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ABSTRACT

This study investigated institutional resource factors that may explain differential performance with university technology transfer--the process by which university research is transformed into marketable products. Using multi-source data on 108 research universities, a set of internal resources (financial, physical, human capital, and organizational) and external influences were found to be significant predictors of one or more of three technology transfer performance outcomes (patenting, licensing, and income generation from licenses). Findings included: (1) federal and industry R&D support are important contributors to patenting activity but not to licensing or income generation from licenses; (2) having a medical or engineering school was not a significant predictor of technology transfer success; (3) the quality of an institution's faculty is a critical resource associated with patenting, licensing, and licensing income; (4) there was no difference between public and private schools in technology transfer; and (5) there was a strongly negative relationship between the venture capitalization of a state and the number of licenses and licensing income, and between state support for higher education and licensing income for public institutions. (Contains 59 references.) (EV)

Academic Venturing in Higher Education: Institutional Effects on Performance of University Technology Transfer

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ABSTRACT

This study investigated institutional resource factors that may explain differential performance with university technology transfer, the process by which university research is transformed into marketable products. Utilizing multi-source data on 108 universities, a set of internal and external resources were found to be significant predictors of one or more of three technology transfer performance outcomes.

In recent years, universities, particularly large research institutions, have rapidly escalated their involvement in technology transfer, the process of transforming university research into marketable products. Fueled in part by redefined external expectations for economic development as well as internal pressures to generate new sources of revenue (Slaughter & Leslie, 1997), this emergent commercialization mission for higher education is serving to transform higher education in substantive ways. For example, since 1980 and the passage of the Bayh-Dole Act, the patenting of academic inventions has increased almost sevenfold from 390 for all academic institutions to 2,681 in 1998 (AUTM, 1998; National Science Board, 1998). Furthermore, between 1991 and 1997, a sample of 64 top research universities reported that their licensing of patented technologies to business and industry had more than doubled from 938 to 1,923 licenses issued (AUTM, 1998). Finally, in their most recent licensing survey, member institutions of the Association of University Technology Managers (AUTM) reported that more than 2,500 new companies had been formed since 1980 for the purpose of commercializing a specific university developed technology.

These new entrepreneurial tendencies, however, have generated considerable controversy. Recent research suggests that as colleges and universities have strengthened their linkages with the for-profit sector, the result has been a shift toward more applied research and restrictions by industry R&D sponsors on the publication of new knowledge (Blumenthal, Campbell, Anderson, Causino, & Louis, 1997; Cohen, Florida, Randazzese, & Walsh, 1998). Other research has suggested that pressures to identify new sources of income to fund the increasingly expensive research enterprise has weakened faculty and administration resistance to external influence on the direction of academic inquiry (Argyres & Liebskind, 1998; Slaughter & Leslie, 1997). Additionally, there is evidence that faculty involved in new ventures may be distracted from their primary duties as teachers and scholars as they seek to simultaneously manage the enormous responsibilities associated with running a business (Campbell & Slaughter, 1999). The negatives associated with the entrepreneurial university phenomena, or what Slaughter and Leslie (1997) call "academic capitalism," have also received considerable coverage in the popular press (Barboza, 1998; Marcus, 1999; Press & Washburn, 2000).

Despite the controversy, universities are forging ahead with their technology transfer activities in a quest for new sources of revenue (Bourke & Weissman, 1990; Jennings, 1992) and new found legitimacy as important sources of innovation in a competitive global marketplace (Mansfield & Lee, 1996). However, only a relatively few number of institutions have experienced financial success in technology transfer (United States General Accounting Office, 1998). High profile success stories such as Vitamin D technologies at the University of Wisconsin ($99 million in licensing royalties), the Cisplantin cancer treatment drug at Michigan State University ($86 million in royalties) and Gatorade at the University of Florida ($33 million) are more the exception than the norm[1] (Riley, 1998).

While universities are undoubtedly aware of the considerable challenges and risks inherent in technology transfer, it does not appear to be thwarting institutional interest in being associated with the next Xerox or Polaroid Corporation, companies built around university born inventions (Matkin, 1990). Consider, for example, the case of Boston University and its promising start-up, Seragen, which was built around a new Cancer drug therapy. In the early 1990s the University poured more than $85 million into the firm, at one point almost a fifth of its endowment, convinced that the firm would create enormous profits. However, as is the case with the vast majority of start-ups, particularly those with long incubation periods, the expected jackpot failed to materialize and the University lost over 90 percent of its investment (Barboza, 1998).

[1] Dollars indicated for each invention reflect the total revenues generated as of 1998.

Considering higher education's increasing enthusiasm for technology transfer, research to inform its practice is important. However, while some research has been done on university-industry collaboration in general (Bowie, 1994; Campbell, 1997; Cohen, et al., 1998) and university technology transfer in particular (Dill, 1995; Feller, 1997; Harmon et al., 1997; Matkin, 1990), relatively little work has investigated factors that may explain differential performance with technology transfer. What has been done has generally been of a case study nature (Brett, Gibson, & Smilor, 1991; Roberts & Malone, 1996), regional in scope (Hauksson, 1998; Smilor, Gibson, & Dietrich, 1990), or descriptive in focus (Matkin, 1990). Thus, this quantitative study seeks to fill this research gap by investigating if particular institutional resource factors may explain differences in technology transfer performance across a representative sample of universities engaged in its practice. More specifically, the research question that I explore is what impact, if any, do particular financial, physical, human capital, and organizational resources of universities have on patenting, licensing, and income generation from licenses, three common metrics of technology transfer practice? Furthermore, to what degree does the external environment in which a university is located matter?

