

Technology Commercialization: Have We Learned Anything?

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Abstract - Economic growth happens when innovation meets entrepreneurship. With the passage of the Bayh-Dole Act in 1980, universities were permitted to commercialize their federally funded research. But it was not until the mid-1990s that universities began in earnest to develop programs to facilitate commercialization and technology entrepreneurship. Despite this effort, today we still have not figured out how to best move more of our research into the market to benefit society. In fact, business struggles with many of the same issues as universities do. What have we learned? In this paper, I review the literature within the four domains of university entrepreneurship – 1) the entrepreneurial research university; 2) new firm creation, 3) productivity of technology transfer offices (TTOs), and 4) the environmental context in which these activities occur - and then offer an argument for a more integrated approach to understanding how universities and their researchers deal with the third mission: university entrepreneurship.

1. Introduction

One of the advantages of having spent many years in a field as an academic and a practitioner is the freedom to move beyond a very narrow research area to begin to look at where we have been and where we still need to go as a field, as researchers, and as educators who translate research into useful insights and practices from which our students and the business world can benefit. With this paper I attempt to provide that perspective and to highlight some ways we might better go about understanding the emerging field that focuses on the commercialization of technology from universities. Positioned within the broader field of entrepreneurship, technology commercialization has been variously called “technology entrepreneurship,” “technology transfer,” and “university entrepreneurship.” The common element among the four is technology, which is developed and brought to market through a variety of devices that include 1) commercialization via a startup, a license, or sale; 2) transfer via a license; or 3) entrepreneurship via a startup or corporate venture. However, the four terms are not entirely synonymous. For the purposes of this paper, I will use the term “university technology commercialization” (UTC) to signal that the focus is on technology that is commercialized out of a university using any one of the available mechanisms.

Another term of importance to this paper is “entrepreneurial university.” In the manner of Rothaermel et al. (2007), I have taken a fairly broad view of the term “entrepreneurial university” to include the various actors, activities, behaviors, policies, and structures that comprise today’s research university and which serve to define it as entrepreneurial or enterprising. In fact, we are talking about a commercialization system (the concept of system will be discussed in a later section) and, in that respect, I am differentiating entrepreneurial university from “university entrepreneurship,” which I see as those activities that produce technology transfer and spin-offs from the university in the form of new ventures and which can occur independently of a

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university being entrepreneurial. In their extensive review of the literature in the field of university entrepreneurship from 1982 – 2005, which included 178 articles in significant journals, Rothaermel et al. (2007) defined four major research streams that appear to dominate the field: 1) the entrepreneurial research university; 2) new firm creation, 3) productivity of technology transfer offices (TTOs), and 4) the environmental context in which these activities occur. I reviewed this literature and then, consulting the same major databases of journal articles (ABI/INFORM, Business Source Premier and Science Direct) for relevant key words, I reviewed the major journal articles in these four research streams from 2006 to the present.

In the following sections, I summarize the key literature and research themes within the four major streams, then offer an argument for a complex adaptive systems view of the UTC, followed by some suggestions for future research.

2. The Literature

This section reviews the four major research themes: 1) the entrepreneurial research university; 2) new firm creation; 3) productivity of technology transfer offices; and 4) the environmental context. I have focused on significant research that addresses the various sub-themes in each research stream.

2.1. Entrepreneurial Research University

The research stream that explores the concept of the entrepreneurial research university essentially appeared after the passage of the Bayh-Dole Act in 1980, so it is appropriate to consider the benefits and consequences of the act, which have produced the sub-themes included in the entrepreneurial research university stream. Prior to Bayh-Dole, the view of the university as having a mission beyond research and education was largely unknown and unexplored. The Bayh-Dole Act, which has been proclaimed in the popular press as “perhaps the most inspired legislation to be enacted in America over the past half century” (Innovation’s Golden Goose, 2002), permitted universities to own the technology they developed on Federal research grants and ultimately translate that research into goods and services that would benefit society (Aldridge and Audretsch, 2011). Ownership incentivized researchers to translate and commercialize their research and, in that capacity, it appears to have found some success. In fact, perhaps the first response to Bayh-Dole was for universities to establish technology transfer offices (TTOs) to manage the patent and licensing process (Feldman et al., 2002). In 1980, there were 25 organized technology transfer offices, and that number grew to 230 by 2004. Between 1996 and 2007, nonprofit institutions reported that faculty doubled their invention disclosures from 67.1 per institution to 131.1, while new patent applications grew from 23.2 per institution to 77.6 per institution. In the same period, licensing income more than tripled and nearly doubled as a percentage of research expenditures to 4.31% (Thursby and Thursby, 2011a).

In 2006, U.S. academic institutions accounted for 56 percent of all the basic research conducted as they spent approximately \$48 billion on R&D (National Science Board, 2008). This research accounts for a considerable amount of impact on the national economy, principally through knowledge spillover activities such as publications, consulting, and license agreements.

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Knowledge spillovers traditionally had been the primary means of knowledge and technology transfer; however, recently licensing has become a more prominent mode of transfer.

