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Abstract

We review and synthesize the burgeoning literature on institutions and agents engaged in the commercialization of university-based intellectual property. These studies indicate that institutional incentives and organizational practices both play an important role in enhancing the effectiveness of technology transfer. We conclude that university technology transfer should be considered from a strategic perspective. Institutions that choose to stress the entrepreneurial dimension of technology transfer need to address skill deficiencies in technology transfer offices (TTOs), reward systems that are inconsistent with enhanced entrepreneurial activity, and education/training for faculty members, post-docs, and graduate students relating to interactions with entrepreneurs. Business schools at these universities can play a major role in addressing these skill and educational deficiencies, through the delivery of targeted programs to technology licensing officers and members of the campus community wishing to launch startup firms.

JEL classification: M13 ; D24; L31; O31; O32

Keywords: University technology transfer, entrepreneurship, technology transfer offices, science parks

I. INTRODUCTION

Universities are increasingly being viewed by policymakers as engines of economic growth, via the commercialization of intellectual property through technology transfer. Indeed recent research suggests that many research universities have adopted formal mission statements regarding the role and importance of technology transfer (Markman, Phan, Balkin and Gianiodis, 2005). The primary commercial mechanisms of university technology transfer are licensing agreements, research joint ventures, and university-based startups. Such activities can also lead to financial gains for the university and other non-pecuniary benefits. As a result, many research institutions are searching for ways to maximize the "efficiency" of technology transfer.

Unfortunately, formal management of an intellectual property portfolio is still a relatively new phenomenon for many universities. This has led to considerable uncertainty among administrators regarding optimal organizational practices relating to inventor incentives, technology transfer "pricing," legal issues, strategic objectives, and measurement and monitoring mechanisms. We contend that the productivity of technology transfer is ultimately determined by the competencies of university scientists, entrepreneurs, technology transfer officers and other university administrators and their incentives to engage in entrepreneurial activities. The purpose of this paper is to explore the implications of recent research on university technology transfer for entrepreneurial education, with the assumption that university administrators are interested in using such means to enhance their effectiveness in this arena.

The rise in the rate of technology commercialization at universities has also attracted considerable attention in the academic literature. While most authors have analyzed university patenting and licensing, some researchers have also assessed the entrepreneurial dimensions of university technology transfer. Many authors have examined the <u>institutions</u> that have emerged to facilitate commercialization, such as university technology transfer offices (henceforth, TTOs), industry-university cooperative research centers (IUCRCs), science parks, and incubators. Other papers focus more directly on agents involved in technology commercialization, such as academic scientists. Specifically, several authors examine the determinants and outcomes of faculty involvement in UITT, such as their propensity to patent, disclose inventions, co-author with industry scientists, and form university-based startups. These empirical papers build on the theoretical analysis of Jensen and Thursby (2001), who demonstrate that inventor involvement in UITT potentially attenuates the deleterious effects of informational asymmetries that naturally arise in technological diffusion from universities to firms.

In this paper, we review the burgeoning literature on institutions and agents engaged in the commercialization of university-based intellectual property. These studies indicate that institutional incentives and organizational practices both play an important role in enhancing the effectiveness of technology transfer. The evidence presented in these papers also clearly demonstrates the considerable heterogeneity in stakeholder objectives, perceptions, and outcomes relating to this activity.

While the degree of variation across institutions makes it somewhat difficult to generalize, we believe that university administrators should consider technology transfer from a strategic perspective. A strategic approach to technology transfer implies that such initiatives should be driven by long-term goals, provided with sufficient resources to achieve these objectives, and monitored for performance. Institutions that choose to stress the entrepreneurial dimension of technology transfer need to address the following issues:

- Competency and skill deficiencies in many technology transfer offices (TTOs)
- Reward systems that are inconsistent with greater entrepreneurial activity

- Education/training for faculty members, post-docs, and graduate students in the specifics of the entrepreneurial process, the role of entrepreneurs, and how to interact with the business/entrepreneurial community.

Business schools at these institutions can play a major role in addressing these skill and knowledge deficiencies, through the delivery of targeted educational programs for technology licensing officers and members of the campus community wishing to launch startup firms (Wright, Lockett, Tiratsoo, Alferoff and Mosey, 2004; Lockett and Wright, 2004).

The remainder of this article is organized as follows. In the following section, we analyze the objectives and cultures of the three key stakeholders in university technology transfer: academic scientists, university research administrators, and firms/entrepreneurs. This discussion underscores the complex, boundary-spanning role assumed by the TTO in facilitating technology commercialization. Section III presents an extensive review of the literature on university licensing and patenting. The next section explores the literature on an institution that was designed to stimulate and support entrepreneurial activities in the technology transfer process: the science park. Section V reviews studies of start-up formation at universities. Section VI presents lessons learned and recommendations relating to entrepreneurial education.

II. OBJECTIVES, MOTIVES, AND CULTURES OF UNIVERSITY TECHNOLOGY TRANSFER STAKEHOLDERS

Following Siegel, Waldman, and Link (2003), we conjecture that the key stakeholders in university technology transfer are academic scientists, technology licensing officers and other university research administrators, and firm-based managers and entrepreneurs who commercialize university-based technologies. In our process model of technology transfer, the technology licensing office assumes the role of a boundary spanner, filling what Burt (1992) terms a ‘structural hole’ to mediate the flow of resource and information within the network of technology transfer stakeholders (see Figure 1). In this framework, academic scientists discover new knowledge when conducting funded research projects and thus, act as suppliers of innovations. Their invention disclosures to the university constitute the critical input in the technology transfer process.

Insert Figure 1 about here

Note that the Bayh-Dole Act, the landmark legislation governing university technology transfer, stipulates that faculty members working on a federal research grant are required to disclose their inventions to the TTO. However, field studies (Siegel, Waldman, and Link (2003a, 2003b)) and survey research (Thursby, Jensen and Thursby (2001)) indicates that many faculty members are not disclosing inventions to the TTO. A failure to disclose invention highlights the importance of licensing officers in the TTO simply eliciting more disclosures.

If the faculty member decides to file an invention disclosure with the TTO, the university administration, in consultation with a faculty committee, must decide whether to patent the invention. At this juncture, the TTO attempts to evaluate the commercial potential of the invention. Given the high cost of filing and protecting patents, some institutions are reluctant to file for a patent if there is little interest expressed by industry in the technology. Sometimes, firms or entrepreneurs have already expressed sufficient interest in the new technology to warrant filing a patent.

If a patent is granted, the university typically attempts to "market" the invention, by contacting firms that can potentially license the technology or entrepreneurs who are capable of launching a start-up firm based on the technology. This step highlights the importance of the technology licensing officer's personal networks and her knowledge of potential users of the technology. Faculty members may also become directly involved in the licensing agreement as technical consultants or as entrepreneurs in a university spin-out. Indeed, Jensen and Thursby

(2001) outline a theoretical model, which suggests that faculty involvement in the commercialization of a licensed university-based technology increases the likelihood that such an effort will be successful. Licensing agreements entail either upfront royalties, royalties at a later date, or equity in a start-up firm launched to commercialize the technology.

Within the context of our model (Figure 1), it is useful to reflect on the incentives and cultures of the three key stakeholders in university technology transfer: academic scientists, the TTO and university administrators, and firm/entrepreneurs. Academic scientists, especially those who are untenured, seek the rapid dissemination of their ideas and breakthroughs. This propagation of new knowledge is manifested along several dimensions, including publications in the most selective scholarly journals, presentations at leading conferences, and research grants. The end result of such activity is peer recognition, through citations and stronger connections to the key social networks in academia. Such notoriety is the hallmark of a successful career in academia. Faculty members may also be seek pecuniary rewards, which can be pocketed or plowed back into their research to pay for laboratory equipment, graduate students, and post docs.

The TTO and other research administrators are also charged with the responsibility of protecting the university's intellectual property portfolio. At the same time, they are also charged with generating revenue from this portfolio and therefore actively seek to market university-based technologies to companies and entrepreneurs. This process takes place within the culture of a university, which may present competing interests related to the democratization of ideas, considerations of internal equity, bureaucratic procedures, and community interests. Some university administrators at public institutions may also understand that the Bayh-Dole Act embodied a desire to promote a more rapid rate of technological diffusion. Thus, these officials may be willing to extend the use of the university's technologies at a relatively low cost to firms.