The Practice of University Technology Transfer

University technology transfer is generally the context in which current discussions of academic entrepreneurship is framed. Larsen and Wigand (1987) define technology transfer as "the process through which the results from basic and applied research are communicated to potential users" (p. 587). Dill (1995) suggests that "university technology involves formal efforts to capitalize upon university research by bringing research outcomes to fruition as commercial ventures" (p.370). Each of these definitions emphasizes the transformation of university based research into marketable products that can be practically used by external customers. The mechanisms or tools employed by universities to achieve these ends are varied but often include such activity as patenting and licensing of inventions and intellectual property, formal and informal partnerships with business, technical and venture capital assistance for promising ideas and inventions, business incubators, research parks, continuing education operations, and university equity participation in start-up companies (Dill, 1995; Matkin, 1990). For the purposes of this study, the definition of technology transfer chosen is the one used by AUTM. Namely, "Technology transfer is the term used to describe a formal transferring of new discoveries and innovations resulting from scientific research conducted at universities to the commercial sector" (AUTM, 1999, p. 1).

A flow-chart of the technology transfer process is presented in Figure 1. In general, the process begins with a faculty member who in the course of his or her research work, develops a technology that seems to have possible marketplace application. By way of example, Professor George Stookey and colleagues at the Indiana University School of Dentistry had done some research in the mid-1980s on ways to reduce tartar build-up in dogs (Stookey, 2000). They found that the chemical pyrophosphate reduced canine tartar and speculated that if a way could be found to coat milk bones, the product might have considerable market appeal. After additional experimentation, they discovered that coating pet foods with sodium hexametaphosphate (HMP), a chemical close in composition to pyrophosphate, was very effective since it quickly separated from the food when brought in contact with saliva.

Armed with this evidence, they approached the Indiana University Office of Technology Transfer with the idea, a step known as invention or technology disclosure. The staff, experts in evaluating a technology for intellectual property protection[2] as well as its marketability, determined that it was patentable and potentially commercializable (the latter being important

[2]While many technologies are protected through the patent process, some technologies are better suited for copyright or trademark protection such as with software.

- Place Figure One about here -

since patenting is an expensive undertaking). A patent application was then filed and subsequently issued by the U.S. Patent Office in March of 1994. Once the patent was filed, the Office of Technology Transfer contacted major pet food manufacturers about possible interest in a license.

Ultimately, a license was negotiated with the H.J. Heinz Company that gave Heinz exclusive, world-wide rights to the use of HMP and required them to cover all patent costs, a standard practice in the licensing of patented technologies. A graduated royalty payment schedule was arranged with lower payments expected in the first year knowing that it would take some time for Heinz to gear-up its manufacturing and distribution operation. The inventors, the inventor's department, and the Office of Technology Transfer all share in the revenues generated from sales of the product marketed as Tartar Check.

Theoretical Frameworks

As mentioned earlier, wide-scale university involvement in technology transfer is largely a phenomenon of the past twenty years (Feller, 1997). Not surprisingly, then, as a topic of inquiry, it is very young and underdeveloped. What has been published is largely atheoretical as researchers seek to describe and/or understand particular aspects of its practice for which a theory of university technology transfer may ultimately take form.

Although no theory of university technology transfer per se exists at this time, there is enough known about the phenomenon that elements of more developed theories in the strategy and organizational theory literatures can be brought to bear in this study since each provides a unique contribution to understanding what may explain differential performance among America's research universities. Specifically, I ground this study using an integrative theoretical framework that incorporates important elements of the resource-based view of the firm (Barney, 1991; Wernerfelt, 1984) and resource dependence theory (Pfeffer & Salancik, 1978). These theories provide valuable and distinct insights into potential contributory factors to a university's performance w 't their technology transfer programs.

Resource-Based View of the Firm

One theory within the strategic management literature that has received considerable attention in recent years is what is known as the resource-based view of the firm (Connor, 1991). Focused on resources internal to an organization, the resource-based view of the firm suggests that particular idiosyncratic resources, those that are difficult or costly to copy, can provide a firm a competitive advantage in the marketplace when appropriately exploited (Barney, 1997; Grant, 1991). Firms that develop particular internal resource attributes may outperform other competing firms in an industry. These resources could be any number of assets, capabilities, organizational processes, organizational attributes, information, knowledge, etc. that the firm possesses (Daft, 1999).

Research using a resource-based view of the firm has investigated numerous resources as possibly providing performance advantages for a firm. In general, these resources have been grouped into four categories as shown in Table 3 (Barney, 1997).

- Place Table One about here -

Of particular interest to this study is the research identifying important resources for entrepreneurial activity such as would occur with university technology transfer. Some of the unique resources identified have included expert knowledge and scientific capabilities (Deeds, DeCarolis, & Coombs, 1997; Finkle, 1998) as well as access to important personnel, information, and support structures (Flynn, 1993; Mansfield & Lee, 1996; Randazzese, 1996). In addition, researchers have found a direct and positive relationship between university research and the creation of new products and processes by high-technology industries (Mansfield & Lee, 1996) as well as birth rates of new organizations (Flynn, 1993). Hence, in a higher education context, such resources as the quality of one's faculty, the presence of particular programs and infrastructures, the amount of R&D support, and location related factors might represent critical resources of this type for a university and hence predictors of technology transfer performance.

Resource-Dependence Theory

As has been discussed, the resource-based view of the firm focuses on internal resource factors to an organization that contribute to its ability to outperform other firms or organizations in an industry. As is true with many organizational entities functioning in open systems (Lawrence & Lorsch, 1967), the ability to achieve high levels of performance may also be attributable to factors in the external environment to which they have been able to effectively respond. For example, organizations confronting possible reductions or disruptions in the supply of critical raw materials may be stimulated to seek alternative sources as a way of ensuring long-term survival. Organizations that successfully extract these important new sources of supply may outperform those that remained dependent on the old source, particularly if the reductions or disruptions in fact materialize.