For all the benefits of Bayh-Dole, a number of unintended consequences came out of the act as well. Jensen and Thursby (2001) identified a moral hazard for the inventor in that university research is generally so embryonic that it requires further development beyond the capabilities and resources of the university inventor. As a result, the inventor is dependent on the licensee to effectively commercialize the technology and appropriate a return on his research.

A number of studies have addressed the issue of “brain drain” as a result of Bayh-Dole. Because the act precipitated a convergence of scientific opportunity and commercial opportunity, there is increasing evidence to support the movement of academic scientists away from the university (Dasgupta and David, 1994; Stephan, 1996; Powell and Owen-Smith, 1998; Stuart and Ding, 2006; Toole and Czarnitzki, 2010). Audretsch and Stephan (1999) found that many life scientists chose to be employed by large firms in order to commercialize their research. Similarly, the research on star scientists and the migration to industry indicates a definite movement toward industry, particularly in the biotech field (Merton, 1973; Zucker and Darby, 1997; Higgins et al., 2011; Hess and Rothaermel, 2012). This “brain drain” is troublesome for universities and may indicate that at least in the life sciences academic knowledge accumulation is being traded in favor of commercialization activities. Some research has found that a significant portion of the benefit from translating basic research comes from those very scientists who migrate from the university to industry (Zellner, 2003). Moreover, since 2002, basic research productivity at universities has flattened while applied research productivity is growing (National Science Board, 2008) which speaks to the question of whether the profit motive has driven away the desire to do research for research’s sake. Providing an alternative view, Thursby and Thursby (2011b) recently discovered that where licensing income is involved, both basic and applied research increase with applied research increasing at a higher rate. Thursby et al.’s earlier work (2007) had considered faculty choices about basic versus applied research regardless of incentives using the Pasteur’s Quadrant where “curiosity-driven research has immediate commercialization applications” (p.583.). This work suggested that basic and applied research are complementary, with the former typically preceding the latter. While addressing the issue of a scientist’s primary Mertonian responsibilities to do research, their evidence found that invention disclosures were increasing while research productivity remained relatively flat.

2.2. The Role of the University

The passage of Bayh-Dole has prompted universities to reconsider their role in society. Traditionally, that role has been two-pronged: research and education. But since 1980, the literature increasingly talks about new roles such as the “triple helix,” (Etzkowitz et al., 2000) and the “third mission” (Etzkowitz and Leydesdorff, 1998) where the boundaries between public and private innovation efforts are blurred and where economic and societal roles overlap. The entrepreneurial economy, as modeled by Audretsch and Thurik (2001), makes knowledge important to economic growth and entrepreneurship a catalyst of economic growth. Knowledge has also been the basis for what some research has defined as the four missions of the university (Krimsky, 2003): 1) knowledge as virtue, 2) knowledge as productive, 3) knowledge in the service of defense, and 4) knowledge in the service of public interests.

The three most prominent models that describe and debate the transforming role of the university are 1) “Academic Capitalism” (Slaughter & Leslie, 1997), which focuses on the market behavior of universities including consulting, patenting, licensing, and entrepreneurship; 2) the “Enterprise University” (Marginson & Considine, 2000), which looks at the transformation of university governance to executive control with business values embedded and a focus on income generation through public-private arrangements; and 3) the “Entrepreneurial University” (Etzkowitz, 1983, 2004), which takes the more extreme approach of making economic development activities the third mission of the university along with research and education.

As an increasing amount of research examines this third mission, some studies argue that the functions, structure, and policies of the university are not aligned to an entrepreneurial university strategy that incorporates the three missions (Laredo, 2007).

2.3. University Policies

One policy signal that a university is entrepreneurial is the way it aligns itself with its commercialization research goals through its claims on future revenue streams from licensing to large companies and smaller entrepreneurial startups (Feldman et al., 2002). For a university, technology transfer has a number of important goals: 1) faculty retention through incentives and rewards for innovation and commercialization efforts; 2) enhanced university-industry partnerships that might increase university resources; and 3) prestige from demonstrating the effectiveness of the university’s efforts vis-à-vis knowledge transfer (Thursby et al., 2001).

The literature is conflicted regarding the influence of university policies on technology commercialization. Policy discussions tend to center on insuring that commercialization efforts are supported, while also addressing the risk that faculty’s research topics have been shifting toward the interests of industry (Thursby et al., 2001). Mowery et al. (2005) suggests that the contemporary university’s focus on patenting and licensing as the third mission may be misplaced or, at least, should not be accorded the emphasis it has been given. A number of field studies (Link et al., 2003 and Thursby and Thursby, 2002), in addition to case studies (Bercovitz and Feldman, 2006), identify informal approaches to commercialization that seem to ignore university policy. Shane (2004, p.4), for example, has pointed to the number of research scientists who avoid the TTO in favor of the “back door” or more informal approaches to commercialization. Some of these more informal approaches also include trade secrets or spin-offs that do not involve patents. However, other studies (Radosevich, 1995) have asserted that university policies with inadequate incentives serve to keep researchers from participating in commercialization activities at all.

An important area of research on university policies related to the third mission focuses on funding of R&D. A number of studies speak about the importance of these resources to the commercialization process (Mansfield and Lee, 1996; Flynn, 1993), concluding that universities that enjoy greater R&D resources should be expected to generate more licenses at higher valuations. And, in fact, several studies have supported the ability of federal R&D resources to predict technology transfer performance at those institutions that secured them (Faulkner and Senker, 1994; Mansfield, 1995).