Companies and entrepreneurs are motivated by a desire to commercialize university-based technologies for financial gain. They wish to secure exclusive rights to such technologies, since it is critical to maintain proprietary control over technologies resources that may constitute a source of competitive advantage. Firms and entrepreneurs also place a strong emphasis on speed, in the sense that they often wish to commercialize the technology as soon as possible, so as to establish a "first-mover" advantage. These agents operate in an entrepreneurial culture.

The stark disparities in the motives, perspectives, and cultures of the three key players in this process underscore the potential importance of organizational factors and institutional policies in effective university management of intellectual property. Thus, it is not surprising that studies of the relative performance of university technology transfer have explored the importance of institutional and managerial practices. In the following section of the paper, we review these papers.

III. REVIEW OF EMPIRICAL STUDIES ON THE EFFECTIVNESS OF UNIVERSITY LICENSING AND PATENTING

Table 1 presents a review of empirical studies on the effectiveness of university technology transfer licensing. Many papers have focused on the role of the TTO. Some have been based on qualitative analysis of agents involved in these transfers.

Insert Table 1 about here

Such qualitative research has played a critical role in informing more accurate empirical analyses. This point was stressed in Siegel, Waldman, Link (2003a), which was based on a combination of econometric analysis and field-based interviews. The authors derived three key stylized facts from their qualitative research. The first is that many academic scientists do not disclose their inventions, as required by the Bayh-Dole Act. The authors also found that patents were not important for certain technologies and industries, such as computer software. This result implies that invention disclosures, *not* patents, are the critical input in university technology transfer. Their third finding was that many universities outsource legal services related to technology transfer, i.e., they use external lawyers to negotiate licensing agreements with firms. The final result is that universities appear to have multiple strategic objectives or perceived "outputs" for technology transfer: licensing and the formation of start-up companies.

As shown on Table 1, several authors have attempted to assess the productivity of TTOs, using data on university technology transfer "outputs" and "inputs" (e.g., Siegel, Waldman, and Link (2003a), Thursby and Thursby (2002), and Friedman and Silberman (2003)). These papers highlight two key issues that arise in the context of production analysis. The first is whether to employ non-parametric methods or parametric estimation procedures.

The most popular non-parametric estimation technique is data envelopment analysis (DEA). The DEA method is essentially a linear-program, which can be expressed as follows:

(1) $$\text{Max } h_k = \sum_{r=1}^{s} u_{rk} Y_{rk} / \sum_{i=1}^{m} v_{ik} X_{ik}$$

subject to

(2) $$\sum_{r=1}^{s} u_{rk} Y_{rj} / \sum_{i=1}^{m} v_{ik} X_{ij} < 1; \; j=1,\ldots, n$$

$$\text{All } u_{rk} > 0; \; v_{ik} > 0$$

where

Y = a vector of outputs
X = a vector of inputs
i = inputs (m inputs)
r = outputs (s outputs)

n = # of decision-making units (DMUs), or the unit of observation in a DEA study

The unit of observation in a DEA study is referred to as the decision-making unit (DMU). A maintained assumption of these models is that DMUs attempt to maximize efficiency. Input-oriented DEA yields an efficiency "score," bounded between 0 and 1, for each DMU by choosing weights (u_r and v_i) that maximize the ratio of a linear combination of the unit's outputs to a linear combination of its inputs (see eq. (2)). DEA fits a piecewise linear surface to rest on top of the observations, which is called the "efficient frontier." The efficiency of each DMU is measured relative to all other DMUs, with the constraint that all DMU's lie on or below the efficient frontier. DEA also identifies best practice DMUs, or those that are on the frontier. All other DMUs are viewed as being inefficient relative to the frontier DMUs.

In contrast, stochastic frontier estimation (SFE) is a parametric method, developed independently by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977). SFE generates a production (or cost) frontier with a stochastic error term consisting of two components: a conventional random error ("white noise") and a term that represents deviations from the frontier, or relative inefficiency.

SFE is based on the assumption that the production function can be characterized as:

(3) $y_i = \mathbf{X}_i \beta + \varepsilon_i$

where the subscript i refers to the i^{th} university, y represents licensing output, **X** denotes a vector of inputs, β is the unknown parameter vector, and ϵ is an error term that consists of two components, $\varepsilon_i = (V_i - U_i)$, where U_i is a non-negative error term representing technical inefficiency, or failure to produce maximal output given the set of inputs used, and V_i is a symmetric error term that accounts for random effects. Thus, we can rewrite equation (3) as:

(4) $y_i = \mathbf{X}_i \beta + V_i - U_i$

Following Aigner, Lovell, and Schmidt (1977), it is typical to assume that the U_i and V_i have the following distributions:

$$V_i \sim \text{i.i.d. } N(0, \sigma^2_v)$$
$$U_i \sim \text{i.i.d. } N^+(0, \sigma^2_u), \quad U_i \geq 0$$

That is, the inefficiency term, U_i, is assumed to have a half-normal distribution; i.e, universities are either "on the frontier" or below it.[1]

SFE and DEA each have advantages and disadvantages. The use of DEA obviates the need to make these assumptions and also allows for multiple output production functions. A major weakness of DEA is that it is deterministic and thus, does not distinguish between technical inefficiency and noise. A key benefit of SFE is that it allows hypothesis testing and the construction of confidence intervals. A drawback is the need to assume a functional form for the production function and for the distribution of the technical efficiency term.

The use of SFE raises the second key issue in the context of production analysis: the choice of a functional form for the production function. Most technology transfer efficiency studies have been based on the Cobb-Douglas specification. Link and Siegel (2003) use a flexible functional form, the Translog, which imposes fewer restrictions on elasticities of substitution than the Cobb-Douglas specification. This can be specified as follows:

$$(5) \qquad \ln y_i = \sum_{k=1}^{K} \beta_k \ln X_{ki} + \tfrac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \gamma_{kl} \ln X_{ki} \ln X_{li} \qquad i = 1, 2, \ldots, N$$

where y and X again denote the technology transfer output and a vector of K technology transfer inputs, respectively, and i refers to the i^{th} university.

[1] Some authors assume a truncated normal or exponential distribution for the inefficiency disturbance (see Sena (1999)).

Thursby and Thursby (2002) employ DEA methods to assess whether the growth in licensing and patenting by universities can be attributed to an increase in the willingness of professors to patent, without a concomitant, fundamental change in the type of research they conduct. The alternative hypothesis is that the growth in technology commercialization at universities reflects a shift towards more applied research. The authors find support for the former hypothesis. More specifically, they conclude that the rise in university technology transfer is the result of a greater willingness on the part of university researchers to patent their inventions, as well as an increase in outsourcing of R&D by firms via licensing.

Siegel, Waldman, and Link (2003) use SFE to pose a different research question: why are some universities more effective at transferring technologies than comparable institutions? Specifically, they attempt to assess and "explain" the relative productivity of 113 U.S. university TTOs. Contrary to conventional economic models, they found that variation in relative TTO performance cannot be completely explained by environmental and institutional factors. The implication of this finding is that organizational practices are likely to be an important determinant of relative performance.

The authors supplemented their econometric analysis with qualitative evidence, derived from 55 structured, in-person interviews of 100 university technology transfer stakeholders (i.e., academic and industry scientists, university technology managers, and corporate managers and entrepreneurs) at 5 research universities in Arizona and North Carolina. The field research allowed them to identify intellectual property policies and organizational practices that can potentially enhance technology transfer performance.

The econometric results indicate that a production function model provides a good fit. Based on estimates of their "marginal product," it appears that technology licensing officers add significant value to the commercialization process. The findings also imply that spending more on lawyers reduces the number of licensing agreements, but increases licensing revenue. Licensing revenue is subject to increasing returns, while licensing agreements are characterized by constant returns to scale. An implication of increasing returns for licensing revenue is that a university wishing to maximize revenue should spend more on lawyers. Perhaps this would enable university licensing officers to devote more time to eliciting additional invention disclosures and less time to negotiating with firms.

