 2008).

Contract research and consultancy. Contract research and consultancy also provide ways in which research and technology can be commercialized. While there is an extensive literature on consultants (e.g. Armbrüster, 2004; Bloomfield and Danieli, 1995; Clark, 2004; Giroux, 2006; Sturdy, 1997), in the context of the commercialization of research and technology generated by universities, this area has been generally neglected. Contract research and consultancy may generate significant revenues, although their measurement may be problematical (Wright et al., 2008a). For corporations, contract research can provide access to new knowledge (e.g. basic science and applied technologies), enhancement of R&D, and access to talent (Poyago-Theotoky et al., 2002). Lam (2007) identifies the notion of an overlapping internal labour market between high-tech firms and universities, which via R&D project collaboration, creates a pool of joint human resources with work experiences and career patterns for scientists that straddle the two sectors.

As with other forms of commercialization, it is unclear how contract research and consultancy counts towards tenure and promotion. Moreover, the fact that university protocols regarding contract research and consulting are frequently stringent (e.g. many universities 'tax' an academic's consulting income), further reduces the incentives to partake in such activity. We, however, see contract research and consultancy as an important dimension of the commercialization of research (cf. Link et al., 2007). This route to commercialization is most likely to be effective when universities have developed centres of research excellence. An example is the Institute for Broad Band Technology (IBBT) which brings together over 600 researchers from several universities and knowledge centres in Belgium. The institute is comprised of specialized research groups that focus on the evolving needs of companies and organizations. However, high level contract research and consultancy pose major challenges for so-called mid-range universities that have few if any such centres. This may be especially acute for mid-range universities seeking to develop relationships with major corporations who are more likely to seek out leading research centres in other regions or even other countries (Wright et al., 2008b).

Joint venture spin-offs, alliances and collaborations. Joint venture spin-offs are new ventures in which technology is assigned to a company that is jointly owned by a university and an industrial partner. Academic scientists typically have an equity stake in the new enterprise, in order to accelerate the development and deployment of the technology into a marketable product (Wright et al., 2004a). Such joint ventures with industry partners allow universities to access important resources required to commercialize activities that are not available within universities or through a spin-off created with investment by venture capital firms. Industrial partners facilitate and accelerate the maturation of joint venture spin-offs through their organizational routines, resources, managerial talent as well as access to a vibrant ecosystem of trading partners. As with most partnerships, the uncertainty regarding ownership and control of the joint venture and its IP is a source of concern and hesitation (Wright et al., 2004b).

Open science and innovation. The decline in search and collaboration costs is accelerating the pace of open innovation, an innovation mode where diverse constituencies, including customers and end users, co-innovate and co-create. From a societal standpoint, the rise of 'open source' innovation is salient. Linux, Wikipedia, YouTube, MySpace, and Facebook are all examples of mass collaboration on open source platforms. Specifically, thousands of programmers contribute to Linux; over 75,000 people are peer-producing Wikipedia (e.g. these volunteers work on more than 10,000,000 articles in more than 250 languages); thousands of people contribute to YouTube (every minute, ten hours of video is uploaded to YouTube); and MySpace and Facebook are each supported by about 100 million active users worldwide. Although economists devote considerable attention to the supply side of the open source movement (e.g. Lerner and Tirole, 2002; Sauer, 2002), they have not directly examined the managerial implications of this phenomenon. This is due, in part, to the fact that it is difficult to parameterize labour supply under open source innovation, where developers and end users are often volunteers who do not appear to profit directly from these activities.

Open innovation firms seek to co-create and co-commercialize research and technology regardless of whether the technology is originated inside or outside their boundaries. Hence, firms and scientists may co-develop research and technology innovations that are commercialized elsewhere. Major issues concern how to access external innovations, how to integrate them, and how to capture and appropriate some of the benefits from such innovations. The development of social capital and external ties plays a central role in attracting scientists, consultants, universities, and industry players who can enhance the promise of external innovations. The development of absorptive capacity is also important in enabling firms to integrate and use research and technology generated externally. Tether and Tajar (2008) find that firms with more open approaches to innovation are more likely to use specialist knowledge providers, such as consultancies, private research organizations, universities and government research laboratories, as sources of information.

