Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study.

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Abstract:

We present quantitative and qualitative evidence on the relative productivity of university technology transfer offices (TTOs). Our empirical results suggest that TTO activity is characterized by constant returns to scale and that environmental and institutional factors explain some of the variation in performance. Productivity may also depend on organizational practices. Unfortunately, there are no quantitative measures available on such practices, so we rely on inductive, qualitative methods to identify them. Based on 55 interviews of 98 entrepreneurs, scientists, and administrators at five research universities, we conclude that the most critical organizational factors are faculty reward systems, TTO staffing/compensation practices, and cultural barriers between universities and firms.

Keywords: technology transfer offices | university/industry technology transfer | stochastic frontier estimation | research policy

Article:

1. Introduction

Universities in the United States have been criticized in some circles for being more adept at developing new technologies than moving them into private sector applications. This is potentially problematic since success in university/industry technology transfer (UITT) could be a critical factor in sustaining the global competitiveness of US firms. Some federal agencies have responded to this concern by providing incentives for universities to form partnerships with firms.1 Expectations regarding a quicker commercial "payoff" to basic research have risen accordingly. To build political support for their institutions, university leaders frequently cite the role of technology transfer in stimulating local economic development. Facing tighter budgets, these administrators often promise to deliver more "bang for the buck" in technology transfer.

The private sector has also chimed in, expressing frustration with obstacles that impede the process of commercialization, such as disputes that arise with the university regarding intellectual property rights.2

These concerns have raised the visibility of UITT in the public policy arena. In recent years, universities have attempted to formalize UITT and capture a larger share of the economic rents associated with technological innovation by establishing technology transfer offices (TTOs). TTOs facilitate technological diffusion through the licensing to industry of inventions or intellectual property resulting from university research.3 Many institutions established a TTO in the aftermath of the University and Small Business Patent Procedures Act of 1980, otherwise known as the Bayh–Dole Act.

Bayh–Dole dramatically changed incentives for firms and universities to engage in UITT. It simplified the UITT process by instituting a uniform patent policy and removing many restrictions on licensing. Furthermore, it allowed universities to own the patents that arise from federal research grants. The framers of Bayh–Dole asserted that a streamlined federal UITT policy and university ownership and management of intellectual property would accelerate commercialization because universities would now have greater flexibility in negotiating licensing agreements and firms would be more willing to engage in them.4

It appears that Bayh–Dole has indeed resulted in a more rapid rate of technological diffusion.5 According to the Association of University Technology Managers (AUTM, 1997), the annual number of patents granted to US universities surged from about 300 in 1980 to approximately 2000 in 1996, while licensing of new technologies has increased almost two-fold since 1991. Annual streams of revenue accruing from these licenses have risen from about US$ 160 million in 1991 to US$ 611 million in 1997, now constituting about 2.5% of university R&D expenditures (GAO, 1998). Major products in a wide variety of industries have been developed through UITT, such as the Boyer–Cohen “gene-splicing” technique that launched the biotechnology industry, diagnostic tests for breast cancer and osteoporosis, internet search engines, music synthesizers, computer-aided design (CAD), and environmentally-friendly technologies.

Despite the potential importance of UITT as a mechanism for generating local technological spillovers and as a source of revenue to the university, there is little systematic empirical evidence on any dimension of the performance or productivity of UITT activity.6 The purpose of this paper is to fill this void.

Our measures of relative productivity are constructed from benchmarking surveys conducted by AUTM for the years 1991–1996. We adjust these estimates of relative efficiency to reflect environmental and institutional factors that can influence the rate of technological diffusion at a given university. We postulate that relative performance in UITT may also depend on organizational practices in university management of intellectual property, which potentially attenuate palpable differences in the motives, incentives, and organizational cultures of the parties to licensing agreements (university administrators/TTO directors, managers/entrepreneurs, and academic scientists).

Unfortunately, there are no existing data on such practices, nor is it precisely clear which organizational factors are most critical to effectiveness in UITT. Therefore, we rely on inductive, qualitative methods (field research) to identify these variables, which are typically ignored in conventional productivity studies. The field research also provided a useful reality check on the specification of our econometric model. Accordingly, we conducted 55 structured, face-to-face interviews of UITT stakeholders (15 administrators, 20 managers or entrepreneurs, and 20 scientists affiliated at five universities). We solicited feedback from these individuals on the nature of the UITT “production process”, barriers to effective UITT, recommendations to improve the process, and the importance of networks and relationships in UITT.

The remainder of this paper is organized as follows. Section 2 describes a set of internal and external factors that influence the extent of UITT at a given university. Differences in the actions, motives, and organizational environments of the parties to licensing agreements are also considered. We conjecture that these differences can potentially undermine efforts to commercialize university-based technologies. This discussion underscores the potential importance of organizational factors as a determinant of UITT performance. Section 3 outlines the method for assessing relative productivity in UITT. Empirical results are presented in Section 4. Section 5 describes our qualitative research design and methods. Section 6 discusses our qualitative findings. The final section consists of preliminary conclusions and suggestions for additional research.