The qualitative analysis identified three key impediments to effective university technology transfer. The first was informational and cultural barriers between universities and firms, especially for small firms. Another impediment was insufficient rewards for faculty involvement in university technology transfer. This includes both pecuniary and non-pecuniary rewards, such as credit towards tenure and promotion. Some respondents even suggested that involvement in technology transfer might be detrimental to their career. Finally, there appear to be problems with staffing and compensation practices in the TTO. One such problem is a high rate of turnover among licensing officers, which is detrimental towards the establishment of long-term relationships with firms and entrepreneurs. Other concerns are insufficient business and marketing experience in the TTO, and the possible need for incentive compensation.

In a subsequent paper, Link and Siegel (2003) find that a particular organizational practice can potentially enhance technology licensing: the "royalty distribution formula," which stipulates the fraction of revenue from a licensing transaction that is allocated to a faculty member who develops the new technology. Using data on 113 U.S. TTOs, the authors find that universities allocating a higher percentage of royalty payments to faculty members tend to be more efficient in technology transfer activities (closer to the "frontier," in the parlance of SFE).

Organizational incentives for university technology transfer appear to be important. This finding was independently confirmed in Friedman and Silberman (2003) and Lach and Schankerman (2004), using slightly different methods and data.

Other authors have explored the role of organizational incentives in university technology transfer. Jensen, Thursby, and Thursby (2003) model the process of faculty disclosure and university licensing through a TTO as a game, in which the principal is the university administration and the faculty and TTO are agents who maximize expected utility. The authors treat the TTO as a dual agent, i.e., an agent of both the faculty and the university. Faculty members must decide whether to disclose the invention to the TTO and at what stage, i.e., whether to disclose at the most embryonic stage or wait until it is a lab-scale prototype. The university administration influences the incentives of the TTO and faculty members by establishing university-wide policies for the shares of licensing income and/or sponsored research. If an invention is disclosed, the TTO decides whether to search for a firm to license the technology and then negotiates the terms of the licensing agreement with the licensee. Quality is incorporated in their model as a determinant of the probability of successful commercialization. According to the authors, the TTO engages in a "balancing act," in the sense that it can influence the rate of invention disclosures, must evaluate the inventions once they are disclosed, and negotiate licensing agreements with firms as the agent of the administration.

The Jensen, Thursby, and Thursby (2003) theoretical analysis generates some interesting empirical predictions. For instance, in equilibrium, the probability that a university scientist discloses an invention and the stage at which he or she discloses the invention is related to the pecuniary reward from licensing, as well as faculty quality. The authors test the empirical implications of the dual agency model based on an extensive survey of the objectives, characteristics, and outcomes of licensing activity at 62 U.S. universities.[2] Their survey results provide empirical support for the hypothesis that the TTO is a dual agent. They also find that faculty quality is positively associated with the rate of invention disclosure at the earliest stage and negatively associated with the share of licensing income allocated to inventors.

Bercovitz, Feldman, Feller, and Burton (2001) examine what could be a critical implementation issue in university management of technology transfer: the *organizational structure* of the TTO and its relationship to the overall university research administration. Based on the theoretical work of Alfred Chandler and Oliver Williamson, they analyze the performance implications of four organizational forms: the functional or unitary form (U-Form), the multidivisional (M-form), the holding company (H-form), and the matrix form (MX-form). The authors note that these structures have different implications for the ability of a university to coordinate activity, facilitate internal and external information flows, and align incentives in a manner that is consistent with its strategic goals with respect to technology transfer.

To test these assertions, they examine TTOs at Duke, Johns Hopkins, and Penn State and find evidence of alternative organizational forms at these three institutions. They attempt to link these differences in structure to variation in technology transfer performance along three dimensions: transaction output, the ability to coordinate licensing and sponsored research activities, and incentive alignment capability. While further research is needed to make conclusive statements regarding organizational structure and performance, their findings imply that organizational form does matter.

In sum, the extant literature on TTOs suggests that the key impediments to effective university technology transfer tend to be organizational in nature (Siegel, Waldman, and Link, 2003, Siegel, Waldman, Atwater, and Link, 2003). These include the problems with differences

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[2] See Thursby, Jensen, and Thursby (2001) for an extensive description of this survey.

in organizational cultures between universities and (small) firms, incentive structures including both pecuniary and non-pecuniary rewards, such as credit towards tenure and promotion, and staffing and compensation practices of the TTO itself.

IV. REVIEW OF STUDIES ON THE EFFECTIVNESS OF SCIENCE PARKS

In recent years, there has been a substantial increase in investment in science parks and other property-based institutions that facilitate technology transfer. Many universities have established science parks and incubators in order to foster the creation of startup firms based on university-owned (or licensed) technologies. Public universities (and some private universities) also view these institutions as a means of fostering regional economic development.

Insert Table 2 about here

Science parks have become an international phenomenon. The Association of University Research Parks (AURP) reports that there are 123 university-based science parks in the U.S. (Link and Link (2003)). The U.K. Science Park Association (UKSPA) reports that there were 32 science parks in 1989 and 46 in 1999 (Siegel, Westhead and Wright, 2003b). According to Lindelof and Loftsen (2003), there are 23 science parks in Sweden. Asia is also a major player. Japan leads the list with 111, China has over 100, Hong Kong and South Korea each report two parks, Macau, Malaysia, Singapore, Taiwan, and Thailand have one each. India established 13 parks in late-1980s. but with the exception of Bangalore, India's Silicon Valley, all have failed.

This increased level of activity has stimulated an important academic debate concerning whether such property-based initiatives enhance the performance of corporations, universities, and economic regions. More practically, it has also led to an interest among policymakers and industry leaders in identifying best practices. Unfortunately, few academic studies address such issues. This can be attributed to the somewhat embryonic nature of science parks and the fact that most science parks are public-private partnerships, indicating that multiple stakeholders (e.g., community groups, regional, and state governments) have enormous influence over their missions and operational procedures. Thus, developing theories to characterize the precise nature of their business models and managerial practices can be somewhat complex.

Link and Scott (2003) examine the evolution and growth of U.S. science parks and their influence on academic missions of universities, employing econometric methods and qualitative analysis. They use two data sources: a dataset constructed by the Association of University Related Research Parks (AURRP) containing a directory of science parks and limited information on their characteristics, and their own qualitative survey of provosts at 88 major research universities, who were asked several questions about the impact of the university's involvement with science parks on various aspects of the academic mission of the university.

Their results suggest that the existence of a formal relationship with a science park enables a university to generate more scholarly publications and patents and also allows them to more easily place Ph.D. students and hire preeminent scholars. They also found that there appears to be a direct relationship between the proximity of the science park to the university and the probability that the academic curriculum will shift from basic toward applied research.

In a subsequent study (Link & Scott, 2004), the authors analyze the determinants of the formation of university spin-off companies within the university's research park and report that university spin-off companies constitute a greater proportion of the companies in older parks and in those parks with richer university research environments. The authors also find that university spin-off companies constitute a larger proportion of firms in parks that are located closer to their university and in parks that have a biotechnology focus.

The best available evidence on the effects of science parks is from the U.K. Several studies were based on longitudinal data consisting of performance indicators for firms located on science parks and a control group of firms not located on science parks (Monck, Porter, Quintas, Storey and Wynarczyk, 1988); Westhead and Storey, 1994; Westhead, Storey, and Cowling, 1995). The authors found no difference between the closure rates of firms located on science parks and similar firms not located on science parks (32% versus 33%), implying that sponsored science park environments did not significantly increase the probability of business survival or enhance job creation.

With respect to the importance of the university, Westhead & Storey (1995) found a higher survival rate among science park firms with a university link (72%) than firms without such a link (53%). Westhead (1997), examining differences in R&D "outputs" (i.e., counts of patents, copyrights, and new products or services) and "inputs" (i.e., percentage of scientists and engineers in total employment, the level and intensity of R&D expenditure, and information on the thrust and nature of the research undertaken by the firm) of firms located on science parks and similar firms located off science parks, found no significant differences between science park and off-park firms.

However, Siegel, Westhead & Wright (2003) found that science park firms have higher research productivity than comparable non-science park firms, in terms of generating new products and services and patents, but not copyrights. These findings are relatively insensitive to the specification of the econometric model and controls for the possibility of an endogeneity bias. This preliminary evidence suggests that university science parks could constitute an important spillover mechanism, since they appear to enhance the research productivity of firms.