West (2008) (this issue) seeks to fill part of the research gap by providing empirical evidence on the commercialization of open science. He conducts a longitudinal analysis of the dissemination of an early open-source innovation: Claude Shannon's information theory of communications. The theory was developed at Bell Telephone Laboratories, but was then commercialized at MIT by two start-up companies as a solution to the challenge of the transmission of information over a noisy channel. West concludes that commercialization was delayed by the scarcity of 'know-why' among top researchers. He also finds that despite public funding and open dissemination, the scientific research was commercialized by researchers with strong ties to a single institution, namely, MIT. He concludes that it is important for star researchers to be involved; to commercialize their own research and to bridge basic and applied research.

DISCUSSION AND FURTHER RESEARCH

Our review and synthesis of the extant literature, including the papers featured in the special themed section of this issue, revealed that the 'who, where, what, how, and why' of research and technology commercialization are still evolving. Many universities and firms are creating or modernizing their TTO and ramping up their practices, thus creating a dynamic state that stimulates diverse questions. A synthesis of this body of research groups the questions into three levels of analysis: (1) the individual level; (2) the organizational level; and (3) the technology level. Collectively, these questions outline an agenda for additional theoretical and empirical work on research and technology commercialization. Table II presents potential research questions and the sections below offer additional synthesis based on the three levels of analysis noted above.

Individual Level

There is considerable debate regarding the trade-off between universities' involvement in commercialization activities and research output. For example, policymakers are

Table II. Research questions relating to research and technology commercialization

Individual level	*Organization level*	*Technology level*
What differences are there in the commercialization activities of star scientists versus non-star scientists?	What is the link between corporate governance and research and technology commercialization?	How does the science/technology co-evolve with the identification of the market, especially for radical innovations?
What are the most effective configurations of entrepreneurial teams for the commercialization of research?	How do internal power relationships within corporations and universities impact the commercialization of research?	How does the commercialization process vary according to the type of technology?
How does the entrepreneurial experience of scientists affect the nature of commercialization?	How can the tensions and paradoxes between stimulating research and technology through open innovation and capturing the benefits of it be reconciled?	What is the most appropriate/effective locus of technology specialists (e.g. within the spin-off, within the university, a contractual arrangement, etc)
How does involvement in technology commercialization affect the quantity and quality of basic research?	How do the challenges relating to research and technology commercialization differ between corporations and universities?	What role does service provision play in technological innovation at different stages of the technological commercialization life-cycle
How does involvement in technology commercialization affect teaching performance?	What is the impact on trading partners of the research and technology commercialized through spin-offs?	What are the most appropriate mechanisms for valuing commercializable research?
How does involvement in technology commercialization affect the career development of faculty members?	What business models are used to commercialize research?	What is the best regional strategy for promoting effective technology commercialization?
What is the relative importance of pecuniary and non-pecuniary incentives in university technology commercialization?	How can value be created most effectively from research: by developing the science or by developing revenue streams?	Which publicly-funded technology programmes have been most effective in facilitating technology commercialization?
How important is training and human resource development for technology transfer officers?	What is the role of boundary spanners, both internally and externally, in commercialization of research?	Should universities and other public research organizations be permitted to patent as much as they currently do?

interested in determining how involvement in technology commercialization affects other performance dimensions of academics, such as the quantity and quality of their basic research, teaching performance, and their career developments. To date, the balance of evidence suggests that academics' involvement in commercialization, especially patenting, is associated with increased publications without affecting the nature of the publications involved (see Siegel et al., 2007). Similarly, the research productivity of university scientists remains stable even after they form start-up companies (Lowe and Gonzalez-Brambila, 2007).

Although it is useful to make some generalizations, it is increasingly evident that the individuals involved in research and technology commercialization are heterogeneous. While the focus of attention has been on the potential effects on star researchers in world class universities (e.g. West, 2008 (this issue); Zucker and Darby, 1996), middle-range researchers in mid-range universities also have a role to play in the commercialization of IP (Wright et al., 2008a). For example, analysis of the link between patents and publication quality in the materials science discipline shows that medium-to-high impact research is associated with greater patenting rates. Scientists who work on applied research tend to patent more than academics who pursue basic research (Calderini et al., 2007). In fact, academics reduce their patenting activity as they become more productive (measured by publications in high-impact and high-quality journals). This heterogeneity calls for additional research on the antecedents and consequences of technology commercialization, particularly empirical evidence drawn from more representative academic institutions – not just elite private universities such as MIT or Stanford.