2. Determinants of UITT

2.1. Internal inputs

To identify the appropriate “inputs”, we begin with a simple description of the process of the transfer of a technology from a university to a firm or entrepreneur, through the negotiation of a licensing agreement. This description reflects the conventional wisdom among academic administrators (see AUTM, 1997) regarding how technologies are transferred. It is important to note that this linear model does not necessarily constitute an accurate representation of how all technologies are actually transferred. Indeed, a key goal of our field research is to determine whether this model understates the complexity of this process.

The first stage of the process is scientific discovery. The Bayh–Dole Act stipulates that scientists must then file an invention disclosure with the TTO. Our field research, which is described in greater detail in 5 and 6, revealed that this rule is rarely enforced. Thus, TTO personnel must devote some effort to encouraging faculty members to disclose inventions. Once the invention is formally disclosed, the TTO simultaneously evaluates the commercial potential of the technology and decides whether to patent the innovation. Often, interest in the technology by an industry partner provides sufficient justification for filing a patent. In other instances, the TTO must make these judgements before industry expresses an interest in the technology. Furthermore, universities must decide whether to seek global or domestic patent protection. Domestic protection is substantially cheaper, but often much less valuable to potential licensees, particularly when foreign markets are perceived to be highly lucrative relative to the US market. As confirmed in our interviews, this decision poses a dilemma for many TTOs because they have limited resources for filing patents.

If the patent is awarded, the TTO will often attempt to market the technology. Faculty members are frequently involved in the marketing phase because they are usually in a good position to identify potential licensees and because their technical expertise often makes them a natural partner for firms that wish to commercialize the technology. It is important to note that the linear model potentially overstates the role of patents in UITT. As reported in Jensen and Thursby (2001) and confirmed in our field research, many firms will license a technology before it is patented.7 This implies that a key input of UITT is invention disclosures, which constitute the pool of available technologies for licensing.

The final stages of UITT involve the negotiation of a licensing agreement with firms or individual entrepreneurs. These agreements could include such benefits to the university as royalties, “follow-on” sponsored research agreements, or an equity stake in a new venture based on the licensed technology. We discovered on our field visits that many universities, especially public institutions, are quite sensitive to the charge that they are “giving away” university-based, taxpayer-funded technologies that yield substantial windfall profits. As a result, many TTOs are adopting a hard line in licensing negotiations.

Interviews with university administrators revealed that TTO involvement does not end with the signing of a licensing agreement. It is quite common for TTOs to devote substantial resources to the maintenance and re-negotiation of licensing agreements. This is attributed both to the embryonic nature of the technologies and to the fledgling nature of many of the firms that license university-based technologies.

We wish to stress that our field research greatly improved our ability to model the "production process" of UITT, by helping us identify the appropriate set of outputs and inputs to include in the production function. For instance, we began this project with the view that there are multiple outputs of UITT. Discussions with university administrators, the "producers" in our model, revealed that licensing activity is by far the most critical output, so we now focus our attention on this critical dimension of UITT performance. Our qualitative work also revealed that we had greatly underestimated the importance of faculty "buy-in" to UITT. This stemmed, in part, from our literal interpretation of the language contained in the Bayh–Dole Act, which stipulates that academics working on federal research grants must disclose their inventions to the TTO. However, we discovered that this provision is rarely enforced, so that disclosure is actually not mandatory.

Thus, invention disclosures are the key intermediate input. The number of disclosures will depend, to some extent, on the efforts of the TTO to elicit them (and faculty interest in UITT). This, of course, raises the critical issue of organizational incentives for faculty and TTO personnel to engage in these activities. Consistent with recent theoretical and empirical studies summarized in Lazear (1999), we hypothesize that human resource management and other organizational practices that influence such incentives could explain some of the variation in UITT performance across universities.

Our initial field research also demonstrated the importance of intellectual property attorneys in UITT. Some universities use these lawyers to help them obtain copyrights and in various aspects of patenting and licensing, especially in support of prosecution, maintenance, litigation and interference. At some institutions, external attorneys are also involved in negotiation and re-negotiation of licensing agreements. Thus, expenditure of external lawyers should also be viewed as an input to UITT.

In sum, we conjecture that the following internal factors are inputs of UITT: invention disclosures (a proxy for the set of available technologies), labor employed by the TTO, and (external) legal fees incurred to protect the university's intellectual property.8 That is, we have specified a TTO "production function" where the relevant inputs are assumed to be under the control of the "producer" or the TTO director.

We also seek to explain deviations from the production frontier, which are presumed to be a function of a set of environmental and institutional variables, which are outside of the control of the TTO director. These variables are not conventional inputs (i.e. resources under the direct control of the producer), but rather external factors that could enhance or reduce the rate at which universities transfer technologies to the private sector. We conjecture that organizational practices (as yet undefined) could also constitute determinants of inefficiency. In the following subsections, we discuss these factors.

2.2. Environmental/institutional factors

University licensing activity may also depend on a vector of environmental and institutional variables. For instance, the presence of a medical school and the public status of the university may be important institutional factors. Pressman et al. (1995) report that over 60% of university licenses result from a biomedical invention. Public universities may have less flexible UITT policies than private universities regarding startup companies and interactions with private firms. Furthermore, public universities may be less focused on UITT as a source of revenue than private universities. The age of the TTO may also be relevant, as universities with more experience in formal management of UITT may be efficient than comparable universities with less experience. An example of an environmental variable is state-level economic growth, which can be viewed as a proxy for the ability of firms in the local region to sponsor R&D at the university.