There have also been several evaluation studies of Swedish science parks. Lindelof and Lofsten (2003, 2004) conducted a "matched pairs" analysis of 134 on-park and 139 off-park Swedish firms using techniques similar to those employed by Westhead and Storey (1994) and found that no differences between science park and non-science park firms, in terms of patenting and new products. However, they report that companies located on science parks appear to have different strategic motivations than comparable off-park companies. More specifically, they seem to place a stronger emphasis on innovative ability, sales and employment growth, market orientation, and profitability. Lindelof and Lofsten (2004) also found that the absolute level of interaction between the university and companies located on science parks is low but that science park firms were more likely to have a relationship with the university than non-science park firms. Considered together with other evidence presented in Ferguson and Olofsson (2004), their results imply that science park firms interacting with nearby universities will achieve higher levels of R&D output than comparable non-science park firms.

In sum, the empirical research on these institutions suggests the importance of a university link in the productivity of science parks. In part, this is because many science parks were created to incubate the spinouts created from university based technology. What has been less clear is the exact nature of this link that contributes to the differences between park and off-park firms. Speculation has ranged from explanations of knowledge spillovers to the proximity of the requisite competencies to staff these firms. Nonetheless, given the technological nature of such firms, we conjecture that there may be an important role for the technology transfer process in the success of the university related science parks and their business tenants. This brings us to the next section of our paper, which is the empirical work related to university based spinouts.

V. REVIEW OF STUDIES OF START-UP FORMATION AT UNIVERSITIES

Although the dominant form of commercialization has traditionally been licensing, there is a rapid growing population of university-based entrepreneurial startup firms. According to the Association of University Technology Managers (AUTM (2004)), the number of startup firms at U.S. universities rose from 35 in 1980 to 374 in 2003. This rise in startup activity has attracted considerable attention in the academic literature. Some of these studies use the university as the unit of analysis, while others focus on the individual entrepreneurs.

Insert Table 3 about here

Studies using the university as the unit of analysis typically focus on the role of university policies in stimulating entrepreneurial activity. Roberts and Malone (1996) conjecture that Stanford generated fewer startups than comparable institutions in the early 1990s because the institution refused to sign exclusive licenses to inventor-founders.

Degroof and Roberts (2004) examine the importance of university policies relating to startups in regions where environmental factors (e.g., technology transfer and infrastructure for entrepreneurship) are not particularly conducive to entrepreneurial activity. The authors derive a taxonomy of four types of startup policies: an absence of startup policies, minimal selectivity/support, intermediate selectivity/support, and comprehensive selectivity/support. Consistent with Roberts and Malone (1996), they find that comprehensive selectivity/support is the optimal policy for generating startups that can exploit venture with high growth potential. However, such a policy is an ideal that may not be feasible, given resource constraints. The authors conclude that while spinout policies do matter, in the sense that they affect the growth potential of ventures, it may be more desirable to formulate such policies at a higher level of aggregation than the university.

DiGregorio and Shane (2003) directly assess the determinants of startup formation, using AUTM data from 101 universities and 530 startups. Based on estimates of count regressions of the number of university-based start-ups, they conclude that the two key determinants of start-ups are faculty quality and the ability of the university and inventor(s) to take equity in a start-up, in lieu of licensing royalty fees. Interestingly, the availability of venture capital in the region where the university is located and the commercial orientation of the university (proxied by the percentage of the university's research budget that is derived from industry) are found to have an insignificant impact of the rate of start-up formation. The authors also find that a royalty distribution formula that is more favorable to faculty members reduces start-up formation, a finding that is confirmed by Markman, Phan, Balkin & Giannodis (2005). DiGregorio and Shane (2003) attribute this result to the higher opportunity cost associated with launching a new firm, relative to licensing the technology to an existing firm.

O'Shea, Allen, and Arnaud (2004) extend these findings in several ways. First, they employ a more sophisticated econometric technique employed by Blundell, Griffith, and Van Reenen (1995) on innovation counts, which accounts for unobserved heterogeneity across universities due to "history and tradition." This type of "path dependence" would seem to be quite important in the university context. Indeed, the authors find that a university's previous success in technology transfer is a key explanatory factor of start-up formation. Consistent with DiGregorio and Shane (2003), they also find that faculty quality, commercial capability, and the extent of federal science and engineering funding are also significant determinants of higher rates of university start-up formation.

Franklin, Wright, and Lockett (2001) analyze perceptions at U.K. universities regarding entrepreneurial startups that emerge from university technology transfer. The authors distinguish between academic and surrogate (external) entrepreneurs and "old" and "new" universities in the U.K. Old universities have well established research reputations, world-class scientists, and are typically receptive to entrepreneurial startups. New universities, on the other hand, tend to be weaker in academic research and less flexible with regard to entrepreneurial ventures. They find that the most significant barriers to the adoption of entrepreneurial-friendly policies are cultural and informational and that the universities generating the most startups (i.e., old universities) are those that have the most favorable policies regarding surrogate (external) entrepreneurs. The authors conclude that the best approach for universities that wish to launch successful technology transfer startups is a combination of academic and surrogate entrepreneurship. This would enable universities to simultaneously exploit the technical benefits of inventor involvement and the commercial know-how of surrogate entrepreneurs.

In a subsequent paper, Lockett, Wright and Franklin (2003) find that universities that generate the most startups have clear, well-defined strategies regarding the formation and management of spinouts. These schools tend to use surrogate (external) entrepreneurs, rather than academic entrepreneurs, to manage this process. It also appears as though the more successful universities have greater expertise and vast social networks that help them generate more startups. However, the role of the academic inventor was not found to differ between the more and less successful universities. Finally, equity ownership was found to be more widely distributed among the members of the spinout company in the case of the more successful universities.

Using an extended version of the same database, Lockett and Wright (2004) assess the relationship between the resources and capabilities of U.K. TTOs and the rate of start-up formation at their respective universities. In doing so, the authors apply the resource-based view

(RBV) of the firm to the university. RBV asserts that an organization's superior performance (in the parlance of strategic management, its "competitive advantage") is related to its internal resources and capabilities. They are able to distinguish empirically between a university's resource inputs and its routines and capabilities. Based on estimation of count regressions (Poisson and Negative Binomial), the authors conclude that there is a positively correlation between start-up formation and the university's expenditure on intellectual property protection, the business development capabilities of TTOs, and the extent to which its royalty distribution formulae favors faculty members. These findings imply that universities wishing to spawn numerous startups should devote greater attention to recruitment, training, and development of technology transfer officers with broad-based commercial skills. We will refer back to these results in the following section of the paper.

Markman, Phan, Balkin, and Giannodis (2005) develop a model linking university patents to new-firm creation in university-based incubators, with university TTOs acting as the intermediaries. They focus on universities because such institutions are responsible for a substantial fraction of technology-oriented incubators in the U.S. While there have been some qualitative studies of university TTO licensing (e.g., Bercovitz Feldman, Feller, and Burton (2001); Siegel, Waldman, Atwater, and Link (2003b); Mowery, Nelson, Sampat, and Ziedonis (2001)), they have been based on data from elite research universities only (e.g., Stanford, UC Berkeley, and MIT) or from a small sample of more representative institutions. These results may not be generalizable to the larger population of institutions that do not enjoy the same favorable environmental conditions. To build a theoretically saturated model of TTOs' entrepreneurial development strategies, the authors collected qualitative and quantitative data from virtually the entire population of university TTOs.

A surprising conclusion of Markman, Phan, Balkin, and Giannodis (2005) is that the most "attractive" combinations of technology stage and licensing strategy for new venture creation, i.e., early stage technology, combined with licensing for equity, are least likely to be favored by the university and thus, not likely to be used. That is because universities and TTOs are typically focused on short term cash maximization, and extremely risk-averse with respect to financial and legal risks. Their findings are consistent with evidence presented in Siegel, Waldman, Atwater, and Link (2003a, 2004), who found that TTOs appear to do a better job of serving the needs of large firms than small, entrepreneurial companies. The results of these studies imply that universities should modify their technology transfer strategies if they are serious about promoting entrepreneurial development.

In additional studies (Markman, Phan, Balkin, and Giannodis (2004a, 2004b), the authors use the same database to assess the role of incentive systems in stimulating academic entrepreneurship and the determinants of innovation speed, or time to market. An interesting result of Markman, Phan, Balkin, and Giannodis (2004a) is that there is a positive association between pay to TTO personnel and both equity licensing and startup formation. On the other hand, royalty payments to faculty members and their departments are uncorrelated or even negatively correlated with entrepreneurial activity. This finding is consistent with DiGregorio and Shane (2003).