Although academic entrepreneurs are often portrayed as neophytes with respect to commercialization, this is far from the case. Mosey and Wright (2007) show that while some academics aspire to become entrepreneurs and others have been involved in the creation of one venture, some are habitual entrepreneurs who have created multiple ventures (Ucbasaran et al., 2008; Westhead and Wright, 1998). Different entrepreneurial exposure has important implications for the commercialization of research and technology. As Mosey and Wright (2007) suggest, habitual entrepreneurs have enhanced human capital and developed commercial and social networks that are highly effective in gaining access to equity finance and management talent. Less experienced academic entrepreneurs are constrained in their ability to create and develop new ventures because they lack corporate experience and industry networks. These differences between habitual academic entrepreneurs and less experienced academic entrepreneurs are important because TTOs are usually ill-equipped to develop the latter's social capital and industry experience. All in all, our synthesis calls for additional research on the heterogeneity of academic entrepreneurs' social capital, business acumen, and academic discipline IP (Mosey and Wright, 2007) and how this feeds through into the process of searching for scientific discoveries that can be commercialized (Fiet, 2007).

Ambos et al. (2008) (this issue) do show that star researchers are better able to be ambidextrous in terms of managing the heterogeneous objectives of teaching, research and commercialization. Yet additional evidence regarding the differences in the commercialization activities of star and non-star researchers is limited and more questions remain. How and why do technology-based ventures created by star researchers differ from those created by non-star researchers? To what extent do ventures created by the former involve newer market creation and more innovative products than those created by the latter? How can star scientists' skills and know-how regarding IP commercialization advance the competencies of other scientists and TTO?

Much attention has been devoted to the need for commercialization skills among academic entrepreneurs and the role of surrogate entrepreneurs in providing these skills (Franklin et al., 2001). However, it is also evident that as part of the evolutionary path of spin-off firms there is often a need to reorient the business and to reconfigure the technology. This reorientation and reconfiguration do not occur in a frictionless way; there is extensive failure and delay in developing products, as the example of Idmos below illustrates. Yet, how the technology co-evolves with the identification of the market is an area that is not well understood. For example, to what extent are initial attempts at converting innovations into products adapted to fit market needs versus to what extent is there a need to begin again with a radically reconfigured technological approach?

Important issues relating to commercialization activities concern the roles of the incentives and motivations of academics. For example, there may be a need to move beyond standard royalty distribution and equity holding formulae adopted by TTOs to make commercialization more enticing to a broader set of scientists yet also more customized (e.g. favourable agreements with repeat scientists or star researchers). A formalized protocol for periods of leave would enable academics to focus on the development of a spin-off with the possibility of a return should a venture fail or academic skills no longer be required in a corporate setting. More generally, the wider range of 'third stream' activities – namely, 'service', which involves research commercialization – needs to become a core competency of universities' activities rather than merely being bolted on to the traditional streams of 'research' and 'teaching'.

Organization Level

Organizational-level issues are relevant to universities and established firms, as well as to spin-offs and their trading partners. Our earlier discussion stressed the importance of internal organizational structures and processes for the effective commercialization of research and technology. A central issue this research has yet to address concerns the optimal organizational mix of activities within which commercialization of research and technology is positioned and appropriate organizational configurations for this portfolio. Our synthesis points out that this is an important research gap, particularly given evidence relating to the challenges in implementing commercialization strategies (Siegel et al., 2007). This also highlights the importance of corporate governance and in particular the role of boards in developing the strategic direction of research and technology commercialization and assuring its implementation. Traditional research and policy approaches to boards have focused on their role in ensuring accountability to shareholders (Keasey et al., 2005). However, there is increasing recognition that corporate boards are an important resource for firms in terms of helping to undertake entrepreneurial activities (Barney et al., 2001). As such, future commercialization research might consider the composition of boards, the roles of individual members, and their skill sets as it relate to research and technology activities. For established corporations and universities, this may mean ensuring that outside directors and managers have expertise in research and technology commercialization. Further, it is necessary to strengthen the links between scientific advisory boards and main boards. There may be important differences between commercial corporations and universities in relation to their ability to attract board members with the appropriate skills and understanding of the institutional context.