In explaining the relative efficiency of TTOs, it may also be important to control for the R&D activity of local firms. A plethora of recent studies provide support for the notion that university research generates local technological spillovers. Bania et al. (1993) find that there is a positive relationship between university R&D and the number of firm startups in the same SMSA. Jaffe et al. (1993) report that patents (new technologies) generated within the same state (and SMSA) are more likely to be cited by firms in the same state or SMSA. Zucker et al. (1998) and Audretsch and Stephan (1996) directly examine interactions between academic scientists and local firms and find that these formal and informal linkages play an important role in promoting innovation in biotechnology.

2.3. Organizational factors

An understanding of the potential importance of organizational practices begins with a consideration of the actions, motives, and organizational cultures of UITT stakeholders. As shown in Table 1, we conjecture that a primary motive of university scientists is recognition within the scientific community, which emanates from publications in top-tier journals, presentations at prestigious conferences, and federal research grants. This is an especially strong motive for untenured faculty members. Other possible motives include financial gain and a desire to secure additional funding for graduate assistants, post-doctoral fellows, and laboratory equipment/facilities. The norms, standards, and values of scientists reflect an organizational culture that values creativity, innovation, and especially, an individual's contribution to advances in knowledge (basic research).

Table 1. Characteristics of UITT stakeholders

Stakeholder	Actions	Primary motive(s)	Secondary motive(s)	Organizational culture
University scientist	Discovery of new knowledge	Recognition within the scientific community	Financial gain and a desire to secure additional research funding	Scientific
TTO	Works with faculty and firms/entrepreneurs to structure deal	Protect and market the university's intellectual property	Facilitate technological diffusion and secure additional research funding	Bureaucratic
Firm/entrepreneur	Commercializes new technology	Financial gain	Maintain control of proprietary technologies	Entrepreneurial

The TTO must work with scientists and managers or entrepreneurs to structure a deal. We hypothesize that the primary motive of the TTO is to protect and market the university's intellectual property. Secondary motives include promoting technological diffusion and securing additional research funding for the university via royalties, licensing fees, and sponsored research agreements. Recall that a primary reason for the federal government's relinquishment of intellectual property rights, as stipulated in Bayh–Dole, was to accelerate the commercialization of university-based technologies. Many managers and scientists remarked that TTOs were especially committed to their role as guardian of the university's intellectual property. As such, technology licensing officers tend to be somewhat inflexible and conservative in structuring deals. This inflexibility is consistent with the bureaucratic organizational culture of the university.

Firms and entrepreneurs seek to commercialize university-based technologies for financial gain. They also wish to maintain proprietary control over these technologies, which can potentially be achieved via an exclusive worldwide license. The entrepreneurial organizational culture of most firms (especially startups) rewards timeliness, speed, and flexibility. Reflecting these cultural values, many managers we visited stressed the importance of "time to market" as a determinant of success in UITT, in part, because they are convinced that there are significant first mover advantages in high technology markets.

Table 1 reveals that there are palpable differences in the motives, incentives, and organizational cultures of UITT stakeholders that can potentially impede technological diffusion. Thus, we hypothesize that some of the variation in UITT performance across universities can be attributed to organizational behaviors that potentially serve to resolve these differences. Our inductive, qualitative analysis, described in 5 and 6, will help us identify these factors.

3. Assessing relative productivity in UITT

In the previous section, we identified a set of potential determinants of UITT, which include internal inputs, environmental and institutional factors, and a set of organizational variables. To assess relative productivity in UITT, we use the stochastic frontier estimation (SFE) method developed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). SFE generates a production (or cost) frontier with a stochastic error term that consists of two components: a conventional random error ("white noise") and a term that represents deviations from the frontier, or relative inefficiency.

SFE can be contrasted with data envelopment analysis (DEA), a non-parametric estimation technique that has been used extensively to compute relative productivity in service industries (Charnes et al., 1994). Thursby and Kemp (1998) use DEA to assess the relative efficiency of TTOs. DEA and SFE each have key strengths and weaknesses. DEA is a mathematical programming approach that does not require the specification of a functional form for the production function. It can also cope more readily with multiple inputs and outputs than parametric methods. However, DEA models are deterministic and highly sensitive to outliers.

SFE allows for statistical inference, but requires restrictive functional form and distributional assumptions. We believe that SFE and DEA are complements, not substitutes.

In SFE, a production function of the following form is estimated:

equation(1)

$$y_i = \boldsymbol{X}_i\beta + \varepsilon_i$$

where the subscript *i* denotes the *i*th university, *y* the output, ***X*** the vector of inputs, β the unknown parameter vector, and ε is an error term with two components, $\varepsilon_i = V_i - U_i$, where U_i represents a non-negative error term to account for technical inefficiency, or failure to produce maximal output, given the set of inputs used, and V_i is a symmetric error term that accounts for random effects. The standard assumption (see Aigner et al., 1977) is that the U_i and V_i have the following distributions:

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

$$V_i \sim \text{i.i.d. } N(0,\sigma_v^2)$$

That is, the inefficiency term (U_i) is assumed to have a half-normal distribution, i.e. universities are either "on the frontier" or below it. An important parameter in this model is $\gamma = \sigma u^2/(\sigma v^2 + \sigma u^2)$, the ratio of the standard error of technical inefficiency to the standard error of statistical noise, which is bounded between 0 and 1. Note that $\gamma = 0$ under the null hypothesis of an absence of inefficiency, signifying that all of the variance can be attributed to statistical noise.