In Markman, Phan, Balkin, and Giannodis (2004b), the authors find that speed matters, in the sense the faster TTOs can commercialize technologies that are protected by patents, the greater the returns to the university and the higher the rate of startup formation. They also report that there are three key determinants of speed: TTO resources, competency in identifying licensees, and participation of faculty-inventors in the licensing process.

Nerkar and Shane (2003) analyze the entrepreneurial dimension of university technology transfer, based on an empirical analysis of 128 firms that were founded between 1980 and 1996 to commercialize inventions owned by MIT. They begin by noting that there is an extensive literature in management that suggests that new technology firms are more likely to survive if they exploit radical technologies (e.g, Tushman and Anderson (1986)) and if they possess patents with a broad scope (e.g., Merges and Nelson (1990)). The authors conjecture that the relationships between radicalness and survival and scope and survival are moderated both by the market structure or level of concentration in the firm's industry. Specifically, they assert that radicalness and patent scope increase the probability of survival more in fragmented industries than in concentrated sectors. They estimate a hazard function model using the MIT database and find empirical support for these hypotheses. Thus, the effectiveness of the technology strategies of new firms may be dependent on industry conditions.

Several studies focus on individual scientists and entrepreneurs, in the context of university technology transfer. Audretsch (2000) examines the extent to which entrepreneurs at universities are different than other entrepreneurs. He analyzes a dataset on university life scientists, in order to estimate the determinants of the probability that they will establish a new biotechnology firm. Based on a hazard function analysis, including controls for the quality of the scientist's research, measures or regional activity in biotechnology, and a dummy for the career trajectory of the scientist, the author finds that university entrepreneurs tend to be older and more scientifically experienced.

There is also evidence on the importance of norms, standards, and culture in this context. Based on a qualitative analysis of five European universities that had outstanding performance in technology transfer, Clark (1998) concluded that the existence of an entrepreneurial culture at those institutions was a critical factor in their success. Roberts (1991) finds that social norms and MIT's tacit approval of entrepreneurs were critical determinants of successful academic entrepreneurship at MIT.

Louis, Blumenthal, Gluck, and Stoto (1989) analyze the propensity of life-science faculty to engage in various aspects of technology transfer, including commercialization. Their statistical sample consists of life scientists at the 50 research universities that received the most funding from the National Institutes of Health. The authors find that the most important determinant of involvement in technology commercialization was local group norms. They report that university policies and structures had little effect on this activity.

The unit of analysis in Bercovitz and Feldman (2004) is also the individual faculty member. They analyze the propensity of medical school researchers at Johns Hopkins and Duke to file invention disclosures, a potential precursor to technology commercialization. The authors find that three factors influence the decision to disclose inventions: norms at the institutions where the researchers were trained and the disclosure behaviors of their department chairs and peers, respectively.

The seminal papers by Lynne Zucker and Michael Darby and various collaborators explore the role of "star" scientists in the life sciences on the creation and location of new biotechnology firms in the U.S. and Japan. In Zucker and Darby and Armstrong (2000), the authors assessed the impact of these university scientists on the research productivity of U.S. firms. Some of these scientists resigned from the university to establish a new firm or kept their faculty position, but worked very closely with industry scientists. A star scientist is defined as a researcher who has discovered over 40 genetic sequences, and affiliations with firms are defined through co-authoring between the star scientist and industry scientists. Research productivity is measured using three proxies: number of patents granted, number of products in development, and number of products on the market. They find that ties between star scientists and firm scientists have a positive effect on these three dimensions of research productivity, as well as other aspects of firm performance and rates of entry in the U.S. biotechnology industry (Zucker, Darby, and Armstrong (1998), Zucker, Darby, and Brewer (1998)).

In Zucker and Darby (2001), the authors examine detailed data on the outcomes of collaborations between "star" university scientists and biotechnology firms in Japan. Similar patterns emerge, in the sense that they find that such interactions substantially enhance the research productivity of Japanese firms, as measured by the rate of firm patenting, product innovation, and market introductions of new products. However, they also report an absence of geographically localized knowledge spillovers resulting from university technology transfer in Japan, in contrast to the U.S., where they found that such effects were strong. The authors attribute this result to the following interesting institutional difference between Japan and the U.S in university technology transfer. In the U.S., it is common for academic scientists to work with firm scientists at the firm's laboratories. In Japan, firm scientists typically work in the academic scientist's laboratory. Thus, according to the authors, it is not surprising that the local economic development impact of university technology transfer appears to be lower in Japan than in the U.S.

The research on TTOs, science parks, and start-up formation summarized in Sections III, IV, and V underscore the importance of identifying the interests and incentives of those who manage the technology transfer process. The extant literature also highlights the need to understand how these managers interact with key stakeholders and those who manage these stakeholders (e.g., science park and incubator managers, department chairs, and entrepreneurs) who are employed at these institutions.

In the case of the university, an internal market for the efficient allocation of resources does not exist. Therefore, decisions relating to technology transfer and new venture creation may be driven by internal bargaining, which would bring to the fore the question of incentives versus university mission. Theoretically, the relationship between TTO managers, the university administration and entrepreneurs can be modeled as a multi-level agency problem. As in the case of all agency problems, the resolution can come through more complete contracts, accurate measurement and monitoring, or the creation of a culture of trust. This again points to the importance of organizational processes and individual behaviors in providing a complete explanation for the link between TTOs and spinouts.

VI. LESSONS LEARNED/RECOMMENDATIONS

A synthesis of the literature suggests that several issues must addressed by university administrators and other policymakers (e.g., regional or state authorities), in order to enhance the effectiveness of technology transfer. First, universities should adopt a *strategic* approach to this activity. Such an approach raises a set of formulation and implementation issues.

The *formulation* of a technology transfer strategy entails a set of choices regarding institutional goals and priorities, allocation of resources to achieve these goals, technological emphasis, and modes of technology transfer. The *implementation* of a technology transfer strategy requires choices regarding information flows, organizational design/structure, human resource management practices in the TTO, and reward systems for faculty involvement in technology transfer. There are also a set of implementation issues relating to different modes of technology transfer, licensing, start-ups, sponsored research, and other modes that are focused more directly on stimulating economic development, such as incubators and science parks. We now consider each of these in turn, in the context of the quantitative and qualitative analyses cited in previous sections of the paper.

Universities must be transparent, forthright, and consistent about their strategic goals and priorities for technology transfer. Such an approach will allow for more efficient matching between the TTO and its suppliers, the academic scientists. Clarity and consistency of purpose is likely to result in more productive interactions between the TTO and university scientists, since TTO officers will hit fewer 'dry wells' and faculty members will find a more receptive audience for their ideas.

Establishing priorities also relates to choices regarding technological emphasis for the generation of licensing opportunities, relating to stage of development and field of emphasis. For instance, proof-of-concept technologies are likely to be more attractive than other technologies if the strategic objective is licensing for cash, since it is relatively easy to compute economic value under this scenario. Furthermore, such technologies can be codified for efficient arms-length transfer and they are more likely than other technologies to result in a commercial product, without substantial additional research expense.

It is important to note that a focus on proof-of-concept technologies will require universities and scholars to devote more resources to incremental research, which may be less attractive to faculty members striving to publish in top journals. Also, resources devoted to achieving proof-of-concept must be diverted from basic research or result from sponsored research. An alternative approach is to license nascent inventions, which will likely lead to lower licensing values, less immediate cash, and will require the assumption of equity shares that may prove to be worthless, but require fewer up-front resources by the university and a greater likelihood of faculty participation.

University administrators and regional policymakers must also make a strategic choice regarding field of emphasis. Opportunities for technology commercialization and the propensity of faculty members to engage in technology transfer vary substantially across fields both between and within the life sciences and physical sciences. For example, many universities have recently launched initiatives in the life sciences and biotechnology with expectations of enhanced revenue and job creation through technology transfer.

As noted earlier, the research on TTOs and licensing revenue suggests that it is difficult for universities to assess financial rates of returns on this activity. We assert that in light of this finding, universities must develop the expertise to manage their licensing portfolio as a set of options, rather than individual wagers on 'winner-take-all' projects. This type of portfolio management has implications for selection, training, and development of TTO personnel and other relevant stakeholders, including faculty members.