Spin-off ventures, like most start-up firms, need to develop their boards as they pass across the threshold from start-up to professionalization and growth. External board members can bring reputations and capabilities to help establish the firm's credibility, scan the environment for new sources of ideas and markets, substitute for and complement the initial founding team, and assist in developing internal processes. These factors are central to the development of research and technology as commercializable products (Filatotchev et al., 2006). To date, very little corporate governance research has addressed issues relating to boards' capabilities and functions vis-à-vis research and technology commercialization.

One lesson learned from our synthesis is that start-up companies are a key dimension for the commercialization of university-based technologies, and yet start-up firms are heterogeneous with respect to their business models and growth prospects (Wright et al., 2007). Nurturing spin-offs hinges on careful analyses of and making choices about how to add value to newly-created research and technology. Research in the entrepreneurship area in particular has focused on strategies to create high growth in terms of either sales revenue or employment. While this line of research recommends the use of multiple measures of growth, it offers little theory on the differences between these two growth strategies (e.g. Delmar et al., 2003). We call to consider a more nuanced view of growth because, for example, conditions in product markets and factor markets differ (Clarysse et al., 2007a; Markman, Gianiodis and Buchholtz, in press). A typical product market strategy aims to achieve revenue growth and greater business presence in a well-defined product category (e.g. increased product market share). On the other hand a factor market strategy places greater emphasis on leadership over inputs, for instance, by developing science and technology competencies, even if no product sales are generated. Naturally, both strategies are critical, but the point we advocate is that because each approach calls for very different skill sets and capabilities, future research should address such differences. Indeed, even an industry sector and appropriability regime may call for different commercialization strategy in product and factor markets. Another likely influence on the choice of commercialization strategy is the accessibility to the necessary complementary assets associated with each growth strategy. Product-market growth strategies call for human capital with commercialization expertise. Factor-market growth strategies require laboratories and human assets that can develop the technology. Currently, we know little about how spin-off firms access various types of resources and human assets in each market.

Our synthesis suggests a further area of research that concerns the impact of the commercialization of research and technology on trading partners and end users. For example, transferring knowledge through alliances and collaborations can be highly inefficient (Becerra et al., 2008; Walter et al., 2008). Indeed, evidence indicates that entrepreneurial firms are generally inefficient in their collaborations due to their tendency to make transaction-specific investments that create hold-up problems relating to contractual renegotiations (Arino et al., 2008). Commercialized research may become an important input to the development of further products by mature corporations that are unwilling or unable to undertake early-stage innovative activities. While larger corporations are critical trading partners for spin-off firms, the latter are usually only a minor part of the larger corporation's portfolio; there is therefore an asymmetry of inter-dependence between large and small partners (Pfeffer and Salancik, 1978). This raises a number of issues concerning the nature of the contractual agreement between spin-offs and corporate partners. Over and above cultural differences, such issues include pricing, length of contract, milestones, expectations about the contribution of each partner, whether the trading relationship will be a precursor to acquisition by the corporate partner, etc. Trading partners also need to address uncertainties about whether a very early stage innovation can indeed be developed into a viable product. Spin-off firms need to ensure that they deliver on their contract with the trading partner, which may require ongoing technology development to a commercializable product. This also raises the issue as to whether the collaboration is explorative in nature or exploitative in relation to the development of technology and/or products. Asymmetry of inter-dependence also introduces challenges concerning the management of the relationships between partners and thus places emphasis on partner selection by both the spin-off and the large corporate partner. Technological proximity may be important in filtering potential partners and decisions may also depend on whether the technology is a platform technology with opportunities for the development of a broad range of products and applications.

