

Entrepreneurial Universities and Technology Transfer: A Conceptual Framework for Understanding Knowledge-Based Economic Development

Janet Bercovitz¹
Maryann Feldmann²

ABSTRACT. This paper offers a framework to illuminate the role of universities in systems of innovation. The framework attempts to incorporate economic, social, and political influences that affect the ability of universities to both create new knowledge and deploy that knowledge in economically useful ways and thereby contribute to economic growth and prosperity. The objective of this paper is to build a more general understanding of university–industry relationships and their role in knowledge-based innovation systems.

Key words: universities, entrepreneurship, technology transfer, economy development, knowledge base.

JEL Classification: O21, O31, O34

1. Introduction

Universities figure prominently in any discussion of the production, diffusion, and deployment of knowledge and innovation that supports economic growth. While universities have long served as a source of technological advances for industry, university–industry collaboration has intensified in recent years due to four interrelated factors: the development of new, high-opportunity technology platforms such as computer science, molecular biology and material science; the more general

growing scientific and technical content of all types of industrial production; the need for new sources of academic research funding created by budgetary stringency; and the prominence of government policies aimed at raising the economic returns of publicly funded research by stimulating university technology-transfer (Geuna, 1998, pp. 5–6). Etzkowitz (1983) has coined the phrase *entrepreneurial universities* to describe the series of changes that reflect the more active role universities have taken in promoting direct and active transfer of academic research.¹ However, technology-transfer is challenging as private firms and research universities have profoundly different missions and often display mutual distrust (Slaughter and Leslie, 1997). While universities are often regarded as holding important assets that could be leveraged for economic development, the presence of a local university may be necessary, but not sufficient, to guarantee that knowledge-based economic development takes place.

The intention of this paper is to offer a framework that may be used to illuminate the role of universities in the study of innovation. Economic development benchmarking relies on a variety of metrics that may be regarded as either inputs to innovation or outcomes. This view tends to ignore the process of transferring technology and the factors that condition its success. The framework proposed here examines the black box of university technology-transfer and considers the motivations and incentives provided to the various actors. These, in turn, are affected by economic, social, and political influences that shape the ability of universities to both create new

¹University of Illinois at Urbana-Champaign
College of Business
1206 South Sixth Street
Champaign, IL 61822, USA
E-mail: jbercov@uiuc.edu

²Joseph L. Rotman School of Management
University of Toronto
105 St. George Street
Toronto, ON, M5S 3E6
Canada
E-mail: maryann.feldman@rotman.utoronto.ca



knowledge and deploy that knowledge in ways that are economically useful to firms. Thus, we identify and examine points of influence and specific factors that enhance or inhibit the creation and transfer of academic science.

Labor mobility is obviously one mechanism of knowledge spillovers and a growing literature documents the importance of social interaction, local networks, and personal communication in knowledge transmission. Yet individual agents work within organizations and institutions that are defined by routines, norms and standard operating procedures. The ways in which social interaction is initiated, the governance and evolution of working relationships, and ultimately, the efficiency with which knowledge is absorbed and put into economic use are a function of this context.

The next section of this paper presents a conceptual framework to model the role of universities in systems of innovation. The elements of this framework are developed and discussed in turn. The final section concludes with policy recommendations.

2. Conceptual model

The commercialization of university research, at its simplest, is a dyad involving transactions between the university and a commercial firm. Commercializing a technology may encompass many different types of transactions between a university and the company and different types of transactions may occur sequentially to reinforce commercialization. Ultimately, a relationship may develop that furthers the interests and goals of each party. Universities themselves are complex bureaucracies with their own rules, rewards and incentive structures. Moreover, in contrast to commercial firms with a relatively simple profit motive, universities have complex objective functions that involve a variety of educational and societal objectives as well as the interests of faculty members and the larger scientific community.

Figure 1 provides the conceptual framework that guides our analysis of university–industry relationships. Universities’ relationships with industry are formed through a series of sequential transactions such as sponsored research, licenses,