Resource allocation decisions must also be driven by strategic choices the university makes regarding various modes of technology transfer. Recall that universities can choose among a variety of "outputs" to emphasize, including licensing, start-ups, sponsored research and other mechanisms of technology transfer that are focused more directly on stimulating economic and regional development, such as incubators and science parks. Licensing and sponsored research yield revenue, while equity from start-ups generates a long-term payoff, if any at all. Universities that stress economic development outcomes are advised to focus on start-ups, since these companies can potentially create jobs in the local region or state. Note also that while a start-up strategy entails higher risk (since the probability of failure for new companies is relatively high), it also can potentially generate high returns if the start-up is taken public. However, a start-up strategy entails additional resources, if the university chooses to assist the academic entrepreneur in launching and developing their start-up.

A strategic approach to university technology transfer should also address *implementation* issues. These refer to the organization processes and structural choices that a university must make in order to execute its technology transfer priorities. Our literature review highlighted the importance of human resource management practices. Several qualitative studies (e.g., Siegel, Waldman, Atwater, and Link (2003.)) indicate that there are deficiencies in the TTO, with respect to marketing skills and entrepreneurial experience. Unfortunately, field research ((Markman, et al., 2004a) has also revealed TTOs are not actively recruiting individuals with such skills and experience. Instead, representative institutions appear to be focusing on expertise in patent law and licensing or technical expertise. Training and development programs for TTO personnel are advised, along with additional administrative support for this activity, since many TTOs lack sufficient resources and competencies to identify the most commercially viable inventions.

Another conclusion that emerges from the literature review is that implementation issues intersect formulation issues at the point where resources are assigned. Given the dual agency role assumed by technology licensing officers (Jensen, Thursby, and Thursby (2003)), a key resource issue is the design of incentives for TTOs to accomplish their tasks. Research has shown that career paths for university technology licensing officers are limited and often of short duration (Markman, et al., 2004a), which implies that incentives should be directed towards creating immediate feedback and rewards (i.e., cash) to elicit the desired behaviors.

Qualitative studies also clearly indicate that information flows between researchers and the TTO must be improved. The first step is for the TTO, working in conjunction with university administration, to be more pro-active in eliciting invention disclosures. Also, faculty members expressing an interest in forming a start-up or sourcing for sponsored research opportunities, information, and even training on 'how to do it' should be able to access such information from the TTO. Given that the formation of a start-up involves activities and skills not typically associated with the competencies of a laboratory scientist, universities should utilize their business school faculty and staff to provide training and mentoring to the academic entrepreneur.

The end result is an expansion of the TTO's role as a boundary spanner to include managerial and "softer" business skills, in order to foster additional entrepreneurial activity at the university. Successful implementation of this approach requires thinking of the technology transfer and entrepreneurial processes in tandem, which calls for a university level *curriculum* approach to an affirmative training and development program to encourage, support, and accelerate start-ups.

Insert Figure 2 about here

Figure 2 illustrate the elements of a technological entrepreneurship curriculum that, while commonly encountered in business schools, can also be applied to technology transfer stakeholders (academic entrepreneur, TTO officer, incubator manager, and small firm licensee) involved in start-up formation. Note that the curriculum is broad in scope, in terms of who participates in the creation and dissemination of knowledge regarding entrepreneurship, but also provides in-depth coverage. Here, the continual creation of new knowledge regarding university start-ups resides with the faculty researcher. Thus, incentives should be created for faculty within the university to expand their research domains to include questions related to innovation and entrepreneurship from technical and managerial perspectives. Universities should also consider establishing a formal program that allows successful faculty entrepreneurs to serve as role models and mentors for faculty, students, and post-docs who wish to engage in new venture creation. The implication of such an initiative is that the entrepreneurship curriculum must be driven from the top of the hierarchy and embedded in the institutional priorities, design principles and measurement systems of the university.

According to Figure 2, the cadre of faculty conducting research on technology transfer and entrepreneurship (a growing number at many institutions) should also be responsible for the creation of entrepreneurship courses and training programs for TTO stakeholders. This closes the loop between knowing and doing. A standard academic curriculum is focused on knowledge accumulation. In contrast, to be immediately useful, the design principle for the training and educational programs we propose should be based on a process perspective, i.e., the new venture startup cycle, and therefore must be oriented towards overcoming problems entrepreneurs face in developing a successful commercial venture. Stakeholders can acquire knowledge in the area they most need, based on the problems they encounter in the startup stage of the venture (e.g., venture capital funding), without having to take all courses. Note that courses can be created and taught by any faculty from across divisions of the university with the appropriate experience or knowledge set. Such a program should be managed by top-level university administrators. Wake Forest and RPI have created top-level administrative positions in entrepreneurship (e.g., a Vice Provost for Entrepreneurship), highlighting the importance of these initiatives within the university, and also sending an important signal to other stakeholders (e.g., faculty, donors) that the university places a high value on such activities.

Insert Figure 3 about here

As Figure 3 illustrates, the primary role of such a program is training on the 'soft drivers' of business venturing. Figure 3 identifies specific courses aimed at addressing the stylized conclusions about entrepreneurial success from research. For example, research has shown that successful entrepreneurs have cognitive routines that allow them to recover quickly from failure, such that the fear of failure, while always present, does not represent a hindrance to the desire to startup new ventures. Research has also revealed that serial entrepreneurs are on average more successful, which suggests the importance of learning and knowledge accumulation of the 'how to' aspects of new venture creation. Therefore, entrepreneurship courses designed for TTO stakeholders should focus both on the mechanics of starting a venture and the economic/strategic implications of the technologies being commercialized. Finally, for the TTO officer or entrepreneur who is not familiar with the specifics of the technology, technology survey courses, taught by faculty scientists, are recommended.

Figure 2 and 3 suggest that the role of the institution in the implementation of a technology entrepreneurship curriculum is to create organizational structures such as a venture forum, incubator or technology park, and so on, in which technology transfer activities are given an institutional context and recognition. More importantly, as the research has shown, attention must be paid to organizational design issues. For example, if the university is serious about increase the rate of start-up activity, then the level at which transfer activities should be resourced and monitored from by top university administrators. Thus, the entrepreneurship curriculum and its related educational program must be institutionally embedded throughout the university, in order to maximize its impact on the effectiveness of the technology transfer process. More specifically, such initiatives cannot be primarily driven by the TTO, business or related school with an entrepreneurship program, or individual stakeholders. Because the problem is multi-level in nature and involves the simultaneous actions of multiple stakeholders, it must be addressed from the highest strategic level of the university. Thus, specific boundary spanning roles must be assigned to the TTO and business school. Such a top-down driven approach attenuates the possibility of role conflict and information gaps caused by the ad-hoc or organic design typically encountered in an academic environment.

Decisions regarding organizational design must be accompanied by appropriate staffing and compensation policies, with respect to the TTO and other university staff directly responsible for start-ups, such as incubator and science park management. For example, TTOs are advised to hire staff with a broad array of skills that cover the spectrum of the new venture creation cycle (Figure 3). Additionally, preliminary research indicates that incentives matter because TTO officers and related stakeholders act as dual agents for the university and the faculty member. Therefore, consistent with agency theory, an appropriate mechanism should be employed that aligns the interests of the agents with their principals, in order to elicit the optimal level of effort. Incentive structures fall into two categories. Pay for effort (behavior) or pay for results (productivity). Appropriate compensation systems balance the mix of both types in order to encourage the appropriate efforts, especially when team effort matters, to sustain productivity levels for the long term.

Appropriate incentives must also be designed for faculty members, who constitute the source of invention disclosures, the critical input in university technology transfer. As discussed extensively, there is a natural conflict of interests generate by the traditional academic reward system, which is focused on peer reviewed publication of (generally) primary research, and the technology transfer reward system, which is focused on revenue generation from (generally) applied research. This dilemma can only be resolved at the highest levels of the university administration because it is the direct result of top level priorities. In a sense, the university can view the faculty member as an agent of its strategic intent. When an agent is exposed to a conflict of interest generated by the conflicting goals of the principal, only the latter can resolve it.