2.4. Academic Scientists: Motivation, Intent and Social Capital

One of the ongoing debates around the third mission of the university is whether the university risks losing the unique incentive system it has had, which has produced knowledge for the public

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good. The literature on social theories of action began with Merton (1973), who asserted that the “institutional norms that exert pressure upon scientists,” rather than the scientist’s personal characteristics, determine the public-good activities the scientist undertakes. (p. 293). Earlier in his career, Merton had described four institutional imperatives for modern science: 1) universalism (anyone can contribute); 2) communism (scientific results benefit all); 3) disinterestedness (scientists act for the benefit of science rather than personal gain); and 4) organized skepticism (science must be exposed to critical scrutiny). However, a number of subsequent studies have refuted this notion, claiming that it is difficult to gauge the diversity of thought, intent, and motivation among scientists because these factors are concealed by institutional norms (Lam, 2010; Bercovitz and Feldman, 2008). Neoclassical economic theory about rational choice contends that rational actors are motivated to act based on preferences, which are generally determined by price and other economic incentives. Glenna et al. (2007, 2011) argue that both Mertonian and neoclassical economic theories simplify the complexity of the situation and ignore individual values, suggesting that more focus needs to be placed on the individual values of scientists.

A number of studies have focused on whether the quality of research is damaged when scientists take on commercialization activities where the research demanded by the market does not require a pioneering effort (Trajtenberg et al., 1997). However, other studies find that relationships with industry enhance the probability of new basic research and that patenting activity augments publication outcomes and quality (VanLooy et al., 2006; Czarnitzki et al., 2007; Breschi et al., 2007; Welsh et al., 2008; Azoulay et al., 2009). However, Azoulay et al. (2007) did caution that the acceptance of patenting activities by universities could influence a shift toward more commercially based research topics. The correlation between publishing and patenting has been investigated by a number of researchers all arriving at positive correlations (Goktepe-Hulten and Mahagaonkar, 2010; Stephan et al., 2007; Breschi et al., 2007; Agrawal and Henderson, 2002).

Several studies have demonstrated a trend of faculty participating in startups and on corporate boards, which often creates conflicts with their primary research responsibilities (Boyd et al., 2003). Thursby and Thursby (2002) conducted a longitudinal study of faculty at six major research universities over two decades and found that the probability of the faculty member disclosing an invention increased by a factor of 10, while their research productivity remained constant. They also found that, in general, faculty members devoted more time to research early in their careers and that licensing incentives resulted in a higher ratio of applied research to basic research. The work of Lam (2011), which draws on theories of motivation in social psychology, finds that there are multiple motives influencing the commercialization behavior of scientists. Lam describes the reward system as “gold” or financial rewards, “ribbon” or reputational rewards, and “puzzle” or satisfaction rewards and finds that the vast majority of scientists find their motivation in reputational rewards, even in their commercial pursuits (Lam, 2011, p.1365). Intrinsic motivation seems to play an important role in the decisions scientists make and it can take a number of forms: pro-social motivation (Grant, 2008), enjoyment based (Lindenberg, 2001), and charismatic based (Gustin, 1973). This line of research attempts to provide a theoretical explanation for the heterogeneity of scientific motivation found in the literature (Shinn and Lamy, 2006; Markman et al., 2008).

Bercovitz and Feldman (2008) uncovered a motivating factor in the context in which the individual was working, claiming that a researcher was more likely to participate in commercialization activities at institutions that supported and rewarded that activity and if their department chair was involved in technology transfer. However, simply having a technology transfer activity on campus does not motivate faculty, who consider funds for sponsored research more important as a motivator than licensing income (Thursby et al., 2007). Recent research has

emphasized the activity of patenting as more of a motivator than licensing income because it signals the novelty of the faculty member's invention (Owen-Smith and Powell, 2001) and it is seen as professionally satisfying (Gulbrandsen, 2005; Baldini et al., 2007). However, Etzkowitz (1998) and Slaughter and Leslie (1997) found that where universities provided valuable incentives to patent in the form of equity or a significant royalty stream, scientists were motivated to patent.

Another important stream of research within the motivation area is that associated with the scientist life cycle and how age and career status might affect the motivation to commercialize research. The findings relative to scientists seem to be very different from those in the entrepreneurship literature relative to the likelihood of someone becoming an entrepreneur. Entrepreneurship literature generally finds a negative correlation between age and the likelihood of becoming an entrepreneur; however, the empirical work of Levin and Stephan (1991) found that a scientist's age is positively correlated with the likelihood of becoming an entrepreneur. This is explained by the fact that early in a scientist's career, he or she is incentivized to focus on research that will enhance his or her reputation. Once that reputation has been established, the scientist is freed to consider the returns on the investment in research. The concept of the scientist life cycle is consistent with studies on entrepreneurial intentions where the ability to recognize opportunities may increase over the life cycle (Wright et al., 2006; and Ajzen, 1991). Thursby and Thursby (2002) also looked at the effects of life cycle on the propensity to enter into commercialization activities and their work concurs with that of Levin and Stephan (1991).