Resource-dependence theory (Pfeffer & Salancik, 1978) provides a useful framework for conceptualizing the impact of external resource dependencies and its linkage to performance, issues of additional importance to this study. Rooted in the organizational theory field and embedded in a social model of behavior (Pfeffer, 1997), resource dependence theory argues that the behavior of organizations is explained through the lens of ongoing social interactions (Granovetter, 1985) and that "organizations are inescapably bound up with the conditions of their environment" (Pfeffer & Salancik, 1978, p. 1). Causal explanations for organizational behavior are found through analyses of the social interactions of an organization with its external environment rather than relying on rational, economic theory approaches to organizational behavior that at times have been inadequate for explaining seemingly irrational action (Pfeffer, 1997).

Considering this perspective, resource dependence theory argues that organizations seek to reduce their dependence on suppliers of critical resources in ways that better ensure the long-term survival of the organization (Pfeffer & Salancik, 1978). Slaughter and Leslie (1997), in their study of higher education and its growing entrepreneurial orientation, argued that research universities, confronted with reductions in tradition sources of income such as through state block grants, have sought to reduce dependence on this source of revenue by escalating their involvement in commercial activity for revenue enhancement purposes. In doing so, universities are ostensibly able to obtain greater control over resource flows while simultaneously enhancing their legitimacy as an engine of economic development, an issue of considerable recent interest to federal and state policymakers. As such, within a resource dependence framework, institutions experiencing greater threats to their revenue streams such as with state block grants would be expected to have technology transfer programs that outperform schools experiencing more robust resource flows from traditional sources of income.

Methodology

The sample of 108 Research I and II institutions was drawn from data reported in the annual licensing surveys of the Association of University Technology Managers (AUTM) for the period 1991 to 1998. The AUTM surveys are the only comprehensive and national source of data on technology transfer activity. The inclusion of these Research I and II institutions in the sample was appropriate because the bulk of technology transfer is largely represented by this subset of American universities and there is considerable variation in technology transfer activity even among this group of institutions. Additionally, these geographically diverse institutions represent 84% of the Carnegie Research I institutions and 62% of the Carnegie Research II institutions in this country as well as 82% of the land-grant institutions. Thus, statistical inferences about the overall population of institutions most likely to be engaged in technology transfer is possible.

Variable Measures

This study drew from multiple archival sources. In addition to data collected from the AUTM surveys, data on internal resources to particular universities were obtained from the National Science Foundation, the National Academy of Sciences, and Peterson's Guide to Colleges and Universities. Information on external resources were collected from Cognetics annual reports of entrepreneurial hotspots, the Venture Capital Yearbook, and Postsecondary Education Opportunity, a private firm that tracks state expenditures on higher education.

Dependent Variables

Three dependent variables were included in this study, all obtained from the 1996-98 AUTM licensing surveys and operationalized as continuous average annual measures of performance. These variables reflect the performance milestones achieved through the technology transfer process flow-charted in Figure One, patents held, licenses executed, and licensing income realized. The first of these, patents held (PATENTS), represents an important first step in the technology transfer process since to outside for-profit firms, it represents a tangible asset with legal protections from copying. As such, it is inherently valuable to companies because it can be developed into a commercializable product with the guarantee that no other firm can utilize the technology for a similar purpose without the patent assignee's permission. Thus, by patenting a university developed technology, it becomes more attractive to a potential licensee seeking to profit from its ultimate sale as a component of a commercial good.

The second milestone step in the technology transfer process is the licensing of a patented technology, another measure of performance included in this study (LICENSES). As mentioned earlier, universities have significantly ramped up their technology transfer efforts in recent years, one manifestation of which is licensing activity. Since simply holding a patent in no way guarantees that it will be licensed or that it will not be made redundant by the emergence of an eclipsing technology, successfully consummating a licensing deal with a firm is a considerable accomplishment. Furthermore, it represents a way of potentially recouping the costs associated with the patenting process and hopefully a means of generating revenues in excess of those costs.

The third milestone of achievement in the technology transfer process included in this study is the realization of a licensing income stream (LICINC). Since university licensed technologies are often at an early stage of development, there is generally considerable time and effort still required on behalf of the licensee firm to develop it into a product with potential for sale. Many factors both inside and outside the firm can derail the chances of even minimal success, let alone the blockbuster achievements of technologies such as Vitamin D, Gatorade, and Cisplantin. Hence, the revenues realized by a university may be limited to just the costs of patenting and perhaps a small to moderate up-front fee, examples of typical terms included in many licensing agreements. Thus, realizing an actual return on investment for a licensed technology is a coveted milestone and something that fuels university interest in pursuing sometimes risky activity.

Independent Variables

As mentioned previously, the purpose of this study was to identity particular resource attributes of universities that may explain differential performance with technology transfer. Hence, a series of internal variables to universities were identified from previous research as potential explanatory factors of performance variability among the sample institutions. These variables are grouped into the resource categories that were described in Figure One.

Financial Resources. Two financial variable were included in this study, the average annual federal and industry R&D revenues for the period 1993-1995 (FEDRD and INDRD respectively). Data for these continuous variables were obtained from the National Science Foundation's annual surveys of research and development expenditures.

Federal R&D resources have long been the most important source for academic R&D, approximately 70% of all R&D expenditures in 1997 (National Science Board, 1998). Additionally, there is strong evidence that federal funds have directly or indirectly funded academic research leading to many industrial innovations (Mansfield, 1995) and that even basic research has been found to be of considerable value to business and industry (Faulkner & Senker, 1994).

Industry sponsored R&D at universities, although considerably smaller in overall terms compared to federal sources, nonetheless is the fastest growing source of R&D funding for university research (National Science Board. 1998). Furthermore, even though industrial support may be quite small by comparison, its emphasis on supporting applied research and targeted outcomes suggests that it might generate considerable technology transfer activity. Previous research on university-industry relations, for instance, indicates that institutions with closer ties to industry do generate greater numbers of spin-offs and entrepreneurial activities such as faculty involvement in new firms or institutional equity participation in start-up firms (Cohen, Florida, Randazzese, & Walsh, 1998; Roberts & Malone, 1996).

Based upon the evidence cited above, it is clear that federal and industry R&D support may represent a critical financial resource to universities as would be predicted by the resource-based view of the firm.