In recent years, SFE models have been developed that allow the technical inefficiency term to be expressed as a function of a vector of environmental and organizational variables. This is consistent with our notion that deviations from the frontier (which measure relative inefficiency in UITT) are related to institutional and organizational factors. Following Reifschneider and Stevenson (1991), we assume that the U_i are independently distributed as truncations at zero of the $N(mi, \sigma u^2)$ distribution with

equation(2)

$$m_i = \boldsymbol{Z}_i\delta$$

where ***Z*** is a vector of environmental, institutional, and organizational variables that are hypothesized to influence efficiency and δ is a parameter vector.[9]

Following Battese and Coelli (1995), we derive maximum likelihood estimates of the parameter vectors β and δ from *simultaneous* estimation of the production function and inefficiency term equations, using the FRONTIER statistical package (Coelli, 1994). Based on these parameter values, we compute estimates of relative productivity.

Our specification of Eq. (1) is based on the knowledge production function framework developed by Griliches (1979), here extended to university licensing, our proxy for UITT output. We assume a three-factor, log-linear Cobb‑Douglas production function, relating licensing to three inputs: invention disclosures, TTO staff, and legal expenditures:

equation(3)

$$\ln(\mathrm{LICENSE}_i) = \beta_0 + \beta_1 \ln(\mathrm{INVDISC}_i) + \beta_2 \ln(\mathrm{STAFF}_i) + \beta_3 \ln(\mathrm{LEGAL}_i) + V_i - U_i$$

where LICENSE is the average annual licensing agreements or revenue, INVDISC the average annual invention disclosures, STAFF the average annual TTO employees, and LEGAL denotes the average annual external legal expenditures with the technical inefficiency (U_i) term expressed as:

equation(4)

$$U_i = \delta_0 + \sum_k \delta_k \, \mathbf{ENV}_i + \sum_m \theta_m \, \mathbf{ORG}_i + \mu_i$$

where **ENV** and **ORG** are vectors of environmental and organizational factors, respectively, and μ is a classical disturbance term. As previously noted, we do not have any systematic measures of **ORG**. Nor is it clear from the literature precisely what organizational factors should be measured, even if we had the ability to do so. Thus, the equation we estimate contains only the following environmental/institutional (**ENV**) factors:

equation(4a)

$$U_i = \delta_0 + \delta_{\mathrm{M}} \, \mathrm{MED}_i + \delta_{\mathrm{P}} \, \mathrm{PUBLIC}_i + \delta_{\mathrm{A}} \mathrm{AGE}_i + \delta_{\mathrm{R}} \mathrm{INDRD}_{ij} + \delta_{\mathrm{Q}} \mathrm{INDOUT}_{ij} + \mu_i$$

where MED and PUBLIC are dummies denoting whether the university has a medical school and whether it is a public institution, respectively, AGE is the age of the TTO, and INDRD and INDOUT are average annual industry R&D intensity and average annual real output growth in the university's state (*j*), respectively, during the sample period.[10]

The characteristics of our data and parameter estimates of (3) and (4a) are presented in the following section.

4. Data and empirical results

Our primary data source is a comprehensive survey conducted by AUTM, which was completed by TTO directors at 183 academic institutions for 1991–1996. After eliminating teaching hospitals, research institutes, and Canadian institutions, we have 113 US universities. Our final sample contains 80 out of 89 US "Research 1" institutions.11

The AUTM file contains annual data on the number of licensing agreements (LICENSE1), royalty income generated by licenses (LICENSE2), invention disclosures (INVDISC), number of full-time-equivalent employees in the TTO (STAFF), and (external) legal expenditures on UITT (LEGAL).12 Our data sources for state-level industrial R&D (INDRD) and real output growth (INDOUT) are NSF and the BEA.13

There are several difficulties with the output data. First, licensing agreements vary substantially in their significance, making it dangerous to draw inferences about aggregate technology flows based on the number of deals.14 To address this concern, we use licensing revenue as an additional measure of output. Another limitation is that we focus only on two UITT outputs: licensing agreements and royalties. Sponsored research and the formation of startups can also be viewed as UITT outputs. However, startups and sponsored research agreements are often a direct result of licensing agreements. Similarly, one could adopt a broad view of technology transfer and treat patents, invention disclosures, and even students as UITT outputs. Given the uncertainty surrounding this issue, we asked UITT stakeholders to identify the outputs of UITT in our field research.

Descriptive statistics and a correlation matrix for the inputs and outputs of the licensing production function are presented in Table 2. The average university in our sample generates 14 licensing agreements per year, earns US$ 1.8 million in licensing income, receives 54 invention disclosures, employs nine workers in the TTO, and spends US$ 353,000 on external legal fees to protect its intellectual property. The correlation coefficients generally have the expected signs and magnitudes (e.g. invention disclosures are strongly positively correlated with the number of licensing agreements and revenue).