Social capital is about the linkages and interactions that scientists have with others in their network, and the theoretical bases for social capital come out of endogenous growth theory, which speaks to the accumulation of knowledge that complements economic growth (Romer, 1986, 1990; Lucas, 1988). Within the entrepreneurship field, a robust stream of research has considered the link between social capital and entrepreneurship (Mosey and Wright, 2007; Shane and Stuart, 2002; Davidsson and Honig, 2003). Thursby and Thursby (2002) have extended this research to look at knowledge spillovers that help scientists understand how their research can be commercialized. Knowledge Spillover Theory (Acs et al., 2004) proposes that new knowledge is commercialized via entrepreneurship when 1) scientists can see the personal benefits to engaging in commercialization; 2) when they can identify the commercial value of their research; and 3) when outsiders demonstrate the value by investing in the knowledge. The Aldridge and Audretsch (2010) study of recipients of National Cancer Institute funding tested this thinking by empirically studying scientists at the individual level rather than using responses from tech transfer office and the universities. They found that approximately one in four scientists had engaged in entrepreneurial activity and that personal characteristics and human capital were not significant factors in the decision to become an entrepreneur. Rather, social capital in the form of linkages to industry increased the chances that a scientist would become an entrepreneur.

2.5. New Firm Creation

Research-based spinouts (RBSOs) from universities have enjoyed growing attention by researchers and, unlike many other areas of research, there appears to be agreement on the elements that compose the definition of an RBSO. Those elements fall into three categories: the outcome, what is transferred, and the stakeholders involved. As to the outcome of an RBSO, the literature agrees that it is firm formation (Carayannis, et al., 1998; Klofsten & Dylan, 2000; Djokovic et al., 2008). In terms of what is transferred to the RSBO, it is essentially technology and/or people. Technology can be a legally protected entity such as a patent or research that may have been developed within the university (Pirnay et al., 2003). As for people, the new RSBO may be founded by the university researchers who are licensing their technology from the

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university to develop it within the startup (Smilor et al., 1990), or the firm may be founded by surrogate entrepreneurs who did not invent the technology but rather acquired the rights to the technology from the university (Radosevich, 1995). In the first case, research has found that generally the research faculty who invented the technology remain involved in all facets of the RBSO (Feldman et al., 2002) and are able to insure the transfer of relevant tacit knowledge to the RBSO (Santoro and Bierly, 2006), which is particularly important when the invention is pioneering in nature.

The stakeholders in the RBSO are the university, the technology inventor, the individual who develops the technology to the point at which it can be transferred, the entrepreneur who forms the new firm, and the investors who fund the new venture (Roberts and Malone, 1996). Problems occur when stakeholders have conflicting objectives as to resources committed and the type of venture to create (Clarysse et al., 2005). Stakeholders must decide whether to license the technology to an existing firm or to launch an RBSO, a difficult decision when the stakeholders have diverse views regarding the correct vehicle for commercialization. For example, the university may view a license to an established firm as a lower risk option while holding equity in a new firm is generally very risky. In addition, because new firms require substantial funding and human capital over a long period of time, it becomes difficult to maintain the interest and motivation of the original research faculty (Nicolaou and Birley, 2003). Given that innovations can be incremental improvements in existing technology or disruptive and pioneering (Zander and Kogut, 1995), spin-offs may be more appropriate for radical innovations while licensing is preferred for incremental innovations.

Whether a new firm is formed as a result of an RBSO is a function of industry-level and individual-level influences. When industries are in the early stages of the life cycle with no dominant players and with many entrepreneurial firms that are not R&D intensive requiring complementary assets, there is a higher likelihood that a new firm will be formed (Audretsch, 1995). At an individual level, the argument is that individuals who have experience starting businesses (Carroll and Mosakowski, 1987), have higher needs for achievement (Roberts, 1991), and are risk and ambiguity tolerant (Begley and Boyd, 1987) are more predisposed to launch a new business. Shane's work (2001) found that four factors seem to influence the chance that an invention will be commercialized through an RBSO: 1) when the technology field is young, 2) when the market is segmented, 3) where patents are effective, and 4) where complementary assets are not necessarily important. Other explanations for the likelihood of spin-offs from the university are proximity to the university (Shane and Stuart, 2002), access to capital (Florida and Kenney, 1988), and a regional innovation network (Saxenian, 1994).

2.6. Technology Transfer and the TTO

The third major research stream is in the area of technology transfer productivity, specifically as it relates to patents and their relationship to commercialization, technology transfer offices and productivity, and appropriating returns from licensing. Rogers, et al. (2001) have identified five types of technology transfer vehicles: spin-offs, licensing, meetings, publications, and cooperative R&D arrangements. Of these the greatest commercialization value comes from spin-offs and licensing.