Physical Resources. Two physical resources were included in this study, the presence of a medical school (MED) and the presence of an engineering school (ENG). Operationalized as dichotomous measures, these data points were obtained from the 1995 edition of Peterson's Guide to Colleges and Universities.

Medical and engineering schools are a valuable physical resource to universities for their technology transfer programs. Not only has the bulk of academic research and development expenditure been allocated to a relatively small group of research institutions, the fields of medicine and engineering have received the lion's share of that funding. For example, in 1995, the medical sciences received the largest percentage of academic research and development funding from all sources (i.e., federal, industry, and institutional), 27 percent of total expenditures. The engineering disciplines received 16 percent of all expenditures, just behind the biological sciences (National Science Board, 1998) at 17 percent. This pattern of disproportional support of these particular disciplines has held for decades.

As it regards university patenting and licensing activity, what evidence is available suggests that a considerable amount of technology transfer occurs in the medical and engineering fields. Thursby and Kemp (1999) in their extensive study of university technology transfer, for example, reported that the biological sciences and engineering are the most important source of university licenses. Not surprisingly, a considerable amount of patent activity is also centered in the life and physical sciences (Feller, 1997; National Science Foundation, 1997). Hence, if a sizeable amount of technology transfer activity comes out of the medical and engineering disciplines and these fields receive the bulk of academic R&D funding, it seems reasonable to conclude that a medical or engineering school is an important revenue generation resource. As per the resource-based view of the firm, then, institutions with these units may be afforded a competitive advantage in technology transfer.

Human Capital Resources. One human capital oriented independent variable (FQUAL) was included in this study, the quality of science and engineering faculty. Data for this continuous variable was obtained from the survey of faculty research quality conducted by the National Research Council (NRC). The NRC data, published in 1995, has been used in previous research exploring the impact of university R&D and the nexus between industry and higher education and is believed to be a legitimate rating publication based on its attention to methodological rigor and comprehensiveness (Mansfield, 1995; Mansfield & Lee, 1996). An average ranking figure was calculated for this variable from reported ratings in the biological sciences, physical sciences, and engineering fields, the ones most likely to be involved in technology transfer.

Previous research has shown a significant relationship between the reputation of university scientists and various measures of economic development. Deeds, DeCarolis, and Coombs (1998), for example, found that university scientist talent was a significant predictor of initial public offering (IPO) performance of biotechnology companies. Zucker, Darby, and Armstrong (1998) found a direct and significant relationship between the reputation of university scientists and the number of products in development or on the market as well as the size of the company measured in number of employees. Finkle (1998) found that biotechnology companies in which the CEO was a former university professor performed better than firms where the CEO was not a former professor. Considering this previous evidence, the quality reputation of an institution's science and engineering faculty should predict technology transfer performance, an outcome in alignment with the tenets of the resource-based view of the firm.

Organizational resources. One organizational resource was included in this study, a dichotomous variable (PRIVPUB) that captures an institution's private or public status. Since private and public universities differ in ways such as how they are funded, how they must meet legal and fiduciary requirements, and how they are accountable to their various stakeholders, it is reasonable to expect that they may differ in their approach to technology transfer practice. For instance, public higher education may be prevented from engaging in certain kinds of entrepreneurial activity that private institutions are not or private universities may have greater flexibility in how technology transfer programs are structured and managed. Thursby and Kemp (1999), for example, found that private universities were able to more effectively leverage their intellectual capital into commercial licenses than public institutions. Historically, some of the most well known institutions with a culture supportive of entrepreneurial activity are also private schools (Matkin, 1990; Louis, Blumenthal, Gluck, & Stoto, 1989). As an organizational resource within the resource-based theory of the firm framework, then, private institutions should enjoy a competitive advantage over their public counterparts.

Control Variables

In addition to the internal resources just described, previous research suggests that it is likely that some universities may enjoy particular locational advantages related to the external environment for entrepreneurial activity (Pouder & St. John, 1996; Roberts, 1991), something that the resource-based view of the firm might also predict. Furthermore, the level of state support for higher education may drive an increased emphasis on technology transfer activity as a resource-dependence reduction response (Slaughter & Leslie, 1997).

In order to investigate and isolate these effects from the aforementioned independent resource factors, three location related resource factors were included as control variables. The first variable (HOTSPOT), an average annual index measure of the entrepreneurial climate within a state for the period 1993-1995, was generated from Cognetics' annual ratings of entrepreneurial hot spots. The reports produced by Cognetics are a respected and reliable source of information on geographical differences in the formation and development of new firms.

A second measure of the entrepreneurial climate included a variable that captured the level of venture capital availability or munificence within a state (VENMUN), a resource often of critical importance to the types of firms likely to be licensing university technologies (Roberts & Malone, 1996). Data for this continuous variable was obtained from the 1993, 1994, and 1995 Venture Capital Yearbooks and represents an average annual figure for that period.

The third variable associated with the external environment was the average annual level of state support for higher education per $1000 of personal income for the period 1993-95 (STATEAP). This continuous measure of state support was obtained from Postsecondary Education Opportunity, a firm that specializes in the analysis of higher education financial data.

Together with the above measures of the external environment, two other internal resource variables were included as controls that have often been shown to be important in firm or technology transfer performance studies, the size and age of the organization (Beatty & Zajac, 1994; Deeds, DeCarolis, & Coombs, 1997; Roberts & Malone, 1996), in this case, the technology transfer office (TTO). These continuous variables (TTOSIZE and TTOAGE respectively) were both obtained from the AUTM licensing surveys.

The size of the TTO came from the 1995 AUTM survey and represents the number of professional staff FTEs in the office at that time. Universities with greater numbers of professional staff to handle technology transfer would be expected to outperform institutions less well endowed with this human capital resource. The age of the TTO, operationalized as the number of years that the office had at least .5 FTE of dedicated professional staff, was obtained from the 1998 licensing survey. Institutions with older TTOs would be expected to have developed superior skill sets for managing the commercialization enterprise and hence enjoy higher performance levels as well based on this human capital resource.