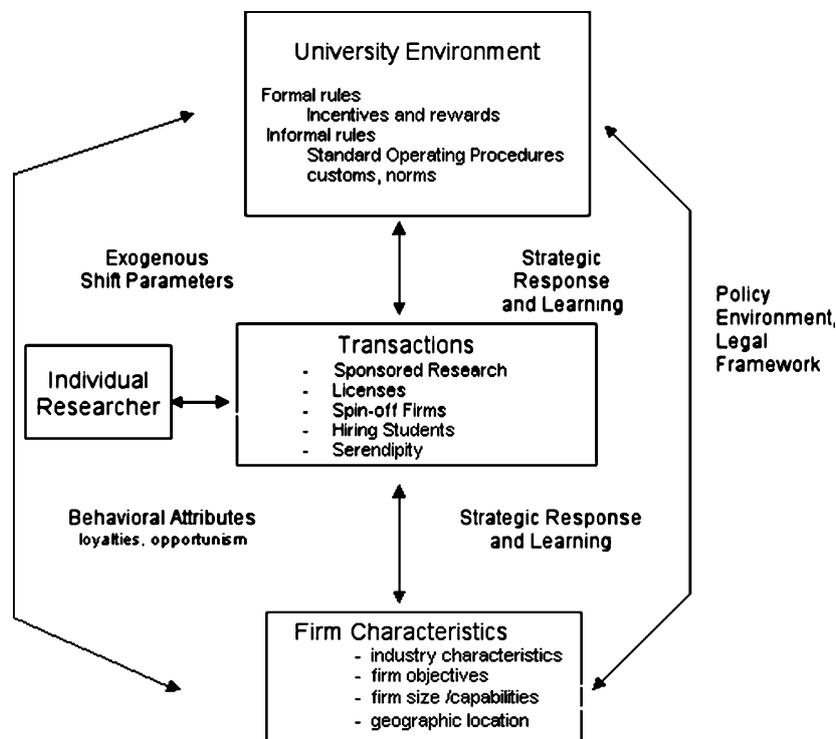


Figure 1. University–industry relationship evolutionary schema.

spin-off firms and the hiring of students. Scholars have tended to analyze formal mechanisms such as sponsored research agreements, licenses, or equity swaps (see, for example, Mowery and Ziedonis, 1999; Siegel *et al.*, 1999; Feldman *et al.*, 2002; Thursby and Kemp, 2002) when investigating technology transfer. While enlightening, this focus is narrow as firm–industry interactions combine formal and informal interactions and are influenced by firm strategy and industry characteristics, university policies as well as the structure of the technology transfer operations and the parameters defined by government policy.

Transactions as transfer mechanisms

The core elements in university–industry relationships are transactions that occur through the mechanisms of sponsored research support (including participation and sponsorship of research centers), agreements to license university intellectual property, the hiring of research students, and new start-up firms. To be inclusive, serendipity is also included as an informal mechanism that might be used to initiate a relationship, which subsequently develops through other mechanisms. Each of these mechanisms is briefly described in Table I.

Sponsored research is defined as a contract between the academic entity and the firm. A sponsored research project supports research commissioned through the university and provides resources for infrastructure, graduate students, course releases and summer support for faculty members. In this way, sponsored research is an important input to the technology transfer process. The majority of sponsored research is funded by government agencies. The amount of industry support varies significantly between countries.

Sponsored research may also involve company participation in an industry-funded research center and consortium. Moreover, individual firms make strategic decisions to sponsor university research which affects the types of alliances they form with universities and the attributes they are looking for in a university partner (Bercovitz and Feldman, 2005). The conventional wisdom, in general, is that government funding is more basic and less restricted while industry funding is more focused and later stage.

The ability of the university scientist to engage in sponsored research as well as the incentives, behavioral norms, and configurations of the relationship are part and parcel of an innovation system and affect both resources available to scientists and the types of problems considered. Sponsored research may take the form of grants or contracts. Grants are more open ended in terms of outcomes, while contracts typically enumerate a set of specific deliverable products and explicit end results. Contracts typically entail closer working relationships with industry, and both parties negotiate the legal specifications of the contract and the ownership of the resulting intellectual property. The sponsored research agreement may specify the ownership of any resulting intellectual property and may also provide details for licensing of potential patents, divisions of royalties, and future sponsored projects. The characteristics of individual companies also affect the choice and specification of the sponsored research transaction. For example, Cohen *et al.* (1992) found that industry–university research center participation was favored for engineering technologies, while biomedical companies are more likely to support sponsored research projects. From the perspective of companies, sponsoring research projects also provides a mechanism to influence the training of

Table I
Formal and Informal transactional mechanisms of university technology transfer

Mechanism	Definition
Sponsored research	An agreement by which the university receives funding for conducting a research project
Licenses	Legal rights to use a specific piece of university intellectual property
Hiring of students	Recruitment of students from the university, especially those working on sponsored projects
Spin-off firms	A new entity that is formed around the faculty research or a university license
Serendipity	Simple luck or chance

advanced students while also observing and screening the students for potential future employment.