The TTOs are the clearest indicators of the effectiveness of Bayh-Dole, and a growing body of research is looking at the impact of TTOs on the commercialization process at universities (Lockett et al., 2003; Breznitz et al., 2008; Phan et al., 2005; Siegel et al., 2007). Most of these studies find that TTOs have been successful in facilitating technology transfer. In fact, one of the key reasons for developing a TTO is to smooth the path to market for researchers (Colombo and

Delmastro, 2002). However, the Association of University Technology Managers (AUTM) provides data that suggests that TTOs have not been as effective as is thought to be true. For example, an AUTM survey of the period between 1995 and 2004 determined that university licensing activity generated only 1.7% of total research expenditures in revenue. In 2004, it was 2.9%. One explanation for the disappointing results was captured in a 2006 survey that found that more than 26% of inventions did not get processed by the TTOs due to lack of capacity: too few staff. Research supports these assertions, finding that most TTOs lack the resources and competencies required to effectively and efficiently process invention disclosures and subsequent patent and licensing activity (Owen-Smith and Powell, 2001b). In fact, the distribution of licensing revenues is highly skewed in a “winner-take-all” pattern that has very few universities appropriating the largest returns (Dechenaux et al., 2008). Examples are Stanford’s Cohen-Boyer gene splicing technology, University of Florida’s Gatorade, and Michigan State’s Cisplatin. On the startup side, the picture is not much brighter. AUTM reported an average of 426 startups per year from 1998 to 2004 across all reporting U.S. universities, which was disappointing considering the investment by federal granting agencies (Aldridge and Audretsch, 2011). One explanation may be that TTOs are not charged with tracking startups and therefore relying on TTO data will likely understate the actual number of startups. Furthermore, commercialization of technology does not always involve the TTO (Thursby and Thursby, 2005; Mosey and Wright, 2007) because either the technology is protected by trade secrets and knowhow or the inventor commercializes via a back-door approach, circumventing the university (Shane, 2004).

The TTO is not seen favorably by industry. The work of Thursby and Thursby (2000) found that only 66% of the business entities they surveyed had licensed intellectual property from a university, principally because 1) the technology was embryonic; 2) the technology was not in a related business line; 3) the university refused to transfer the technology; 4) policies regarding delaying publication were too strict; and 5) their concerns about their ability to get the cooperation of the relevant faculty researchers.

An important question that has received some attention is whether patents are an essential part of commercialization. One recent study (Webster and Jensen, 2011) looked at 3,162 inventions for which patent applications had been made and found that only about 40 percent of them actually went to a product launch and mass production. They further determined that the patent grant did not increase the chances of commercialization, but a rejected patent reduced the probability that the technology would be commercialized. Patents do appear to reduce the problem of adverse selection through the disclosure process, and they serve to minimize moral hazard because certain details regarding the quality of the patent are shared in the transfer. Patents also minimize the problem of hold-up because the actual patents incorporate specifics that make contracts more complete and less subject to prolonged negotiation (Shane, 2002; Dechenaux et al., 2011).

Licensing creates a complex set of strategic decisions. Both the university and the inventing parties take on risk by licensing because, depending on the structure of the agreement, the licensee can opt to commercialize, drop the license, or delay commercialization (Dechenaux et al., 2008). But who is taking on the greater risk, the university or the licensee? From the perspective of the firm, if lead time is important, then the firm is best served by delaying commercialization unless the technology under consideration is an embryonic invention that benefits from learning (p. 905). From the perspective of the TTO, a real options approach might be more effective to account for the complexity of the decisions available. There may be cases where delaying commercialization is called for, and, at a minimum, the right strategy is affected by the line of business (Gans et al., 2003). Where patents are strong and have intrinsic value, the TTO can choose not to cancel the license if the technology is not commercialized, because it can still appropriate returns through royalties on the patents.

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The type of licensing agreement is important to the university's ability to appropriate returns from licensing. An empirical study by van den Berghe and Guild (2008) of 66 technology transfer projects out of the information and communications technology industry indicated that when the invention is new to the licensing firm or new to the market, the form of licensing agreement is typically exclusive, which is beneficial to the firm but less so to the university. In an exclusive agreement, the university is dependent on the success of a single licensee and therefore has no reasonable way to mitigate the risk that the licensee does not perform.

The number of universities including equity in their licensing agreements has grown significantly. By 2000, 70% of technology managers responding to a survey reported having taken equity in companies that licensed their technology (Feldman et al., 2002). Several advantages accrue to universities that take equity: the university receives options on the licensing company's future revenue streams, which helps it deal with the inherent uncertainty of commercialization; equity aligns the commercializing firm with the university's goal of commercializing the technology; and taking equity signals to the market that the university is entrepreneurial (Feldman et al., 2002).

Making decisions about invention commercialization is an area that has received some attention, although most of the focus has been on work conducted on MIT-licensed patents. Nevertheless, it does provide a window into the determinants of invention commercialization, which is a critical decision that universities must make. The work of Nerkar and Shane (2007) focused on the ability of firms to appropriate returns from the inventions they commercialize. Shane's prior work (2001) had found three attributes that influence appropriability through a spinoff: 1) the patent scope or breadth of protection, which makes imitation more difficult; 2) the pioneering nature of the invention, which offers possibilities for disruption and for taking advantage of the learning curve and lead time; and 3) the importance of the patent.