Results

The data were analyzed using both univariate and multivariate statistical techniques. First, descriptive statistics were calculated on each of the variables (e.g., means, standard deviations, and frequencies of dichotomously coded variables) and are listed in Table Two.

- Place Table Two about here -

Second, a correlation matrix was calculated as a collinearity check and shown in Table Three. Since a few of the bivariate correlations among independent variables were somewhat high, although still below the rule of thumb threshold of .8 (Lewis-Beck, 1980), a more thorough investigation for collinearity was conducted. Variance inflation factors were computed for each variable, all of which were under five, well below the concern level of ten that previous researchers indicate is suggestive of collinearity problems (Von Eye & Schuster, 1998). Finally, a series of regression model pairs were run in which each independent variable with a correlation above .5 was included and then subsequently excluded from the models to see if the regression coefficient results were substantively effected.. No differences were found, indicating the absence of excessive collinearity.

- Place Table Three about here -

Finally, additional tests of the data for Ordinary Least Squares (OLS) regression violations were investigated. A series of histograms and normal probability plots were created with the results indicating the need to log transform the number of licenses (LICENSES) and licensing income (LICINC) variables to adjust for skewness in the data.

Once it was clear that the data were ready for ordinary least squares regression, a block step entry procedure was employed such that the control variables were entered in step one (the partial model) and the independent variables in step two (the full model). The results of this analysis including beta-weights, F-values, adjusted R-squared values, and indicators of significance at the .1, .05, .01, and .001 levels are reported in Table Four.

- Place Table Four about here -

It is evident from the regression results, that the three models explained a significant amount of the variation in each of the dependent variables and that the inclusion of the independent variables significantly (p=.001) improved the model fit in each case. The full models explained between 48 and 73 percent of the variance in their respective dependent variable and the F-statistic was highly significant in all cases, findings indicative of good model fits and the appropriateness of using the full models for drawing inferential conclusions.

In Model One involving the patents dependent variable, the age of the TTO and level of industry R&D revenue was highly significant ($p<.001$) in the full model while federal R&D

revenues and the quality of the science and engineering faculty was strongly significant ($p<.01$). Hence, this result provides confirmatory evidence of the value of these resources for patenting activity. Specifically, institutions with older TTOs, greater levels of federal and industry R&D revenues, and more highly reputable science and engineering faculty have more patents than institutions less resource rich in these areas.

In Model Two involving the number of licenses performance outcome, the faculty quality variable was highly significant, the age of the TTO strongly significant, and size of the TTO significant ($p<.05$), all in the positive direction. The venture capital variable, however, was strongly significant but in the negative direction, suggesting that institutions located in states with lower levels of venture capital actually outperform institutions in states with more robust venture capital resources in terms of the number of licenses held.

For Model Three that included the licensing income variable, once again the faculty quality variable was strongly significant with the size of the TTO approaching significance ($p=.06$). The venture capital munificence variable, though, was strongly significant but in the negative direction, once again suggesting the benefits to institutions in states with smaller levels of venture capital. Similarly, the state appropriations variable approached significance ($p=.08$) in the negative direction, suggesting some support for a resource-dependence explanation for this relationship. In order to test if this relationship holds for both private and public institutions, a separate set of regression analyses were conducted for these respective types of institutions (not shown). The results indicated a strongly significant finding in the negative direction for publics ($p=.01$; Beta of -.27) and a strongly significant finding for privates but in the positive direction ($p=.003$; Beta of .77). This result suggests that the licensing income received by both public and private institutions are highly influenced by state appropriations but in opposite ways. States with lower appropriation levels are associated with higher licensing income amounts to their public institutions but lower amounts to their private institutions and visa versa.

Discussion

As stated earlier, the purpose of this study was to investigate the possible effects of a set of internal and external resource factors on the achievement of particular technology transfer milestones. Considering the range of performance exhibited by institutions in this data set, the results of the analysis provide useful insights into the resource factors of critical importance to technology transfer practice. In the context of each of the resource categories, I provide commentary on the results in the sections that follow.

Financial Resources

It appears from this study that federal and industry R&D support are important contributors to patenting activity as the resource-based view of the firm would predict but that their effect disappears when considering the licenses consummated or licensing income performance variables. By way of explanation for the federal R&D results, it is important to remember that federal sponsorship of academic research has historically been for basic research. Although federal policy since 1980 has sought to encourage the ultimate dissemination of research for economic development purposes, it has not generally been prescribed that a recipient of a federal grant must seek to license a technology developed from federal funds. The Bayh-Dole Act of 1980 simply allowed universities to keep the patent rights to inventions created from federal research dollars. Hence, it is not surprising that this resource was not associated with the latter two performance outcomes. ~~However, this view appears to be misplaced, at least for these measures of technology transfer performance.~~

The result for industry R&D was particularly interesting. Industry R&D support is generally given to universities for specific applied purposes for which a firm believes it will ultimately directly benefit. The results of this research suggests again that it does have a strong influence on patenting activity but no measurable affect on the number of licenses produced or licensing income realized by a university. Hence, either industry is not benefiting to the degree previously thought or the manner in which it was studied in this research was not able to detect it.

One explanation may be that industry is benefiting through simply contractual agreements to conduct a study or clinical trial for which they are provided the results directly and not via a license on a patented technology. This form of industry sponsored research is common. In cases where the intent of the research is to develop a new technology for which a firm may enjoy exclusive or non-exclusive rights to the technology, it may also be that the original sponsored research agreement specified that the company would have the rights to any technologies that might develop out of the research without cost to the firm (J. Johncox, personal communication, October 5, 2000). As such, the accrued benefits to universities would not appear in the form of licensing income. Nevertheless, the lack of a linkage between industry R&D revenues and licensing activity or income is a noteworthy one and a valuable area for future inquiry.