Inter-partner problems are illustrated by the example of the dental technology firm Idmos, a university spin-off created in 2001, that had been listed on the London-based Alternative Investment Market (AIM). In 2005, Idmos entered into a technology licensing agreement with Dentsply, a NASDAQ listed $4 billion market capitalization firm. According to the agreement, Dentsply would invest in Idmos' product development in return to exclusive global rights to market and sell current and future dental products based on Idmos' technology. The partnership made sense because Dentsply is a world leading manufacturer and distributor of dental prosthetics, precious metal dental alloys, endodontic instruments and materials, and other dental products, with distribution channels in over 120 countries. Unfortunately, the agreement foundered amid accusations by Dentsply that Idmos had met neither milestones nor the final product and counter-accusations by Idmos that Dentsply had unrealistic expectations about what the technology could do, and in April 2008, Idmos entered bankruptcy proceedings. Given the cost of failure, analysing the role, types, and utility of partnerships in the commercialization of research and technology is urgently needed.

Some of the knowledge necessary for commercialization is available within university and spin-off ventures, but it tends to be dispersed across university departments or it calls for special skills located outside universities. Accessing, using, and sharing this knowledge is problematical, given that its transmission occurs at the boundaries of different professional and scientific communities. The transfer of knowledge into and out of universities is also problematical because of the differences between the traditionally non-commercial context of universities and the commercial environment; these challenges entail cultural issues (as noted earlier) as well as divergent positions on the utility of emerging science and technology vis-à-vis markets. There is thus a need for mechanisms to transcend these internal and external boundaries. As Colyvas et al. (2002) show, informal relations may be more important for transferring technology than formal mechanisms, particularly when the knowledge involved is tacit.

Boundary objects – objects that are shared across contexts because they inhabit several communities of practice (Star and Griesemer, 1989) – facilitate the process for transforming knowledge, research, and technology across organizational boundaries. Boundary objects are particularly effective when they establish a shared syntax or language and provide concrete means for individuals to learn about their differences and dependencies across boundaries (Carlile, 2002). Sharing boundary objects among dispersed individuals and groups such as scientists and business persons, between different university departments involved in academic entrepreneurship, or between academics and corporations is a complex task, suggesting that individuals with boundary-spanning skills can accelerate research and technology transfer.

Through the development of boundary objects, boundary spanners acquire knowledge from one domain and deploy it in another (Tushman and Scanlan, 1981). The distance between communities of practice (e.g. in terms of language, culture, and subject matter), increases the important role that these individuals play in mitigating complexity associated with bridging boundaries (Kostova and Roth, 2003). Boundary spanners encounter difficulties when groups have conflicting expectations about how the former should fulfil their role (Van Sell et al., 1981). This problem may be especially acute among boundary spanners in a university context, where there are conflicting objectives and ambiguities about the purpose of commercialization. Such concerns are exacerbated by the differences in language, mores, and power relations between TTOs and scientists. We stress these issues because business schools can play a critical boundary spanning role by filling knowledge gaps in the development of academic entrepreneurship and in inculcating commercial knowledge to scientists (Wright et al., 2008b). Further research is needed on the challenges involved in these boundary spanning roles and how they may be overcome.

Technology Level

The approach to commercialization of research and technology is also influenced by the nature of the research and technology. Research and technology from different disciplines – e.g. biotechnology, engineering, and information and communication technology (ICT) – involve quite distinctive uncertainties, time scales, and appropriability regimes (Druilhe and Garnsey, 2004).

The institutional or market context within which the technology is generated may also be influential. Recalling our earlier distinction between product and factor markets, mature firms focus on customers' needs and develop their technology with a product-market view. In contrast, university researchers typically adopt a factor-market approach; they focus on developing basic research and raw technology without considerable attention to customers' needs or product-market penetration. Basic research and raw technology, however, are less predictable than end products because the endogenous value of inputs – in a university context, basic science and technology – is rarely known prior to the deployment of such resources in product markets (Markman, Gianiodis and Buchholtz, in press). This market distinction has implications for spin-off venture creation and development. Corporate spin-offs tend to have a well-defined, narrow product-market scope and thus well-positioned offerings, whereas university spin-off ventures usually needs product-market reorientation because their resource position could be far afield of the product space they are trying to enter (Markman, Gianiodis and Buchholtz, in press). This distinction also implies that spin-offs (from corporations or universities) with a broad technology platform may be better placed to adapt their product-market application.