Consulting agreements with individual faculty are outside the university technology transfer purview, and the company that pays the faculty member for his time typically owns any intellectual property created. In this way, the university does not have any rights to the intellectual property and loses the potential funding source. To the extent that legal and institutional constraints favor consulting instead of sponsoring university research, the position of universities may be diminished. The university may reserve the right to review research agreements done through faculty consulting or may monitor the amount and compensation received. While measures of sponsored research are routinely published, less is known about faculty consulting. This yields an underestimation of the impact of the university in transferring technology. Most pointedly, faculty consulting may complement university technology transfer potential if it opens new research topics and insights into practical problems for the faculty member.

Another contractual technology-transfer mechanism is university licenses, which provide the right for companies and others to use university intellectual property in the codified form of either patents or trademarks. These formal transactions involve a quid pro quo motivated to provide funding to universities while transferring knowledge and intellectual property rights to firms.

Licensing agreements differ significantly in terms of their specifications and scope. Contractual licensing agreements involve selling a company the rights to use a university's inventions in return for revenue in the form of up-front fees at the time of closing the deal, and annual, ongoing royalty payments that are contingent upon the commercial success of the technology in a downstream market. The licensing deal depends upon the assessment of the value of the technology in a downstream product market which is often difficult to assess and highly uncertain.

Knowledge is both difficult to value and difficult to appropriate (Zeckhauser, 1996). Contractual mechanisms used to transfer knowledge such as licensing agreements are structured as market transactions—the terms of the transaction are mutually negotiated and voluntarily agreed upon.

But in contrast to the typical goods involved in market transactions, the value of knowledge is uncertain, with uncertainty being highest for the most upstream, basic research activities. Formal technology-transfer agreements are negotiated prior to the research being complete and at a time when the commercial value of the end results is not known. Thus, negotiations are based on estimates of the subjective expected value of that portion of the knowledge that a firm will be able to appropriate. This imperfect estimate of the value of knowledge to the contracting firm may entail a market failure: the contractual price may significantly differ from the social value.

Royalty rates and terms, and license issue fees are negotiated. Bray and Lee (2000) report that license issue fees typically range from \$10,000 to \$50,000 but may be as high as \$250,000 while royalty rates are typically 2–5%, but may be as high as 15%. Licensing agreements vary significantly in terms of the scope of the license granted—nonexclusive/exclusive scope (by sector or geography), the level of royalty rates, publication delay allowances, duration, and future option rights (cf. Raider, 1998; Barnes *et al.*, 1997). Other critical factors—such as the attributes of the technology, the characteristics of the corporate partner, the policy(ies) of the university holding the patent, the history of relationships between the two players, the role of spatial proximities, or other idiosyncratic factors—have not yet been studied in detail. The relative bargaining power of the university and the company may be very uneven depending upon such factors as the relative sophistication and resources of the two players and attributes of the technology such as its commercial promise and distance to market, among others. As a result, the deals negotiated between one firm and several universities or between one university and its licensees may be very different. This negotiation, often the first transaction in what both parties might initially see as a long term relationship in order to commercialize a technology, potentially sets up adversarial positions between the two actors.

In addition to the potential for generating new sources of revenue for universities, the licensing mechanism offers an opportunity for demonstrating that the university was actively engaged

in disseminating research results attractive to industry. In addition, licensing had previously been conducted by a small number of elite universities and these cases were well-known and generally regarded as examples of the activist roles that were required of universities in the wake of declining industrial competitiveness that was the rhetoric of Bayh-Dole. New entrants tried to emulate these efforts and increased licensing activity was perceived as an indication that these universities had the potential to advance industrial activity as well as to serve as engines of growth for their local economies. Thus, licensing activity conferred a certain degree of prestige for these universities.

The right of faculty to share in the licensing revenue was a provision of the US Bayh-Dole Act, but the percentage varies as a matter of university policy. Although faculty enjoy the prospect of increasing their income, the after-tax return to faculty from royalties has been relatively disappointing and compares unfavorably with the revenue that faculty may earn from consulting (Blake, 1993).

The product on which license income is paid may be profitable only because of extensive in-house R&D, manufacturing competitiveness, or the marketing strength of the licensor. A recent survey of technology transfer officers (Jensen and Thursby, 2001) found that only about 12% of technology that is licensed is ready for commercialization. The majority of licensed technology requires significant development work and ongoing cooperation with faculty to advance towards a commercial product.

There is anecdotal evidence that the dimensions of licensing agreements have changed over time. At first in the US, most university licenses were granted on a non-exclusive basis to all companies reflecting provisions of the Bayh-Dole Act. Universities now are more likely to negotiate licenses that are calibrated to certain use or specific geographic markets and reflect industry practices. American universities have also experimented with taking equity in lieu of traditional licensing fees (Feldman *et al.*, 2002).