Table 2. Descriptive statistics and correlation coefficients for inputs and outputs of the stochastic frontier production function (Eq. (3))

Variable name	Description	Mean	Median	Standard deviation	
LICENSE1	Average annual licensing agreements	14.3	8	21.4	
LICENSE2	Average annual licensing revenue (US$ 000)	1803.7	321	4997.4	
INVDISC	Average annual invention disclosures	53.9	24	67.4	

STAFF	Average annual TTO employees	9.1	5	16.1	
LEGAL	Average annual external legal expenditures on UITT (000)	352.6	129.8	640.1	
Variable name	LICENSE1	LICENSE2	INVDISC	STAFF	LEGAL
Correlation coefficients					
LICENSE1	1.00	0.89	0.66	0.47	−0.39
LICENSE2	0.89	1.00	0.68	−0.03	0.57
INVDISC	0.66	0.68	1.00	0.43	0.48
STAFF	0.47	−0.03	0.43	1.00	0.49
LEGAL	−0.39	0.57	0.48	0.49	1.00

N=113 universities, 1991‑1996; source: AUTM (1997).

Note that each variable is computed as an annual average over the sample period. Although it may be desirable econometrically to construct a panel consisting of annual observations, this approach is problematic for two reasons. First, the use of annual data or lagged values to estimate the production function would result in an unbalanced panel, since all universities are not continuous reporters during the sample period. A related concern is that it is desirable to have a large sample of establishments when fitting the production function, given that the precision of this estimation will be highly dependent on the number of establishments used to project the frontier. Computing annual averages over the sample period yields the largest possible number of universities for the econometric estimation.

Table 3 contains two sets of parameter estimates of the stochastic frontier production function and inefficiency models outlined in the previous section ((3) and (4a)) for two dependent variables: average annual number of licensing agreements and average annual licensing revenues, respectively.15 Columns 1 and 4 present OLS results, which are used to obtain starting values for regression parameters in the SFE model.16 Columns 2 and 5 contain maximum likelihood estimates of the SFE model without the environmental and institutional variables, while columns 3 and 6 present the coefficients of the “full” version of the SFE model, including the inefficiency model with environmental and institutional variables.

Table 3. Maximum likelihood estimates of the stochastic frontier and inefficiency models ((3) and (4a))

	Dependent variable					
	Average annual number of licensing agreements			Average annual licensing revenue		
	OLS (1)	SFE1 (2)	SFE2 (3)	OLS (4)	SFE1 (5)	SFE2 (6)
Stochastic frontier						
Intercept	−0.363[a](0.172)	−0.218[a](0.108)	−0.297[a](0.146)	2.210[b](0.598)	1.948[b](0.902)	1.501[b](0.739)
INVDISC	0.669[b](0.094)	0.657[b](0.096)	0.649[b](0.087)	1.295[b](0.281)	1.386[b](0.349)	1.316[b](0.510)
STAFF	0.445[b](0.087)	0.395[b](0.119)	0.379[b](0.095)	−0.219 (0.343)	−0.206 (0.371)	−0.198 (0.299)
LEGAL	−0.061[a](0.028)	−0.060[a](0.028)	−0.038[a](0.018)	0.526[b](0.110)	0.463[b](0.129)	0.412[b](0.145)
Inefficiency model						
MED			0.136 (0.270)			−0.011 (0.126)
PUBLIC			0.012 (0.035)			0.050 (0.067)
AGE			−0.103 (0.189)			−0.115[a](0.052)
INDRD			−0.125[a](0.060)			−0.093 (0.071)
INDOUT			−0.044 (0.057)			−0.052 (0.083)
R^2	0.822			0.752		
F statistic for $\beta_1 + \beta_2 + \beta_3 = 1$	1.21			9.95[b]		

log likelihood		−20.79	−19.76		−22.61	−21.41
$\gamma=\sigma u^2/(\sigma v^2+\sigma u^2)$		0.775[b](0.173)	0.651[b](0.259)		816[b](0.311)	0.716[b](0.268)
Mean technical efficiency		0.77	0.83		0.76	0.80

Notes: standard errors in parentheses; *N*=113 universities; SFE1 denotes stochastic frontier estimation excluding environmental/institutional determinants of inefficiency; SFE2 denotes stochastic frontier estimation including environmental/institutional determinants of inefficiency.

a Significant at the 5% level.

b Significant at the 1% level.

The production function model appears to fit quite well, based on the R2 values (0.82 and 0.75 for agreements and revenue, respectively). Across all variants, the estimated elasticity of licensing output with respect to invention disclosures is positive and highly significant. It appears that hiring additional TTO staff results in more agreements (columns 1–3), but not additional revenue (columns 4–6). This finding suggests that university administrators have established TTO incentives in a manner that is consistent with the spirit of Bayh–Dole, i.e. to maximize the number of licensing agreements.

On the other hand, the results imply that spending more on (external) lawyers reduces the number of licensing agreements, but increases licensing revenue. This finding is consistent with the feedback we received from firms in our field research. Several managers reported that it was much more difficult to negotiate with outside attorneys than university administrators, because the lawyers tended to adopt a tougher negotiation stance. Other managers viewed a university's liberal use of outside lawyers as a signal that the institution would be aggressive in exercising its intellectual property rights.

It is difficult to assess the validity of these hypotheses without additional information on the composition of the TTO staff, as substantial external legal expense could actually reflect outsourcing of legal functions or defensive actions in the aftermath of a major lawsuit. Moreover, there could be reverse causality at play, i.e. universities with more lucrative inventions, or those who focus on particularly contentious fields, may be more likely to use outside counsel to protect their intellectual property.17 These interpretations imply that it is not the actions of lawyers that generate higher licensing revenue.