One line of research has explored the effect of institutional prestige on the effectiveness of licensing where prestige is related to the quality of past and present inventions (Sine et al., 2003). In this study, the researchers controlled for the volume of technology produced, the sources of research funding, the presence or absence of a medical school, the location, and the TTO resources. They found that under conditions of uncertainty, prestige will influence the decision to license. This is congruent with research in the area of the sociology of technology (Podolny and Stuart, 1995), which found that the likelihood of technology transfer was explained by attributes beyond technical ones, and with Allen (1984), who found that the perception of prestige becomes embedded in the perception of a university and serves to signal future invention quality.

2.7. Environmental Context

The research in the fourth stream, the environmental context for commercialization, comprises the studies focused on research and science parks, incubators, innovation networks, and regional clusters. These elements represent the external factors that influence the commercialization of technology from universities. Researchers in this area have identified four primary factors that affect university entrepreneurship: 1) innovation networks, 2) science parks, 3) incubators, and 4) geographic location, and they agree that "university entrepreneurship is a result of being embedded in networks of innovation, which in turn are influenced by the larger environment" (Rothaermel et al., 2007, p.75).

Innovation networks have been studied both from the perspective of the entrepreneur or the entrepreneurial venture and from the perspective of the network as a system, although fewer

studies take the systems approach. More recent studies have focused on regional innovation networks and clusters, often to support economic development initiatives (Schoonmaker and Carayannis, 2010). Cooke (2004) looked at Silicon Valley and found that the essential elements of a regional cluster were “1) basic research, knowledge generation, and application capabilities, 2) venture capital funding and other support services, and 3) a local value chain.” In general, the clusters contained related technologies and were supported by knowledge, expertise, personnel, and resources.

Innovation networks or ecosystems represent the intersection between entrepreneurship and regional economic development and the theory supporting them has come from population ecology and institutional theory (Zacharakis et al., 2003; Neck et al., 1999) and the economic ecosystem research of Moore (1993). Innovation networks have been found to have numerous benefits that are supported by research findings. Innovation collaboration, particularly in the biotechnology industry, has received a lot of attention (Liebeskind et al., 1996). Risk sharing and gaining access to new markets and technologies, pooling complementary assets (Hagedoorn and Duysters, 2002), and firm survival have all been addressed. Innovation networks foster both informal and formal collaborations, and consist of everything from facility sharing to knowledge exchange in the form of joint projects (Zucker et al., 2002; Lindelöf and Löfsten, 2005). Although research, such as that of Zucker and Darby (2001), points to the positive effects of networks on R&D output, some research (Lindelöf and Löfsten, 2005) has found the opposite. Further research in this area will need to be conducted before any definitive conclusions can be drawn.

The research on science parks attempts to address issues related to the role of the university and the impact of a science park on the ability of a university to commercialize its research. In addition to the literature coming out of entrepreneurship and business in this area, there is also a related stream of research on economic development that looks that the impact of research or technology clusters on regional economic growth (Swann et al., 1998; Porter, 2001a, b). Studies have discovered various factors that seem to lead to higher performance of science parks, such as founder motivation, collaborative agreements, and the strength of associated networks (Westhead and Storey, 1995; Lindelöf and Löfsten, 2005); however, much like the research on innovation networks, research on the impact of science parks has been both limited and inconclusive.

Much more research has been devoted to the study of university technology business incubators (UTBI) and their impact on new venture creation and performance (Mian, 1996). These studies have looked at the factors that enhance the incubation process, including the flow of new ideas, creation and maintenance of networks, and the exit strategy for incubator companies (Patton et al., 2009). Some research has taken a resource-based perspective, finding that incubators add to the resource stock of a new venture without subjecting the venture to substantial costs (Rothaermel and Thursby, 2005; Carayannis et al., 2006). Others have noted that the university itself becomes a resource to the incubatees, potentially providing technical expertise and the latest knowledge (Zucker et al., 2002) and access to students as interns and future employees. Some of the tangible benefits of incubators that have been studied include enhancing the commercialization of research (Zucker et al., 2002) and the technology transfer and subsequent income opportunity benefits (Thursby et al., 2001; Shane, 2002). However, the impact of context on incubators has received less attention, which is surprising given that incubators create proximity between new ventures and facilitate the development of social networks, which have been found to be significant for firm survival and growth (Uzzi, 1997). Some research has looked at the implications of the funding source for the incubator, suggesting that it determines the performance outcomes of the ventures in the incubator (Hannon and Chaplin, 2000). University incubators exist to promote technology transfer, while government-funded incubators seek economic development goals, and private sector incubators tend to seek a return on investment to

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their funders. In this regard, some studies conclude that private sector incubators are more aligned with rapid market entry and the creation of value (Barrow, 2001; Hannon and Chaplin, 2003).

McAdam and Marlow (2007) caution that proximity of firms in an incubator can also be the source of threats to intellectual property rights and that the complexity of the relationship between the academic and business community can also be a source of ongoing tension.

One final area of study relative to the environmental context is the geographic location of the university relative to the research/science park or UTBI. Some researchers have looked at the effect of a university being located within a regional technology cluster (Audretsch and Stephan, 1996). The proximity of startup firms to a university has been found to be based on the need to transfer tacit knowledge (Audretsch and Stephan, 1996) and to be more competitive (Lindelöf and Löfsten, 2004).