The last two mechanisms in Figure 1, spin-off companies and the hiring of students are somewhat different in that they involve a more direct technology transfer that takes place through the

movement of people. The typical model of the advanced research student is predicated on the German model, which essentially provides a scientific apprenticeship. As such it depends on a great deal of attention and mentoring. The opportunities to implement this model depend on the workload of professors, the incentives and rewards offered for different types of activities, and the supply of well-prepared students. Kim (1993) concludes that the Korean system of innovation was adversely affected from 1966 to 1985 when the student–professor ratio increased from 22.6 to 35.8, effectively changing the orientation from research to undergraduate teaching. This effectively decreased the supply of advanced students who could be hired by industry and the supply of ideas that might be used to form companies (Kim, 1993).

University spin-offs have become a favored mechanism by which universities transfer technology to the commercial realm. Based in part on the examples of the Massachusetts Institute of Technology and Stanford University, which played an active role in the genesis of industrial clusters in Route 128 and Silicon Valley, respectively, university spin-offs are seen as a means to transform local economies and a mechanism which provides a way to capture the benefits of proximity to research universities. A variety of definitions may be used to describe university spin-offs: firms formed by university, faculty, or staff; firms formed around a university license of intellectual property; startup firms that have joint research projects with the university; and firms started by students or post-docs around research conducted at the university.²

While university licenses have no locational constraints, entrepreneurship is a decidedly local phenomenon. In general, entrepreneurs who start companies do not relocate but instead stay close to the source of their perceived competitive advantage, which is typically the referent organization where the founder was previously employed (Feldman and Francis, 2002). For university-based spin-offs the university serves as the source of advantage providing skilled labor, specialized facilities and expertise. In addition, faculty who start companies will split their time between the university and the firm making close location advantageous. As universities and state

governments have provided incentives for faculty to start companies or engage in joint research projects with companies, the attraction of proximity to universities has grown. In 1999, AUTM reports that university licensing led to the formation of 344 new companies, with 82% operating in the same state as the university that provided the license.

Individual researcher

At the heart of technology transfer is the individual faculty member who is motivated by a set of personal and institutional incentives. Life-cycle models of scientists suggest that scientists invest heavily in human capital early in their careers to build reputation and establish a position in a field of expertise (Stephan and Levin, 1992). In the later stages of their career, scientists typically seek an economic return for their human capital. For scientists, starting a company serves the purpose of appropriating the value of their intellectual property as well as providing access to additional funding mechanisms to further the scientist's research agenda. Most critically, academic researchers, especially government-funded researchers, must have the ability to retain some rights over their intellectual property to engage in commercial activity (Eisenberg, 1987). The potential financial rewards of starting a company coupled with tightening university budgets and competition for the relatively fixed pool of public funding create incentives for scientists to engage in entrepreneurial activity (Powell and Owen-Smith, 1998).

Individual scientists have the intellectual capital to engage in commercialization activity whether by simply disclosing an invention or the more involved activity of starting a company; however, there are other barriers to consider. For example, both national culture and academic socialization can influence the degree to which individual scientists participate in technology-transfer activities. McFetridge (1993) finds that Canadian academics are relatively immobile and have no incentives to engage in entrepreneurial activity. Also, Keck (1993) concludes that the intellectual orientation of German university professors made them averse to exploiting new ideas for commercial purposes even as they were encouraged to do so by university and government policy.

Thursby and Thursby (2002) provide three reasons why individual faculty members in the United States might not choose to participate in technology transfer activities. First, faculty who specialize in basic research may not disclose because they are unwilling to spend time on the applied R&D required to interest businesses in licensing the invention. Second, faculty may not disclose inventions because they are unwilling to risk publication delays associated with patenting that may be required to interest industrial partners in licensing the technology. Third, faculty members may not disclose, because they believe that commercial activity is not appropriate for an academic scientist. This view certainly represents the established norms of open academic science that favour publication over patenting.

Bercovitz and Feldman (2004) find that the decision of the individual faculty member to participate in technology transfer through the process of disclosing inventions is strongly influenced by three factors: training effects, leadership effects and cohort effects. Individuals are more likely to disclose inventions if they trained at institutions at the forefront in terms of technology transfer benchmarking. Individuals who trained at institutions that have long established and relatively successful technology transfer operations are more likely to disclose their inventions. In addition, the longer the time that had elapsed since graduate training, the less likely the faculty member was to actively embrace the new commercialization norm. Moreover, the actions of the chair of the department appear to influence behaviour: if the chair is active in technology transfer then other members of the department are also likely to disclose. Most strikingly, technology transfer behavior is mediated by the experience of those in a similar position, in terms of academic rank and departmental affiliation. If an individual can observe others at their academic rank disclosing, then they are more likely to participate in technology transfer.