F statistics presented in Table 3 imply that licensing revenue is subject to increasing returns, while licensing agreements are characterized by constant returns to scale. The latter result is consistent with Adams and Griliches (1998), who examined the research productivity of universities (using papers and citations as outputs and R&D expenditures as inputs) and found evidence of constant returns to scale. An implication of increasing returns for licensing revenue is that a university wishing to maximize revenue should spend more on lawyers. Perhaps this would free up TTO staff to spend more time “matching” scientists to firms. Still, this result should be interpreted with caution, as licensing revenue, even when computed over a six-year period, can be a somewhat misleading indicator of current TTO performance, as royalty streams may reflect transactions that were consummated many years ago. For instance, the University of Florida has consistently ranked among the top 10 US universities in licensing income due to Gatorade.

Next, we focus on parameter estimates of the “full” SFE model (SFE2), including the inefficiency equation (Eq. (4a)). In general, the coefficients on the environmental and institutional variables have the right signs, but are statistically insignificant. However, the licensing agreement equation (column 3) results indicate that universities in states with higher levels of industrial R&D activity (INDRD) are less inefficient, that is closer to the frontier. This finding implies that there is a positive association between R&D conducted by local firms and UITT productivity at universities in the same state. In the licensing agreement equation (column 6), we find that older TTOs tend to be closer to the frontier, implying that there is a learning effect in university management of intellectual property. Our results are consistent with evidence presented in Mowery et al. (2001), which reports that over time, newer TTOs learn how to raise the quality of their patent portfolios.

Despite the lack of significance of most of the coefficients, the γ values are highly statistically significant, indicating that the (null) hypothesis that inefficiency effects are absent from the model can be decisively rejected in each instance. Further evidence that external factors provide some explanatory power is shown in Table 3, which contrasts the mean technical efficiency in versions of the model excluding (columns 2 and 5) and including (columns 4 and 6) the environmental and institutional variables. The latter set of findings indicate that these external factors explain some of the variation in technical inefficiency across universities, 26.1 and 16.7%, respectively.18

In this section, we specified a TTO "production function" where the outputs are the number of licensing agreements (LICENSE1) and licensing revenue (LICENSE2) and the inputs are invention disclosures (INVDISC), employees in the TTO (STAFF), and (external) legal expenditures (LEGAL). These variables are assumed to be under the control of the "producer" or the TTO director. We also attempted to explain deviations from the production frontier (relative inefficiency), which are assumed to be a function of a set of environmental and institutional variables that are outside of the control of the TTO director. These are external factors that could enhance or reduce the rate at which universities transfer technologies to the private sector. Our econometric results suggest that while the TTO production function fits well, deviations from the production frontier cannot be completely explained by environmental and institutional factors.

As previously noted, we conjecture that some of the variation in relative productivity can also be attributed to organizational practices in university management of intellectual property. These practices could potentially serve to mitigate conflict caused by palpable differences in the motives, incentives, and organizational cultures of scientists, firms, and administrators. Unfortunately, there are no existing data on UITT organizational practices, nor is it even precisely clear what needs to be measured.

Accordingly, we outline our inductive, qualitative approach to the examination of organizational issues in the following section. We also provide detailed description of our qualitative research methods, as most economists are unfamiliar with these techniques. This information may be beneficial to economists who are contemplating fieldwork.

5. Qualitative research methods

Researchers conducting interview-based, field studies confront four methodological issues: sample selection, the nature of the interview questions, procedures for conducting interviews, and qualitative data analysis. Table 4 summarizes how we dealt with these issues.19 In doing so, we borrow heavily from the fields of management and sociology, where such methods are prevalent. We now briefly consider each of these issues in turn.

Table 4. Four key methodological issues in a field study and how we addressed them

Sample selection	Nature of interview questions	Procedures for conducting interviews	Qualitative data analysis
Convenience sample of five universities from two regions	Semi-structured (some questions were the same for each group, some were tailored to a particular group)	Face-to-face interviews	Tape recording and transcription of interviews by neutral third party
Stratified approach to the selection of interviewees: managers/entrepreneurs, university administrators, university scientists	Open-ended questions	Team approach	Identification of themes from transcripts by multiple assessors
		Neutral probing	Coding of themes
		Pledge of confidentiality	Frequency tables displaying important themes
		Interviewees had prior knowledge of the goals of the study and backgrounds of the researchers	*Z* tests comparing proportion of responses between stakeholder groups

We interviewed TTO stakeholders at five US universities in the southwest and southeast. This is a convenience sample, due to our familiarity with these institutions and the surrounding regions. Yin (1989) reports that convenience samples are common in inductive, exploratory studies, especially when researchers have limited funding. Although our approach precludes an examination of such hotbeds of UITT activity as Cambridge (MIT, Harvard) or Silicon Valley (Stanford, UC-Berkeley), the schools we visited are probably far more representative of the modal university experience with UITT.