In conclusion, our review of the literature suggests that for university technology transfer to be productive in the creation of spinouts, the university must adopt a strategic approach to the commercialization of its intellectual property portfolio. Such an approach begins with establishing clear priorities at the university level, combined with appropriate organization design choices focused on eliciting an ample supply of invention disclosures. It also entails changing incentives to encourage entrepreneurial behaviors and establishing a university level process-based educational curriculum for all stakeholders engaged in the technology transfer process.

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Table 1
Empirical Studies of University Technology Licensing and Patenting

Author(s)	Data Sets	Methodology	Key Results
Siegel, Waldman, and Link (2003)	AUTM, NSF, and U.S. Census Data, Interviews	TFP of University Licensing -Stochastic Frontier Analysis and Field Interviews	TTOs Exhibit Constant Returns to Scale With Respect to the # of Licensing; Increasing Returns to Scale With Respect to Licensing Revenue; Organizational and Environmental Factors Have Considerable Explanatory Power
Link and Siegel (2003)	AUTM, NSF, and U.S. Census Data, Interviews	TFP of University Licensing -Stochastic Frontier Analysis	Land Grant Universities Are More Efficient in Technology Transfer; Higher Royalty Shares For Faculty Members Are Associated With Greater Licensing Income
Friedman and Silberman (2002)	AUTM, NSF, NRC, Milken Institute "Tech-Pole" Data	Regression Analysis- Systems Equations Estimation	Higher Royalty Shares For Faculty Members Are Associated With Greater Licensing Income
Lach and Schankerman (2004)	AUTM, NSF, NRC,	Regression Analysis	Higher Royalty Shares For Faculty Members Are Associated With Greater Licensing Income
Rogers, Yin & Hoffmann (2000)	AUTM, NSF, NRC	Correlation Analysis of Composite Technology Transfer Score	Positive Correlation Between Faculty Quality, Age of TTO, and # of TTO Staff and Higher Levels of Performance in Technology Transfer
Thursby, Jensen, and Thursby (2001)	AUTM, Authors' Survey	Descriptive Analysis of Authors' Survey/ Regression Analysis	Inventions Tend to Disclosed At An Early Stage of Development; Elasticities of Licenses and Royalties With Respect to Invention Disclosures Are Both Less Than One; Faculty Members Are Increasingly Likely to Disclose Inventions.
Foltz, Barham & Kim (2000)	AUTM, NSF	Linear Regression	Faculty Quality, Federal Research Funding, and # of TTO Staff Have A Positive Impact on University Patenting
Bercovitz, Feldman, Feller, and Burton (2001)	AUTM and Case Studies, Interviews	Qualitative and Quantitative Analysis	Analysis of Different Organization Structures for Technology Transfer at Duke, Johns Hopkins, and Penn State; Differences in Structure May Be Related to Technology Transfer Performance

Table 1 (cont.)
Empirical Studies of University Technology Licensing and Patenting

Author(s)	**Data Sets**	**Methodology**	**Key Results**
Thursby and Kemp (2002)	AUTM	Data Envelopment Analysis And Logit Regressions on Efficiency Scores	Faculty Quality and # of TTO Staff Has a Positive Impact on Various Technology Transfer Outputs; Private Universities Appear To Be More Efficient Than Public Universities; Universities With Medical Schools Less Efficient
Thursby & Thursby (2002)	AUTM and Authors' Own Survey	Data Envelopment Analysis	Growth in University Licensing and Patenting Can be Attributed to an Increase in the Willingness of Professors to Patent and License, As Well As Outsourcing of R&D by Firms; Not to a Shift Towards More Applied Research
Chapple, Lockett, Siegel, and Wright (2005)	U.K.-NUBS/ UNICO Survey-ONS	Data Envelopment Analysis and Stochastic Frontier Analysis	U.K. TTOs Exhibit Decreasing Returns to Scale and Low Levels of Absolute Efficiency; Organizational and Environmental Factors Have Considerable Explanatory Power
Carlsson and Fridh (2002)	AUTM	Linear Regression	Research Expenditure, Invention Disclosures, and Age of TTO Have a Positive Impact on University Patenting and Licensing

Note: This table is based on material presented in Link and Siegel (2005)

Table 2
Recent Empirical Studies of Science Parks in the U.S., U.K., and Sweden

Author(s)	Country of Analysis	Data/ Methodology	Proxies for Performance	Key Results
Westhead and Storey (1994)	United Kingdom	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in the United Kingdom	Survival	No Difference in the Survival Rates of Firms Located on University Science Parks and Similar Firms Not Located on University Science Parks
Westhead, Storey, and Cowling (1995)	United Kingdom	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in the United Kingdom/ Multivariate Logistic Regression Analysis.	Survival	Sponsored Science Park Environments Did Not Significantly Increase the Probability of Firm Survival
Westhead and Storey (1995)	United Kingdom	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in the United Kingdom	Survival	Science Park Firms With a Link to the University Have a Higher Survival Rate Than Science Park Firms Without Such a Link
Westhead, and Cowling (1995)	United Kingdom	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in the United Kingdom	Employment Growth	No Difference in Employment Growth Rates of Firms Located on University Science Parks and Similar Firms Not Located on University Science Parks

Table 2 (cont.)
Recent Empirical Studies of Science Parks in the U.S., U.K., and Sweden

Author(s)	Country of Analysis	Data/ Methodology	Proxies for Performance	Key Results
Siegel, Westhead, and Wright (2003)	United Kingdom	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in the United Kingdom	Productivity of Research Efforts/Estimation of R&D Production Function	Science Park firms are More Efficient Than Non-Science Park Firms in Research (i.e., Generating New Products and Services and Patents)
Link and Link (2003)	United States	Association of University Related Research Parks (AURRP) Survey; Survey of Park Directors	Employment and Tenant Growth on All Research Parks	Real Estate Parks Are The Fastest Growing Type of Park, But Their Growth Is Not Related to Being Close to a University
Link and Scott (2003)	United States	Association of University Related Research Parks (AURRP) Survey; Authors' Survey of University Provosts /Hazard Function Regression Analysis/Ordered Probit Equation Estimation	Employment Growth /Six Dimensions of the Academic Mission of the University:	Proximity to a University and the Availability of Venture Capital Have a Positive Impact on Growth; Science Park Enables Universities to Generate More Publications and Patents, More Easily Place Graduates, and Hire Preeminent Scholars
Link and Scott (2004a)	United States	Association of University Related Research Parks (AURRP) Survey; Authors' Survey of University Provosts	% of University Research Park Tenants That Are University-Based Start-ups	There is a Positive Association Between the % of University-Based Start-ups and the Age of the Park, the Quality of the Research Environment at the University, Proximity to the University, and Whether the Parks Has a Biotechnology Focus

Table 2 (cont.)
Recent Empirical Studies of Science Parks in the U.S., U.K., and Sweden

Author(s)	Country of Analysis	Data/ Methodology	Proxies for Performance	Key Results
Lindelof and Loftsen. (2003)	Sweden	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in Sweden	Two Dimensions of R&D Output: Counts of Patents and New Products/ Self-Reported Data on Strategic Motivations	Insignificant Differences between Science Park and Non-Science Park Firms, Along Two Dimensions of R&D Output: Counts of Patents and New Products. However, Science Parks Place a Stronger Emphasis on Innovative Ability, Sales and Employment Growth, Market Orientation, and Profitability Than Non-Science Park Firms
Lindelof and Loftsen. (2004)	Sweden	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in Sweden	Measures of R&D Output, Sales and Employment Growth	Insignificant Differences in R&D Output Between Science Park and Non-Science Park Firms; However Science Park Firms With Stronger Links and Networks to Universities Have Higher Levels of R&D Output and Growth Than Comparable Non-Science Park Firms
Ferguson and Olofsson (2004)	Sweden	Longitudinal Dataset Containing Information on the Characteristics and Performance of Firms Located On and Off Science Parks in Sweden	Survival, Sales and Employment Growth	Science Park Firms Have a Higher Survival Rate Than Non-Science Park Firms; However, There is No Difference in Sales and Employment Growth

Note: This table is based on material presented in Link and Siegel (2005)

Table 3
Studies of the Antecedents and Consequences of Start-up Formation at Universities