Firm characteristics

The picture is not complete without an understanding of university-industry technology transfer from the firm's perspective. Unfortunately, there are few studies that consider the

firm, rather than the university, as the focal actor. Prior research demonstrates significant variation in firms' use of external resources, organization of inter-firm R&D activity, and objectives in inter-firm R&D strategic partnerships. Though the broad literature on strategic R&D alliances mentions the importance of firm–university alliances, it does not specifically focus on the unique aspects of universities as research partners. As such, we have only limited understanding of how university interactions fit within the firm's broader R&D strategy—and how firm strategy and organizational structure influence both the technology-transfer mechanisms employed by the firm and the ultimate relationship the firm maintains with the university.

Previous research has shown, however, that linking with external entities is a key element of successful exploration strategies that emphasize the search, discovery, and development of new knowledge (Von Hippel, 1998; March, 1991; Cockburn and Henderson, 1994; Rosenkopf and Nerkar, 2001). Specifically, such interactions give the firm access to knowledge that differs from, but can complement, the firm's existing technology portfolio. It is the integration of this new knowledge that leads to path-breaking innovation. Academic researchers perform a great deal of cutting-edge research and universities are known sources of new knowledge (Rosenberg and Nelson, 1994). As such, we expect that pursuing university interactions to tap into such expertise is likely to be more highly valued by firms with innovation strategies that emphasize exploration rather than exploitation—the refinement, extension, and intelligent use of existing competencies (March, 1991; Levinthal and March, 1993).

In general, early stage technologies such as those originating at universities require more extensive research investment to reach commercial viability. Further, while the transfer of knowledge across organizational boundaries is always challenging, this challenge is intensified the more radical the technology to be transferred. As Mowery and Rosenberg (1989, p. 7) note, “a new technology is a complex mix of codified data and poorly defined ‘know-how’”. The successful transfer of the tacit component of this new knowledge generally requires close and ongoing

interactions between the inventor and the purchaser (Teece, 1985). This is particularly true if the recipient has limited direct experience with the technology (Cohen and Levinthal, 1990). This implies that the firm's capacity and willingness to engage in multiple transactions will affect the potential of effectively transferring meaningful university-based knowledge.

University technology transfer strategy and structure

Universities are social as well as economic institutions. Faculty behavior is based on social norms, organizational structure, and incentives regarding promotion and tenure (Geiger, 1993). For example, institutional policies regarding faculty commercialization incentives, acceptable publication delays and the charters of technology transfer offices vary greatly across research institutions and have evolved over time. University policies influence the comparative cost of technology transfer, and there is great variation in the composition of university–industry relationships across institutions and the ways in which participation in technology transfer activities is rewarded.

Understanding historical context provides an instructive though unfortunately overlooked perspective on current activity and performance. Feldman and Desrochers (2003, 2004) focus on the evolution of technology transfer activities at Johns Hopkins University. By any number of measures and independent assessments, it is one of the world's leading institutions of higher education and research. Yet, despite substantial academic achievements, Hopkins provides an example of a university that has had little direct effect on the regional economy in terms of reaping the benefits of the university's research in terms of spin-off companies and mutual relationships (Feldman, 1994) and thus provides an interesting contrast to the well-studied examples of Stanford and MIT. Changing university culture is possible; however it takes time and requires providing the correct incentives (Bercovitz and Feldman, 2004).

The ability of individual scientists to appropriate the value of intellectual property will be affected by university patent and copyright policies. Consequently, variation in intellectual

property rights is one important factor that may affect technology transfer outcomes (Lach and Schankerman, 2003). Siegel *et al.* (1999) have noted that technology transfer outcomes may depend on organizational practices that potentially attenuate palpable differences in the motives, incentives, and organizational cultures of the players involved in this process.

Bercovitz *et al.* (2001) consider how university organizational structure mediates technology transfer outcomes, finding that technology transfer activities, manifested as licensing university-created knowledge, seeking additional sponsorship of R&D projects or a combination of these two, are shaped by the resources, reporting relationships, autonomy, and/or incentives of technology licensing offices. The analysis treats the structure of the technology transfer office as an independent variable that accounts, in part, for measured inter-institutional differences in patenting, licensing, and sponsored research activities. This analytical lens permits a sharpened focus for examining variation which others have alluded to in caveats or qualifying statements, but which has not been systematically studied.