Both university and corporate spin-off ventures introduce novel offerings, but the impetuses for their innovation are different. Even if a market can be identified, universities' spin-off ventures develop innovations that are often a long way from commercializable products because, as noted above, their innovations hinge on basic research and raw science (Wright et al., 2007). Corporate spin-offs also introduce novel offerings, but their innovations are driven by the necessity to differentiate themselves from their parent corporation, yet remain useful to customers (Klepper and Sleeper, 2005; Van de Velde et al., 2008). In short, both venture types seek to innovate, but the motivation differs, and because corporations tend to support applied research, their spin-off ventures tend to be more effective (than university spin-offs), in terms of identifying and realizing commercial opportunities.

As noted in Siegel et al. (2003c, 2004), estimation of the potential commercial value of university-based research poses major challenges. Clarysse et al. (2007b) have shown that problems may arise where public research organizations overestimate the value of the technology and that this overvaluation can create difficulties in attracting private sector venture capital. Negotiations between universities, academics, and venture capital providers can be difficult and prolonged given the uncertainty about the transition of technology from the laboratory to a marketable product. As a result, some universities are moving towards standard pre-agreements with financiers that avoid the delay associated with these negotiations (Wright and Filatotchev, 2008). These arrangements may also involve standard equity splits between the parties. Further research is needed to examine the outcome of these agreements, especially over subsequent rounds of finance.

CONCLUSIONS

We provide an introduction to the special themed section of *JMS* on organizational interactions involving universities and firms that result in the commercialization of research and technology. We also developed a taxonomy of modes of commercialization consisting of internal approaches, quasi-internal approaches (e.g. incubators), university research parks, regional clusters, academic spin-offs and start-ups, licensing, contract research and consultancy, corporate venture capital, and open science and innovation. This taxonomy is important because different commercialization types require different ways of organizing.

We have also identified areas for additional research: at the individual level (e.g. heterogeneity of entrepreneurial teams and experience; incentives), organizational and intra-university level (e.g. corporate governance; nature of growth strategies; relationships with trading partners; boundary spanning activities), and technology levels (e.g. institutional context; reconfiguration of technology; valuation of technology). These areas constitute fertile ground for theoretical and empirical analyses relating to the opportunities and challenges involved in commercializing research and technology. The literature on this topic has progressed from descriptive, a theoretical, survey and case study based work to more conventional hypothesis testing (Rothaermel et al., 2007). The research questions we have identified, as well as the papers contained in this issue, demonstrate the need to integrate theoretical perspectives, such as traditional agency theory and corporate governance with a resource-based perspective in understanding organizational level issues and institutional, technology and strategy perspectives in understanding growth and technological reconfigurations.

For example, let us consider agency theory, which has recently been applied to university technology commercialization, i.e. to the technology transfer officer and the academic scientist (see Jensen et al., 2003; Markman et al., 2008). Principal agent models are based on what game theorists refer to as Bayesian rationality, meaning that an agent can assign a probability value to each uncertain event, and then attempt to maximize the expected value of his/her utility. It is also assumed that these probabilities are updated (according to Bayes' rule) when the agent receives new information. Recent developments in prospect theory could be useful because the theory can incorporate the concept of previous gains or losses into the models of choice (e.g. a faculty member's decision to license a technology or launch a new venture). Transactions cost theory could also be useful in the context of university technology commercialization, especially in terms of understanding the opportunity costs encountered by scientists and their teams, as well as the 'make or buy' decisions that universities and firms face. A contrasting theoretical perspective is provided by actor network theory. For example, this approach could be applied to understand the evolution from science to technology that can be commercialized, specifically in terms of the need for translation of the science through enrolling others to elaborate and iterate theoretical ideas (Alvesson et al., 2008; Latour, 1986).

Finally, from an empirical perspective, it is also clear that 'mixed methods' – combining quantitative and qualitative techniques; 'micro' and 'macro' data; presenting results at multiple levels of analysis; and longitudinal studies, sometimes over considerable periods of time (Echambi et al., 2006; Shah and Corley, 2006) – are both feasible and central to understanding of research and technology commercialization.

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