Author(s)	Unit of Analysis	Data/ Methodology	Key Results
Di Gregorio and Shane (2003)	University-Based Startups	AUTM Survey/Count Regressions of the Determinants of the # of Startups	Two Key Determinants of Start-up Formation: Faculty Quality and the Ability of the University and Inventor(s) to Take Equity in a Start-up, in Lieu of Licensing Royalty Fees; A Royalty Distribution Formula that is More Favorable to Faculty Members Reduces Start-up Formation
O'Shea, Allen, and Arnaud (2004)	University-Based Startups	AUTM Survey/Count Regressions of the Determinants of the # of Startups	A University's Previous Success in Technology Transfer is a Key Determinant of Its Rate of Start-up Formation
Franklin, Wright, and Lockett (2001)	TTOs and University-Based Startups	Authors' Quantitative Survey of U.K. TTOs	Universities That Wish to Launch Successful Technology Transfer Startups Should Employ a Combination of Academic and Surrogate Entrepreneurship
Lockett, Wright, and Franklin, (2003)	TTOs and University-Based Startups	Authors' Quantitative and Qualitative Surveys of U.K. TTOs	Universities That Generate the Most Startups Have Clear, Well-Defined Spinout Strategies, Strong Expertise in Entrepreneurship, and Vast Social Networks
Lockett and Wright (2004)	TTOs and University-Based Startups	Authors' Quantitative Survey of U.K. TTOs/ Count Regressions of the Determinants of the # of Startups	A University's Rate of Start-up Formation is Positively Associated with Its Expenditure on Intellectual Property Protection, the Business Development Capabilities of TTOs, and the Extent to Which its Royalty Distribution Formula Favors Faculty Members
Nerkar and Shane (2003)	University-Based Startups	Longitudinal Data from MIT Startups/ Hazard Function Analysis	"Radicalness" of the New Technology and Patent Scope Increase the Probability of Survival More in Fragmented Industries than in Concentrated Sectors ⇨ Effectiveness of Technology Strategies of New Firms Appears to Depend on Industry Conditions

Table 3 (cont.)
Studies of the Antecedents and Consequences of Start-up Formation at Universities

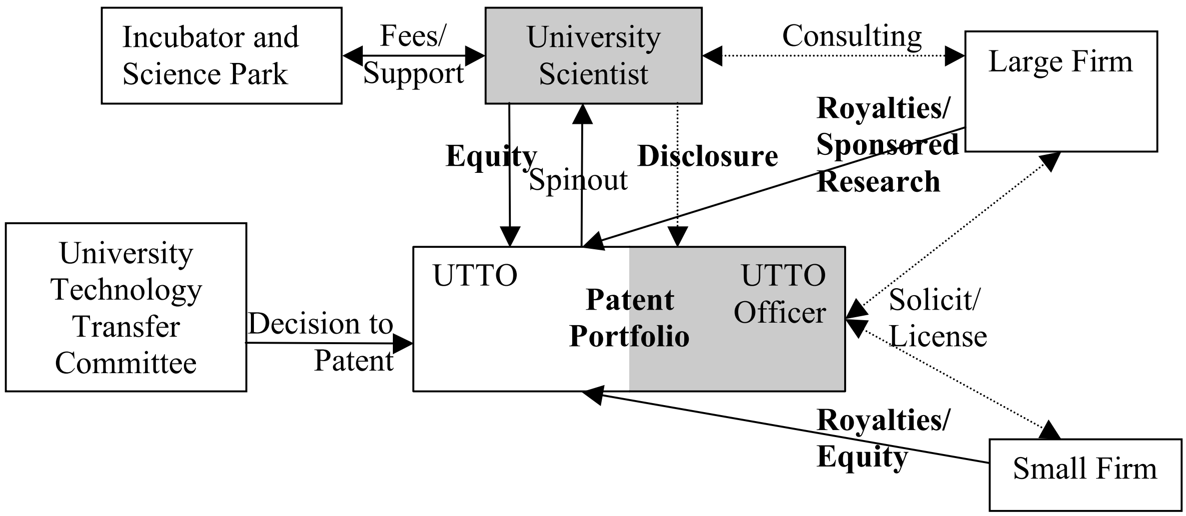
Author(s)	**Unit of Analysis**	**Data/ Methodology**	**Key Results**
Meseri and Maital (2001)	TTOs and University-Based Startups	Authors' Qualitative Survey of Israeli TTOs	Criteria Used by Israeli TTOs to Appraise Entrepreneurial Startups Are Similar to Those Employed by Venture Capitalists
Markman, Phan, Balkin, and Giannodis (2004a)	TTOs and University-Based Startups	AUTM Survey, Authors' Survey/Linear Regression Analysis	Equity Licensing and Startup Formation Are Positively Correlated With TTO Wages; Uncorrelated or Even Negatively Correlated With Royalty Payments to Faculty Members
Markman, Phan, Balkin, and Giannodis (2004b)	TTOs and University-Based Startups	AUTM Survey, Authors' Survey/Linear Regression Analysis	There Are Three Key Determinants of Time-to Market (Speed): TTO resources, Competency in Identifying Licensees, and Participation of Faculty-Inventors in the Licensing Process
Markman, Phan, Balkin, and Giannodis (2005)	TTOs and University Startups	AUTM Survey, Authors' Survey/Linear Regression Analysis	The Most Attractive Combinations of Technology Stage and Licensing Strategy for New Venture Creation-Early Stage Technology and Licensing for Equity-Are Least Likely to Favored by the University (Due to Risk Aversion and a Focus on Short-Run Revenue Maximization)
Audretsch (2000)	Entrepreneurs in the Life Sciences	101 Founders of 52 Biotech Firms/Hazard Function Regression Analysis	University Entrepreneurs Tend to Be Older, More Scientifically Experienced
Louis, Blumenthal, Gluck, and Stoto (1989)	Faculty Members in the Life Sciences	778 Faculty Members from 40 Universities/ Regression Analysis	Key Determinant of Faculty-Based Entrepreneurship: Local Group Norms; University Policies and Structures Have Little Effect

Table 3 (cont.)
Studies of the Antecedents and Consequences of Start-up Formation at Universities

Author(s)	Unit of Analysis	Data/ Methodology	Key Results
Bercovitz and Feldman (2004)	Medical School Researchers at Johns Hopkins and Duke	Determinants of the Probability of Filing an Invention Disclosure	Three Factors Influence the Decision to Disclose Inventions: Norms at the Institutions Where the Researchers Were Trained and The Disclosure Behaviors of Their Department Chairs and Peers
Zucker, Darby, and Brewer (1998)	Relationships Involving “Star” Scientists and U.S. Biotech Firms	Scientific Papers Reporting Genetic-Sequence Discoveries, Data on Biotech Firms from the North Carolina Biotechnology Center (1992) & Bioscan (1993)/Count Regressions	Location of Star Scientists Predicts Firm Entry in Biotechnology
Zucker, Darby, and Armstrong (2000)	Relationships Involving “Star” Scientists and U.S. Biotech Firms	Scientific Papers Reporting Genetic-Sequence Discoveries, Data on Biotech Firms from the North Carolina Biotechnology Center (1992) & Bioscan (1993)/Count Regressions	Collaboration Between Star Scientists and Firm Scientists Enhances Research Performance of U.S. Biotech Firms, As Measured Using Three Proxies: Number of Patents Granted, Number of Products in Development, and Number of Products on the Market
Zucker and Darby (2001)	Relationships Involving “Star” Scientists and Japanese Biotech Firms	Data on Biotechnology Firmsand the Nikkei Biotechnology Directory	Collaboration Between Star Scientists and Firm Scientists Enhances Research Performance of Japanese Biotech Firms, As Measured Using Three Proxies: Number of Patents Granted, Number of Products in Development, and Number of Products on the Market

Note: This table is based on material presented in Link and Siegel (2005)

Figure 1: A Process Model of University Technology Transfer



*Shaded areas are potential entrepreneurial actors
** Bold represent resource flows

Figure 2:
Example of a Complete Technological Entrepreneurship Curriculum

Faculty	**Institution**	**TTO Stakeholders**
Interdisciplinary theory	Incubator/ Technology Park	Entrepreneurship courses
Evaluation/Policy research	Technology transfer	Technology familiarization
Practitioner research	Knowledge clusters	Internships
Academic conferences	Angel Network	Idea labs
Research workshops	Venture forum	Business plan competitions
Ph.D. program		Venture forum

Figure 3:
A Phase-Model of a Technological Entrepreneurship Program for TTO Stakeholders