3. Dynamics: from transactions to relationships

As depicted in Figure 1, the five transaction mechanisms listed in Table I do not occur in isolation. University–industry relationships are multifaceted, complex, and diverse, and feedback loops are common. Commercializing a technology may encompass many different transactions between a university and a company. For example, commercialization can involve multiple licenses and require that a company fund a sponsored research project for developmental work to usefully apply the licenses. In addition, the company may subsequently hire students who worked on the sponsored project. The relationship may be so fruitful that the company may ultimately endow a university chair or make another type of philanthropic gift. Only by considering the complexity of the industry–university relationships can we obtain a fuller understanding of their nature and impact.

This framework also incorporates organizational learning effects that dictate evolution in the

form of the industry–university relationship. Feedback effects, for example, may include an improvement in contract specification, brought about because the existing specification was found to be poorly suited to support the integrity of contract. Moreover, through the knowledge exchange of a single transaction additional projects and ideas for research may result.

In this framework, we expect to see a progression from single transactions to longer-term relationships as trust and joint vision are built. For example, a firm's licensing experience with a particular university, if positive, is expected to increase the likelihood of the adoption of a sponsored research agreement. Following this, firm involvement with sponsored research or licensing may increase the likelihood of corporate gifts. Alternatively, if initial experience with the university technology-transfer office is negative, firms may engage in opportunistic behavior by contracting directly with faculty members, bypassing the university intellectual property apparatus.

These elements may be best understood by framing patent and licensing transactions within the larger relationship framework. The national and local policy environment and legal framework, the university environment, and the characteristics of companies influence the efficiency and thus evolution of these university–industry relationships. Institutional policies, for example, regarding faculty commercialization incentives vary greatly even within the same innovation system.

4. The policy context for innovation

Academic research, whether basic and largely uncodified or applied and codified in the form of patents, represents only the raw material from which commercially competitive technological innovations are constructed (Von Hippel, 1998; David *et al.*, 1992; Dasgupta and David, 1994). Supporting institutions and legal frameworks are credited with the emergence of the industrial revolution (Rosenberg and Birdsell, 1986). Similarly, the institutions at both the national and regional level set the parameters for the effectiveness of the commercialization of academic research and the resulting impacts on economic growth.

Technology transfer policies involve an inherent compromise that accommodates the public good nature of knowledge spillovers while providing the property rights that are required to guarantee returns for the additional private investment required to commercialize academic research. Although governments typically have provisions for university intellectual property protection, there are great differences in their enforcement and use. In the US case, commercialization of biotechnology and microelectronics by university startups was aided by a permissive intellectual property regime. For example, the 1986 consent decree that settled the suit against AT&T resulted in liberal licensing and cross-licensing policies that aided start-ups in telecommunications. In biotechnology, uncertainty over both the strength and breadth of intellectual property protection discouraged litigation and encouraged industry and academia to work together (Mowery and Rosenberg, 1993, p. 49).

Nations also differ greatly in terms of the resources allocated to university R&D and in terms of the percentage of funds that come from industry. Table II demonstrates that the percentage of GNP spent on university R&D varies from a high of 2.8% in Japan to a low of 0.7% in the Russian Federation. Industry support of academic R&D varies from a high of 10.7% in Canada to a low of 2.3% in Japan. Of course, caution should prevail when interpreting these numbers given

differences in the way governments account for expenditures.

Universities are involved in a two-phase process that involves first the production of knowledge and then its application and diffusion. Linkages between academic and industrial research appear to be powerfully influenced by the degree of centralization of the funding system. There is a belief that competition for funding, diversity of funding sources, and, in general, a decentralized funding system would be more conducive to university–industry relationships. It is easier for industry to sit at the table in a decentralized system. In addition, decentralized systems tend to be responsive to local industries. For example, Mowery and Rosenberg (1993, pp. 35–36) argue that systems in which the federal government allocates research funding (for example the United Kingdom and France) are not as responsive to industry as are systems such as the United States and Germany, where states allocate substantial funding. Decentralization may also be manifested by a number of separate federal agencies with distinctly separate missions and goals that generate heterogeneous demand for research. We may expect that considerations such as the degree of competition between universities for funding, the diversity of sources such as foundations, and other entities that may fund riskier research can have an effect on the relationship. For example, the four Framework Programs of the European Communities for the support of cooperative R&D

Table II
University funding varies significantly across nations (percent)

Country	University Funds as a Percent of GNP	Percent of University R&D Funded by Industry
Japan	2.78%	2.33%
Germany	2.28%	7.54%
France	2.34%	3.15%
United Kingdom	2.05%	6.20%
Italy	1.14%	5.53%
Canada	1.61%	10.67%
United States	2.52%	5.47%
Russian Federation	0.73%	N/A
Czech Republic	1.15%	N/A
Hungary	0.75%	N/A
Poland	0.74%	N/A

Source: NSF (1998. (Washington, DC: Government Printing Office). Appendix table 4–42, 4–43, 4–45, 4–46). Data are for the year 1995 for Japan, the United Kingdom, the United States, the Russian Federation, Czech Republic, Hungary, and Poland. Data are for 1996 for Germany, Italy, and Canada. French data are for 1994.

projects have taken a highly competitive approach. Knowledge production increasingly is trans-disciplinary and depends on the ability of researchers to work with others across a broad spectrum of disciplines. A system that adheres to rigid disciplinary boundaries in funding research projects will inhibit these interactions and thus may limit technology-transfer opportunities.