Physical Resources

As was shown in the study results, having either a medical or engineering school was not a significant predictor of any of the measures of technology transfer performance. This result suggests that institutions with one of these units on their campus do not outperform their counterparts that do not have one. In order to further fine grain this analysis, a regression model was run (not shown) that compared institutions with both an engineering school and a medical school with those that had only one or the other. Once again, no significant differences were found. Comparing schools with both units against those with neither type was not possible since so few institutions in the sample had neither a medical or engineering school.

While this result may seem counterintuitive, it is also true that many of the advances in the life sciences do not emerge from medical schools but rather from within arts and sciences units. For example, blockbuster licenses such as Taxol at Florida State University, Cisplantin at Michigan State University, and the Vitamin D technologies at the University of Wisconsin all came out of chemistry departments. If licensing is as strong in non-medical or non-engineering disciplines as anecdotal evidence suggests, it might negate any potential performance advantages in either of these units. It is also likely that not all medical or engineering schools are the same and as such, measures of unit quality might actually reveal significant results.

Human Capital Resources

The finding regarding the quality of science and engineering faculty suggests the central importance of this resource for achieving high levels of performance in technology transfer. In fact, this variable was the only one significant across all three measures of performance. This result is consistent with Mansfield & Lee's (1996) research on the contribution of universities to industrial innovation from the perspective of industry. Specifically, he found that institutions with more reputable faculties (also measured using National Academy of Sciences ratings) were more likely to be cited by industry as having contributed significantly to industrial innovation. Hence, it is perhaps not surprising to find that one benefit of being highly cited by industry is their interest in licensing technologies that in turn generate royalties. Furthermore, institutions with strong faculty reputations are probably able to negotiate more lucrative licensing deals than those universities that are not as highly regarded.

It may also be that institution's with less reputable faculties focus their licensing efforts more regionally and thus reduce their chances for negotiating a license with a large, wealthy, multinational firm. This was another phenomenon that Mansfield and Lee (1996) found. Namely, when industrial firms cited schools with less reputable faculties as being important contributors to industrial innovation, these schools were generally within 100 miles of the firms. Finally, if schools with lower faculty reputations are more locally focused, their licensing portfolio is probably more heavily weighed with smaller, less mature companies, the ones unlikely to be in a position to offer a university a highly lucrative licensing deal. Regardless the reason for the differential performance, it is evident that the quality of an institution's faculty is a critical resource associated with patenting, licensing, and licensing income, and as the resource-based view of the firm would predict, those institutions with stronger faculty reputations outperform those with less reputable faculties.

As it regards the size and age of the TTO, two control variables in the study, they also were positively predictive of performance, the former with licenses and licensing income and the latter with patents and licensing. These results are also consistent with prior research on organizational performance (Deeds, DeCarolis, & Coombs, 1998; Geisler, 1998) and indicative of the importance of strong skill sets and sufficient staff to manage the complex and time intensive tasks associated with technology transfer practice.

Organizational Resource

The one organizational resource investigated for this study was the private or public status of a university. In this case, the status of an institution does not appear to make a difference in terms of technology transfer performance on any of these outcomes. Hence, the perception of private schools as somehow being more effective at technology transfer, ceteris paribus, is unfounded. If at one time private universities did enjoy performance advantages, the recent increased emphasis by states for university participation in economic development may have afforded public institutions greater flexibility to engage in commercial activity (Wilson &

Szygenda, 1990) and hence increased their own performance to match that of their private counterparts.

External Environment Effects

The final area of investigation in this study involved the external environment effects on technology transfer performance, namely the entrepreneurial climate and venture capitalization of a state as well as the level of state support for higher education. The environmental variable results indicated a strongly negative relationship between venture capitalization and the number of licenses and licensing income for a university and a slightly + ~~negative~~ relationship for number of licenses and the entrepreneurial climate variable. Furthermore, there was a strongly negative relationship between state support for higher education and licensing income for public institutions and a strongly positive one for private schools.

As it regards the venture capitalization variable, this result was puzzling since it implies that schools in venture rich states underperform in relation to their counterparts in venture poor states. Upon surface observation, this result seems counter to what the data might suggest considering that the top three performers in terms of licensing income (Columbia, UC-San Francisco, and Stanford) came from states with high levels of venture capital (California and New York). However, in looking at the data as a whole, there were a number of schools from states with high venture capitalization that are low performers in terms of licensing income.

While a visual examination of the data appears to affirm the accuracy of the regression result, it does not explain why this relationship might exist. One likely explanation for this association is that states with lower levels of venture capital also have fewer smaller companies or an overall environment that is not particularly supportive of the type of firms that might develop out of universities. Hence, in these states, technology transfer activity is de facto forced to emphasize a licensing strategy with large established firms, the very types of companies that are likely to generate the greatest amount of licensing income in the short term. Thus, the linkage between venture capital munificence and licensing income may be more indirect with small companies in a state being an intervening variable.

A second related explanation for this finding is that there may in fact be a positive relationship between a state's venture capital munificence but only with the in-state portion of its licensing income, an investigation that was beyond the scope of this study. However, when out of state income is considered as well, the relationship may have been reversed. Research by Mansfield & Lee (1996) provides support for this explanation, particularly at institutions that have what they coined, faculty stars. Specifically, they found that while the majority of university-industry linkages were within 100 miles of each other, universities with better faculty reputations (measured using the same National Academy of Sciences data used in this study) were more likely to have a national reach. Additionally, based on general observation of annual reports of technology transfer offices for this study, it appears that the licenses that generate the largest amounts of income are often with large companies located outside of that institution's state. Hence, it may be that the benefits of venture capital munificence are being accrued by institutions in less venture capital robust states who seek licenses with companies in states like California, Massachusetts, and New York where the opportunities for investment are greater. In the event that is true, schools located in states flush with venture capital may face particularly strong competition for licensing opportunities from the very best of the out of state schools.