In the area of the contextual environment for commercialization, it should be noted that most studies on technology entrepreneurship have been conducted in the United States and in certain European countries. Within this group, very few studies compare commercialization activities and practices across countries (Etzkowitz et al., 2000; Klofsten and Jones-Evans, 2000; Owen-Smith et al., 2002; Mowery and Sampat, 2005). As a consequence, it is difficult to extrapolate from current findings to other countries, particularly in the case of emerging economies. It seems logical to postulate that local context influences the commercialization activities and strategies that universities undertake, but to date, we have no clear sense of how important that impact is and how it might affect the design of commercialization activities. We are beginning to see research emerging from other parts of the world as these countries begin to reflect on their unique experiences (Upadhyay et al., 2010; Martínez-Cañas and Ruíz-Palomino, 2011), so it is likely that there will be further interest in doing comparison studies for the purpose of better understanding these differences.

3. An Argument for a Complex Adaptive System View

All research must strike a balance between a focus narrow enough to be able to control as many variables as possible but broad enough in scope to be relevant and not fail to include critical moderating variables. In the literature related to UTC, we find that, much like any emerging industry, the field is littered with many competing concepts that provide small insights into the nature of the field but rarely from the perspective of theory. Universities, which for centuries operated free of the lens of economic policy, today find themselves to be the focus of what has become the knowledge economy. They are now expected to drive innovation, regional growth, and competitiveness. This third mission has been the driving force behind the uptick in research on universities and technology transfer, but that research has largely been atheoretical (Nelles and Vorley, 2011), which is not surprising considering the theory issue still plagues the broader field of entrepreneurship as well. Busenitz et al., (2003) assert that one reason the field has struggled to achieve true legitimacy with its counterparts in strategy and management is that it lacks unifying ontological and epistemological paradigms.

Nelles and Vorley (2011) have attempted to develop a conceptual framework to bring “theoretical development to the study of the entrepreneurial university and university entrepreneurship” (2011, p. 345). They argue that to leverage the third stream contribution of universities, we must understand the basis for internal institutional productivity “irrespective of context” (2011, p.345). Given that universities operate in diverse policy environments, are embedded in regional

economies, and, as a result, have developed unique capabilities and resources, it would be important to understand how any university can more effectively respond to its third mission. They have proposed that the architectural metaphor is useful in framing the institutional approach to the Third mission. The architectural concept actually began in the literature on corporate entrepreneurship (Burns, 2005), but the five elements of the framework work well with the concept of university entrepreneurship: 1) structures, 2) systems, 3) strategies, 4) leadership, and 5) culture. All five are required to effectively implement the third stream mission. While each of these elements has been studied independently in some manner, research has not to date integrated them into a complete picture that addresses their recursive relationship. In their paper, which fully develops the concept of entrepreneurial architecture, Nelles and Vorley (2011) make a compelling case, asserting that “successful appropriation to the third mission depends on the degree to which entrepreneurial architectures are embedded and consolidated within contemporary universities” (p.347). They propose that their framework addresses the research gap between university entrepreneurship (technology transfer and commercialization *from* the university) and the entrepreneurial university (the institutional ideology incorporating education, research, and economic purposes). The advantage of aggregating the many variables that are included within the five elements of the entrepreneurial architecture is the possibility of achieving holistic theory-building about organizational transformation and adaptation. Nelles and Vorley’s (2011) approach is useful, but it does not take advantage of the existence of a theory base relative to systems that might accomplish, perhaps more effectively, what they are proposing with their framework.

I propose that taking a complex systems theory (CST) view of UTC may be a more effective way to account for the interdependencies within the entrepreneurial architecture of a university and to explore the underlying forces within the system. This approach would also facilitate comparisons across different universities and enable the study of how these systems evolve over time. Too frequently, the research on UTC has focused on narrow topics such as those covered within the four domains that Rothaermel et al. (2007) identified without considering the interrelationship of those domains with other elements in the broader system. The problem is that the results of a domain-specific research do not account for the interdependency with other heterogeneous and autonomous parts of the system and, therefore, cannot be completely explained. Furthermore, the tendency to reduce a very complex process to a more simplified form so that it can be studied empirically loses valuable information that might adversely affect the outcome. CST actually includes all of Nelles and Vorley’s five elements but raises the system element to overarching importance and subsumes structures, strategies, leadership, and culture under it.

In proposing a complex systems view of UTC, I am not claiming that either systems theory or complexity theory is the grand unified theory that explains everything, nor am I suggesting that a theory that would predict how any complex system would respond in any given situation is the goal. I agree with Cohen (1999) that, at a minimum, a framework is needed so that researchers can determine the right questions to ask and how these questions might be interrelated. What I am proposing is that we cannot understand how successful universities are at achieving the third mission if we do not have a clear understanding of how all the components in the system work together to produce or inhibit a desired outcome.