Regional policy operates within the confines of parameters defined by the national system with great variation in autonomy regarding funding local initiatives. Within the federalist systems found in the US, Germany, Canada and Australia, there is greater autonomy and more focus on increasing economic efficiency and competitiveness. For example, in the US, each of the fifty states provide a myriad of specialized programs ranging from business planning services to marketing and personnel training assistance (Schachtel and Feldman, 2000). More centralized governments tend to place greater focus on redistribution.

Regions begin with pre-existing industrial structures that are the result of history. An older economic development strategy of providing cost-reducing incentives is based on the neoclassical view that firms' location decisions are responsive to small difference in input prices: firms should prefer locations that offer lower factor prices and therefore state programs that reduce costs should influence locational decisions. However, for high technology firms in particular, skilled labor services and proximity to sources of knowledge and expertise are much more important than cost reductions. Indeed, innovative start-ups frequently create new markets where no competition exists and demand is not sensitive to product costs. The small firms' competitive advantage lies in being first to market or offering a higher quality product. Small firms, lacking the resources of their larger counterparts, are more dependent on resources in their local environments. Indeed, many times small firms become the mechanism by which academic knowledge is commercialized. Therefore, the success of the firm and the success of the region are inter-related or endogenous in the terminology of economics.

Many local political initiatives are aimed at leveraging local universities for their knowledge-based growth potential and have met with varying degrees of success. Visible efforts such as local

incubators and science parks are demonstrable indicators of commitment (Link *et al.*, 2003). The cases where governments have established a cluster by fiat such as Science Park in Taiwan or the Bio-Regio clusters in Germany have not yet generated mature, innovative industrial clusters. Perhaps it is too early to judge in all cases. In other cases, the attempt to artificially establish a cluster where none existed previously has resulted either in failure or resulted in a completely different type of cluster than initially envisioned. A good example is New Jersey's attempt to create a Silicon Valley-type high tech sector that eventually resulted in a limited research consortium (Kargon and Leslie, 1997). Cortright and Mayer (2001) conclude that there is no general set of conditions that generate particular industrial clusters in the US; rather, there appears to be a unique factor associated with each. An alternative view is that cluster formation is a process—a complex self-organizing process that is predicated on the actions of entrepreneurs and their symbiotic relationship with their local environments. The cluster and the characteristics of the cluster therefore emerge over time from the individual activities of the entrepreneurs and the organizations and institutions that co-evolve to support them (Feldman, 2000; Feldman and Francis, 2002).

The idea that universities may be engines of local economic development is challenged by the counterfactual cases of prominent research universities that have not spawned technology-based spin-offs. Feldman (1994) examines the case of Johns Hopkins University and the Baltimore region. Although Johns Hopkins is one of the world's pre-eminent institutions and receives more research funding than either Stanford or MIT, the surrounding region has not benefited from technology-based industrial activity. Feldman (1994) provides evidence that the region was not able to develop an innovative infrastructure that allowed it to capture the benefits of proximity to the local research university. In subsequent work, Feldman and Desrochers (2004) examine the historical relationship of the university with the local economy and question if the current emphasis on academic-industry interaction with its emphasis on short-term measure transactions may undermine and destroy that very strength and diversity

Table III
 Considerations that affect university technology transfer mechanisms

Mechanism	Considerations
Sponsored research	Is there a supply of research relevant to industry? Are there economic incentives to finance university R&D? Are there antitrust provisions that limit company involvement in research consortia?
Hiring of students	Is there a sufficient supply of students? Are there screening mechanisms at work?
Spin-off Firms	Are faculty permitted to work outside the university? Are there special provisions to facilitate spin-offs regarding equity swaps, assistance, etc.?
Licenses	What restrictions do funding sources place on licensing? What restrictions do universities place on licensing?
Serendipity	How rich/relevant is related activity in the field/region?

that distinguished universities from other institutions.