In the case of the climate for entrepreneurship variable (HOTSPOT), it was mildly significant (p=.058) in the positive direction in model two involving the number of licenses performance variable. Considering that this environmental measure is more broadly reflective of the climate for all kinds of young businesses, not just those needing venture capital, it would be expected to possibly have a different predictive effect on performance than the venture capital variable. Based on the result involving the HOTSPOT variable, then, it appears that universities with stronger overall climates for entrepreneurship (and hence the greatest likelihood for licensing opportunities with smaller firms), enjoy a small performance advantage over institutions located in states with weaker external environments of this kind.

The final finding of significance associated with the issues of location involved the state appropriations variable and licensing income. It was most interesting to find strong significance in the negative direction for public universities but strongly positive significance for private institutions, a result supportive of a resource-dependence theory explanation for the phenomenon.

Taking the public school result first, it appears that the incentive to seek alternative revenue sources when state funding is lower is considerable. These institutions may have sought to pursue the most promising licensing opportunities with shorter-term payoff than public schools with less threatened traditional resource streams and been rewarded with higher levels of income realized. Considering the legitimacy now afforded to institutions that support an economic development agenda, it may also be that public institutions with less state support may be seeking to leverage their involvement in technology transfer as a means of increasing their perceived level of excellence or relevance in the eyes of state legislators and taxpayers with the ultimate hoped for reward being increased state support.

In the case of private universities, they may be affected by support of public universities but in the opposite direction. Specifically, when resources are greater for public higher education, the overall economic health of the state is often made stronger, a finding with support in the literature (Paulsen, 1996). Thus, when the state's economy and workforce productivity is enhanced, private schools may benefit in the form of more lucrative opportunities for technology transfer. Additionally, in states where support of higher education is high, demand for private post-secondary education may be lower, increasing the pressure on the most critical resource to privates, tuition income. With concern over tuition income heightened, then, private institutions may feel the need to develop new and risky income sources such as could be pursued through technology transfer. Similarly, in states with low levels of support for public higher education, student demand for private education may be higher, reducing pressure on the critical resource of tuition income. Hence, in this situation, private institutions would not feel as strong a need to advance their technology transfer programs.

OPPORTUNITIES FOR FUTURE RESEARCH

As is often the case with academic inquiry, particularly in areas covering new ground, a research project can raise as many or more questions than it answers. Such is the situation with this study. Much was revealed about the contributory role of particular internal and external resource factors, yet much work remains to be done to more fully understand the nature of the linkages and to chip away at the unexplained portion of the regression models. A qualitative study focused on technology transfer practitioners or faculty actively involved in patenting and licensing, for instance, might reveal excellent insights into the explanation of findings reported here. A second area of useful inquiry would be to test different operationalizations of some of the variables. For example, the state measures of venture capital and entrepreneurial climate might be improved by substituting a regional ones since technology transfer certainly occurs across state lines. Additionally, it would be most interesting to do a comparative study between Canada and the United States. The data is available in the AUTM survey reports but no research to date has analyzed it in this way. Finally, it would be useful to broaden the measures of performance to include university start-up formation or affiliations with firms that go public, two additional measures of performance not addressed in this study.

CONCLUSION

This research represents the first national study of its kind exploring specific institutional factors that may explain differential performance with technology transfer. Considering the increasing expectations for higher education to serve specific economic development needs, this study provides a useful window into what institutional resources or capabilities may contribute to higher levels of performance. While it does not specifically address the normative question of whether or not higher education should be engaged in entrepreneurial activity, it is suggestive of the forces that may be driving institutions and their faculty to embrace a commercialization mission. Thus, this study contributes both to knowledge and the informed practice of university technology transfer.

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Figure 1. Model of the University Technology Transfer Process