Management science’s view of the organization evolved from a mechanistic perspective to a more holistic, systems perspective decades ago (Katz and Kahn, 1966; Stacey, 1995; McKelvey, 1997, 1999; Cohen, 1999). The systems perspective defines an organization as a socio-cultural unit with multiple interrelationships that create complexity (Gharajedaghi, 2006). This firm-level system is able to self-organize in order to adapt to change and to restructure itself appropriately in new situations to achieve its outcomes (Boland et al., 2006). Complex systems theory (CST) is a

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multidisciplinary field that looks at many of the same issues as systems theory, such as the emergence of new forms and patterns that occur naturally within the system as well as the dynamics of adaptation and evolution. However, CST, rather than a unifying theory, is a way to conceptualize and model dynamic systems (Morel and Ramanujam, 1999). Large complex systems are generally composed of a great number of elements that interact by way of feedback mechanisms. These elements can be anything from machines to people, but it is the behavior of these elements as they interact that produces patterns or “emergent properties” that are observable and verifiable. The environments in which these systems operate are largely not predictable and they evolve over time.

The paradigms typically associated with complex systems are emergence and complexity (as noted previously); self-organization, which implies unplanned creation resulting from the system’s internal dynamics; path dependence, which addresses legacy behaviors and contingencies; operational closure and thermodynamic openness, which suggests mutual exchange between the internal environment of the system and the external environment (Bertschinger et al., 2006); and co-evolution, which addresses the continual adaptation of the autonomous components of the system to environmental stimuli (Anderson, 1999; Lewin and Volberda, 1999; Volberda and Lewin, 2003).

Complex adaptive systems are simply a subset of the larger theory on complex systems and are useful to apply to systems that are evolving in uncertain environments such as the UTC. In a world where knowledge and the rate of technological change are growing exponentially, uncertainty is an inherent aspect of complex adaptive systems, so a CAS approach is particularly appropriate for dealing with environmental uncertainty, whether endogenous or exogenous. An additional advantage of the CAS approach is that it considers both the whole and the individual parts as autonomous but co-existing within the system (McKelvey, 1999). In this respect, a CAS approach should facilitate a better understanding of inter-organizational networks, which are an important element of UTC.

Taking the CAS perspective, it is fairly easy to see how the activities embedded in the university technology transfer and commercialization process, if viewed together, qualify as a CAS. (See Table 1).

Today it is much easier to look at complex adaptive systems because of the benefit of computer models and simulations, which have triggered more research on systems and their context. As the body of work on CAS grows and is critiqued by scholars, we have the potential to unlock additional insights into the university technology transfer and commercialization system that can be shared with researchers and practitioners in the form of best practices.

Table 1. The CAS Attributes of University Technology Transfer and Commercialization

CAS Attribute	UTC Manifestation
Environmental Uncertainty	Inability to predict the external environment or the outcomes of technology transfer efforts
Autonomous but interdependent components	Multiple organizations within and outside the university that perform specific functions of the process
Emergent	New institutional forms, behaviors, and outcomes develop as a result of stimuli from the internal and external environments and collective behavior
Self-organizing	Unplanned creation of activities resulting from internal stimuli such as learning, improvement, and process variation
Complexity	Multiple, non-linear inputs and outputs that co-evolve over time
Path dependence	Legacy policies, behaviors, and other stimuli embedded in the process
Operational openness and closure	The need to engage in mutual exchange of resources, knowledge, and capabilities that are both open and closed between the university and the external environment to achieve its goals

4. Future Research

One of the benefits of reviewing the literature on UTC is that it offers some insights into where we should place our research efforts going forward. Entrepreneurs find opportunity in unserved or underserved niches that often turn into major markets at some point in the future. The same can be said of research niches. In the previous section, I presented a major call for research at the systems level; however, in an effort to provide some possibilities for areas of research that would contribute to our understanding of the field, here are some further suggestions.

- What does it take to move an institution from university entrepreneurship to an entrepreneurial university? We need a more systemic understanding of the phenomenon.
- We currently lack a coherent theoretical framework within which to evaluate university responses to the imperatives of the third mission (Nelles and Vorley, 2011).
- We need a better understanding of the inefficiency of the IP market for technology transfer. Some of the contributing factors include the difficulty of valuing intangible

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- assets, the requirement for complementary assets, the embryonic stage and low quality of university patents, and issues of adverse selection, moral hazard and hold-up.
- What is the role of surrogate entrepreneurs in successful university spin-outs?
 - How do R&D network activities differ in their impact on a firm's R&D output?
 - How effective are various types of linkages a firm can utilize to connect and collaborate with a university technology transfer system?
 - More studies are needed that compare or contrast university commercialization activities across countries and regions. The majority of the research is still U.S.-based.
 - Are there intrinsic motivators for scientists to become engaged in commercialization activities? This would contribute to our limited understanding of what motivates scientists.
 - We need longitudinal studies on the evolution of role identity over the course of a scientific career. Does a new academic philosophy that perhaps combines Mertonian and entrepreneurial norms become the new normal for the scientist over the course of a career?
 - What are the effects of institutional prestige on a university's ability to transfer its technology?
 - We need a better understanding of why university inventions generally fail to produce income.
 - What are the post-graduation success rates from technology incubators?
 - What role can real options reasoning play in providing architectural resilience in the system and enhance decision making? (Madni and Allen, 2011)

All indications are that the activities and organizations involved in university entrepreneurship and its desired outcome, the “entrepreneurial university,” represent a complex system that adapts to uncertainty in ways that we don't fully understand. As such, a more integrated approach to studying this system should offer a rich opportunity for research that will advance the field and provide guidance to universities as they grapple to fulfill the third mission.

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