The top panel of Table 5 presents some information on the five universities in our field study. These include private and public universities, land grant institutions, and universities with and without a medical school. There is also considerable variation with respect to size and age of the TTO, extent of licensing activity, and technical efficiency.20 The bottom panel of Table 5 compares mean values of licensing agreements, licensing revenue, TTO staff and age, and technical efficiency for the five institutions we visited and the 113 universities in our econometric analysis. Although these five schools generate below average licensing revenue, they are quite similar to the average AUTM respondent along the other dimensions. These findings lend further credence to our assertion that the universities in our field study are representative institutions with respect to UITT.

Table 5. Characteristics of the five universities in our field study and comparison of mean values of key variables with full statistical sample of 113 universities

	University A	University B	University C	University D	University E
Organizational status	Private	Public	Public	Public	Public
Medical school	Yes	Yes	No	No	Yes
Land grant institution	No	No	Yes	No	Yes
TTO established in	1984	1985	1982	1985	1988
STAFF	14.2	11.5	11.1	2.9	8.5
LICENSE1	28.1	19.0	26.1	3.4	12.0
LICENSE2	1213.2	773.3	1535.7	382.7	177.0
Technical efficiency	84.1	80.2	87.8	71.3	74.8
Variable name	Description	Five universities in our field study	One-hundred and thirteen universities in our statistical sample		
Mean values of key variables					
LICENSE1	Average annual licensing agreements	17.7	14.3		
LICENSE2	Average annual licensing revenue (US$ 000)	816.4	1803.7		
STAFF	Average annual TTO employees	9.6	9.1		
AGE	Numbers of years since TTO was established (as of 1996)	11.1	12.5		

Technical efficiency	Estimate of relative productivity based on SFE	79.6	76.9

We constructed a stratified sample of interviewees, drawn from each stakeholder group. At each university, we interviewed academic scientists, TTO directors, and top-level research administrators. Within the surrounding region, we also met with entrepreneurs, directors of business development, intellectual property managers and other research executives of large companies, and executives of patent management firms and non-profit organizations with an interest in UITT. All in all, we conducted 55 interviews: 20 managers and entrepreneurs, 15 administrators (including the five TTO directors), and 20 scientists.21

Potential respondents were selected in two ways. First, we identified the TTO director and other administrators with UITT responsibilities, such as a Vice Provost, Vice President, or Vice Chancellor for Research.22 Second, to identify managers/entrepreneurs and scientists, we solicited feedback from two non-partisan, non-profit organizations that serve as UITT facilitators in each region. These facilitators helped us select managers and scientists with different perspectives on UITT.23

In formulating our set of questions, we adopted a “semi-structured” approach (Miles and Huberman, 1994), whereby interviewees within each stakeholder category were asked the same questions. According to these authors, the best approach for an inductive study is to ask open-ended questions, such as “what are the outputs of UITT?”, “what are the barriers to effective UITT?”, and “how would you improve the process?” We asked such questions to all stakeholders, although some queries were tailored to a particular group. For example, TTO directors were asked about TTO managerial practices, while administrators were asked broader questions regarding strategic goals for UITT.

Following Sekaran (1992), we conducted face-to-face interviews, which the author contends is the best approach for an inductive study on a controversial topic. We paired economists with management professors, as management professors have much more extensive experience and training in qualitative methods.24 The use of teams can also enhance the overall effectiveness of a face-to-face interview by increasing the likelihood that a researcher can respond to a clarifying question or establish a rapport with the interviewee. We also employed three tactics (see Waldman et al., 1998) that increase the accuracy of qualitative data: neutral probing of answers, a pledge of confidentiality, and prior knowledge of the goals of the study and backgrounds of the researchers.25

Based on the 55 transcripts, we implemented the three stages of qualitative analysis of interview data outlined in Miles and Huberman (1994): data reduction, data display, and conclusion drawing/verification (Miles and Huberman, 1994, pp. 10–12). Data reduction involves the selection, simplification, and transformation of raw data (interview responses) into an analyzable form. First, we developed a list of general categories for content analysis. These categories were based on general research questions, such as identifying the barriers to UITT.26 Next, for each transcript, all comments were independently categorized by at least two members of the research team into four areas: UITT outputs, networks/relationships in UITT, barriers to UITT, and proposed improvements to the UITT process. Researchers' lists of comments within a topic area were then compared and discrepancies discussed, until agreement was reached regarding comments that were pertinent to each category.27

Following identification of relevant comments in each topic area, each researcher then worked with five interview transcripts to generate a list of more specific themes within the four categories. The research team then met and discussed the themes that emerged. There was a great deal of similarity in the lists of themes that emerged from the separate samples of comments. After a consensus was reached regarding the themes, we returned to the lists of comments pertinent to each of the four general categories and sorted them into the themes identified for that respective category. For data display purposes, we tabulated frequency counts for each major theme that emerged.

In Table 6, Table 7, Table 8 and Table 9, we display percentages of respondents who identified a particular theme relating to UITT outputs, relationships/networks, barriers to effective UITT, and suggested improvements to the UITT process. For example, the first column on Table 6 reveals that 75% of the managers/entrepreneurs we interviewed identified licenses as an output of UITT. Note that these analyses are conducted separately for each stakeholder group. Proportion tests of differences (Z tests) were computed to compare whether the proportion of respondents mentioning a theme in a given group differs from the proportion of respondents mentioning a theme in another group. For instance, Z12 compares managers/entrepreneurs (Group 1) and TTO directors/university administrators (Group 2).