To summarize, Table III provides a summary of policy considerations that impact university technology-transfer mechanisms and would vary across innovation systems. These may be regarded as questions to begin an inquiry about considerations that affect the ability of the university to transfer knowledge.

5. Conclusions

Economic development is about innovation and innovative activity. Typically, studies of the role of universities in systems of innovation tend to focus on metrics that are related to inputs and outputs in the familiar logic of a production function. Inputs such as amounts of research funding, numbers of faculty or scientific personnel, quality of academic programs or resources devoted to technology transfer are measurable and collected by government and professional organizations (See, for example, US National Science Board, 2002; AUTM, 2003). The outputs in this context are the number of patents, the number of licenses to industry, the number of spin-off firms or indicators of employment change or economic growth. These elements form a quantifiable component of university–industry interaction; however there is great variation in commercialization of academic discoveries among universities and the relationship of university inputs to a variety of technology transfer output measures is not strictly deterministic and many universities operate below the efficient production frontier (Siegel *et al.*, 1999; Thursby

and Kemp, 2002). This suggests that technology transfer involves social convention and legal rights as well as economic interests.

While universities have a long recognized role in the system of innovation, this role has changed. The new role of universities as engines of local economic development (Feller, 1990) or magic beanstalks of invention and research (Miner *et al.*, 2001) places new demands on universities and raises question about the role of research universities in advanced economies. Many universities have restructured their research capabilities to be more responsive to local industry—for example, setting up specialized research units, joint cooperative ventures or interdisciplinary projects that are more receptive to industrial needs. These specialized units may focus on revitalizing existing industries. In transferring technology, universities contribute to the stock of technologies that firms may draw on for innovation and economic growth. Some have raised the concern that universities are being asked to deviate from a historically successful role and that increased commercial influences may destroy the norms of open science that have promoted the national interest (Nelson, 2001). These same concerns may be raised at the regional level. Universities certainly add more to their local economies than the metrics of technology transfer capture. There are certainly many different modes of how universities interact with and enrich their local economies than simply counting technology transfer indicators.

In the wake of the success of Silicon Valley and Route 128, where thriving locally based firms were often linked to the major academic institutions such as Stanford University and the Massachusetts

Institute of Technology (MIT), research universities have been increasingly called on to help foster local economic development through technology transfer and the formation of startup firms based on academic research. Universities are viewed by many as engines of economic growth and continue to be cited as an important factor in regional technology development and revitalization. However, the process of university-led economic development takes considerable time and patience that is often outside of the immediate demands of the political process. Link (2002) concludes that the development of North Carolina's Research Triangle Park was the result of deliberate public policies that began in the 1920s and took 50 years to realize tangible economic benefit in terms of job growth and enterprise development. Sturgeon (2000) finds similarly that the genesis of Silicon Valley may be traced to the early twentieth century.

Universities have demonstrated their adaptability in their response to active technology transfer. Certainly, attempts to spin off new companies satisfy an increased expectation that universities need to be engaged in local economic development and to demonstrate relevance. We may question if university programs aimed to encourage entrepreneurship are the best use of state and university resources. One of the strengths of the American system of higher education has been its diversity and decentralization. We may also question if the examples provided by WARF, Stanford University and MIT have established a de facto standard against which all research universities are judged and what the long run implications will be.

The basic premise of this paper is that the legal, economic, and policy environments that comprise the system of innovation determine the rate and type of university knowledge production and thereby influence the rate of technological change. Moreover, within a given university, there will be additional internal influences that determine the rates and directions of knowledge flow from that institution. This paper has the modest aim of identifying these influences and speculating on their effect on knowledge transfer. Certainly, given the limitations of space and time, this paper raises more questions than it answers. But certainly an understanding of the evolution of the role of the

university in systems of innovation warrants further attention. If we are going to think creatively about public policies towards increasing university technology transfer, we need to focus on the larger innovation context.

Notes

1. Critics argue that these relationships may detract from the university's basic mission, inhibit intellectual freedom, and foster public mistrust of science. Aspects of these changes have been described in abundance, written from many different analytical perspectives. See, for example, Baldwin and Green (1984–1985), Brooks and Randazzese (1998), Etzkowitz and Peters (1991), Etzkowitz and Leydesdorff (1997), Feller (1990), Geiger (1993), Government–University–Industry Research Roundtable (1986), Lee (1998), Luger and Goldstein (1991), Peters and Fusfeld (1983), Praeger and Omenn (1980), Rahm (1994), Slaughter (1990).
2. The Association of University Technology Managers (AUTM) uses the second criteria, firms formed around a university license to track university spin-offs. In practice, this definition is restrictive as more spin-offs are likely to be the result of individuals associated with the university promoting technology by beginning firms.

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