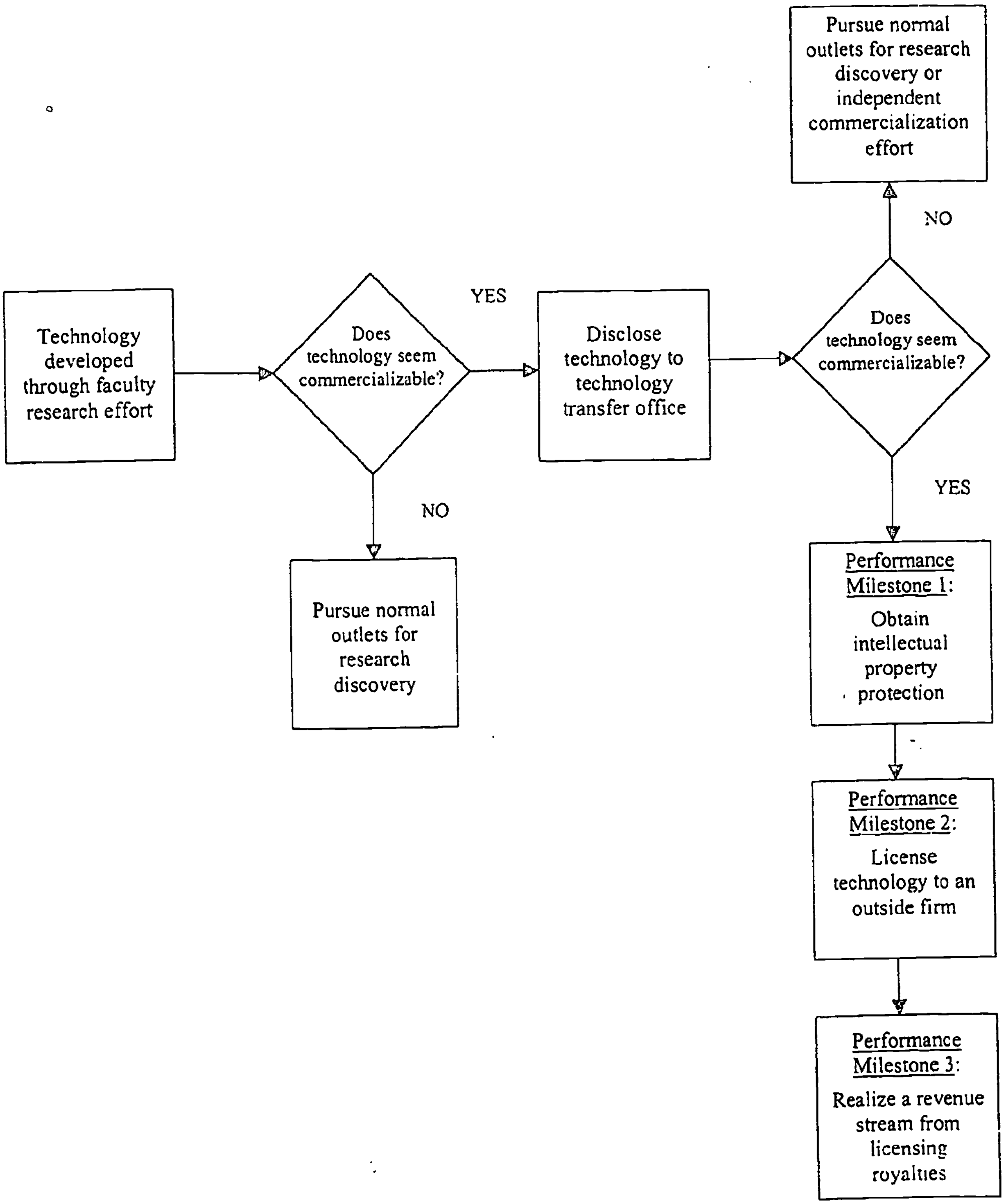

Table 1: Firm Resource Categories

Resource Category	Description
Financial Resources	Monetary related resources such as capital investments from entrepreneurs, venture capitalists, equity holders, or banks as well as other types of financial capital such as retained earnings.
Physical Resources	A firm's plant and equipment, technology utilized, geographical location, and access to raw materials.
Human Capital Resources	Aspects of the firm's workforce including training, experience, judgement, intelligence, relationships, and insight.
Organizational Resources	The firm's organizational structure, planning, controlling, and coordinating systems, culture, and informal relationships between groups within and outside the firm.

Table 2: Means, Standard Deviations, Range Values, and Frequencies

Variable	Mean	Standard Deviation	Range (min. – max.)	Frequencies
HOTSPOT	46.49	14.31	18.67 – 82.33	
VENMUN	$238.41 mil.	$368.4 mil.	0 - $1.11 bil.	
STATEAP	8.37	2.53	5.52 – 16.22	
TTOSIZE	2.38	2.29	0 – 11	
TTOAGE	16.56	12.00	1-75	
PATENTS	19.68	18.83	0 – 124	
LICENSES	24.24	26.51	1 – 146	
LICINC	$4.25 mil.	$8.49 mil.	$15,000 – $48.86 mil.	
FEDRD	$88.43 mil.	$69.07 mil.	$6.20 mil. - $280.38 mil.	
INDRD	$9.57 million	$9.03 million	0 – $55.45 mil.	
MED	.52	.50		56 with medical schools; 52 w/o medical schools
ENG	.84	.37		91 with engineering schools; 17 w/o engineering schools
FQUAL	3.01	.71	1.28 – 4.64	
PRIVPUB	.28	.45		30 private universities; 78 public universities

Table 3

Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. FEDRD	1.00													
2. INDRD	.62	1.00												
3. MED	.43	.14	1.00											
4. ENG	.19	.27	-.01	1.00										
5. FQUAL	.75	.41	.27	-.01	1.00									
6. PRIVPUB	.23	.08	.18	.10	.35	1.00								
7. HOTSPOT	.08	.07	.04	-.12	.08	-.13	1.00							
8. VENMUN	.29	.00	.07	-.10	.41	.19	.03	1.00						
9. STATEAP	-.17	-.07	-.06	.13	-.36	-.30	.26	-.41	1.00					
10. TTOSIZE	.67	.40	.28	.06	.55	.03	-.03	.46	-.16	1.00				
11. TTOAGE	.37	.23	.12	.09	.30	.06	-.01	.24	-.02	.44	1.00			
12. PATENTS	.78	.63	.26	.11	.70	.18	.06	.32	-.15	.63	.55	1.00		
13. LICENSES	.67	.47	.19	.15	.57	.20	.03	.17	-.01	.61	.55	.71	1.00	
14. LICINC	.48	.17	.22	-.07	.44	.20	-.01	.25	-.20	.40	.19	.53	.45	1.00

Note. Correlations above | .24 | are significant at p<.01; those above | .18 | are significant at p<.05. N's vary from 103-106 because of missing data.

Table 4

Regression Results of all Models

Variables	Model 1: PATENTS N=103 Partial Model	Model 1: PATENTS N=103 Full Model	Model 2: LNLICENSES N=106 Partial Model	Model 2: LNLICENSES N=106 Full Model	Model 3: LNLICINC N=104 Partial Model	Model 3: LNLICINC N=104 Full Model
HOTSPOT	.11	-.03	.23**	.13$^+$	.21*	.13
VENMUN	-.04	.03	-.27**	-.23**	-.28**	-.27**
STATEAP	-.09	.07	-.21*	-.03	-.31***	-.16$^+$
TTOSIZE	.49***	.07	.56***	.20*	.53***	.22$^+$
TTOAGE	.35***	.26***	.25**	.18**	.13	.05
FEDRD		.33**		.19		.16
INDRD		.24***		.10		.01
MED		-.06		.04		.11
ENG		-.06		.05		.08
FQUAL		.26**		.41***		.38**
PRIVPUB		-.004		.04		.003
F-Value	20.11***	25.41***	16.19***	17.41***	10.68***	9.51***
Adjusted R^2	.48	.73	.42	.63	.32	.48

*p<.05; **p<.01; ***p<.001; $^+$p<.1