Table 6. Outputs of UITT as identified by interviewees in our field study

Outputs	Type of interviewee			Z_{12}	Z_{13}	Z_{23}
	Managers/entrepreneurs (1)	TTO directors/administrators (2)	University scientists (3)			
Licenses	75.0	86.7	25.0	−1.37	2.14**	3.24*
Royalties	30.0	66.7	15.0	−1.74	0.91	2.61*
Patents	10.0	46.7	20.0	−2.91*	−0.84	2.23**
Sponsored research agreements	5.0	46.7	0.0	−2.72*	0.44	3.33*
Startup companies	5.0	33.3	10.0	−2.07**	−0.56	1.64
Invention disclosures	5.0	33.3	5.0	−2.81*	−0.99	2.28*
Students	25.0	26.7	15.0	−0.22	0.88	1.22
Informal transfer of know-how	70.0	20.0	20.0	2.69*	3.31*	0.03
Product development	40.0	6.7	35.0	2.08**	0.12	−2.01**
Economic development	35.0	20.0	0.0	0.52	2.98*	2.03**
Number of interviews	20	15	20			

Note: the values presented in columns 1–3 are the *percentages* of respondents who identified a particular item as an output of UITT. The values displayed in the last three columns are *Z* statistics for differences in proportions between each class of interviewee.

** $P<0.05$.

* $P<0.01$.

Table 7. Aspects of relationships/networks in UITT as identified by interviewees in our field study

Relationships/networks	Type of interviewee			Z_{12}	Z_{13}	Z_{23}
	Managers/entrepreneurs (1)	TTO directors/administrators (2)	University scientists (3)			
Personal relationships	75.0	66.7	80.0	0.68	−0.42	−1.63
TTO as a facilitator of relationships between scientists and firms	25.0	75.0	40.0	−2.65*	−0.91	1.92
Knowledge transfer from industry to faculty members	25.0	20.0	65.0	0.35	−2.46*	−297*
Conference/expos/town hall meetings on TT issues	35.0	80.0	15.0	−2.34**	1.59	3.56*
Contractual relationships	15.0	6.7	0.0	0.84	1.80	1.02
Number of interviews	20	15	20			

Note: the values presented in columns 1‑3 are the *percentages* of respondents who identified a particular item as an aspect of relationships/networks in UITT. The values displayed in the last three columns are *Z* statistics for differences in proportions between each class of interviewee.

** $P<0.05$.

* $P<0.01$.

Table 8. Barriers to UITT as identified by interviewees in our field study

Barriers	Type of interviewee			Z_{12}	Z_{13}	Z_{23}
	Managers/entrepreneurs (1)	TTO directors/administrators (2)	University scientists (3)			
Lack of understanding regarding university, corporate, or scientific norms and environments	90.0	93.3	75.0	−0.25	1.19	1.30
Insufficient rewards for university researchers	35.0	60.0	70.0	−1.29	−2.46*	−1.03
Bureaucracy and inflexibility of university administrators	80.0	6.7	70.0	3.96*	0.74	−3.51*
Insufficient resources devoted to technology transfer by universities	35.0	53.3	20.0	−0.95	0.93	2.05**
Poor marketing/technical/negotiation skills of TTOs	55.0	13.3	25.0	2.07**	1.91	−0.71
University too aggressive in exercising intellectual property rights	80.0	13.3	25.0	3.30*	2.94*	−0.91
Faculty members/administrators have unrealistic expectations regarding the value of their technologies	25.0	40.0	10.0	−0.94	1.13	1.90
“Public domain” mentality of universities	40.0	6.7	5.0	1.86	2.60*	0.38
Number of interviews	20	15	20			

Note: the values presented in columns 1–3 are the *percentages* of respondents who identified a particular item as a barrier to UITT. The values displayed in the last three columns are *Z* statistics for differences in proportions between each class of interviewee.

** $P<0.05$.

* $P<0.01$.

Table 9. Suggested improvements to the UITT process, as identified by interviewees in our field study

Improvements	Type of interviewee			Z_{12}	Z_{13}	Z_{23}
	Managers/entrepreneurs (1)	TTO directors/administrators (2)	University scientists (3)			
Universities and industry should devote more effort to developing better mutual understanding	80.0	93.3	75.0	−0.96	0.33	1.28
Modify reward systems to reward technology transfer activities	85.0	80.0	80.0	0.35	0.36	−0.00
Universities need to provide more education to overcome informational and cultural barriers	85.0	86.7	60.0	−0.09	1.70	1.74
Universities should devote additional resources to technology transfer	45.0	46.7	60.0	0.11	−1.00	−1.25
Universities should be less aggressive in exercising intellectual	55.0	10.0	15.0	2.52*	2.62*	−0.36

property rights						
Increase formal and informal networking between scientists and practitioners	35.0	26.7	40.0	0.65	−0.34	−1.09
Universities need greater technical expertise and marketing skills in the TTO	50.0	20.0	25.0	1.76	1.54	−0.37
Number of interviews	20	15	20			

Note: the values presented in columns 1–3 are the *percentages* of respondents who identified a particular item as a suggested improvement to UITT. The values displayed in the last three columns are *Z* statistics for differences in proportions between each class of interviewee.

* *P*<0.01.

6. Qualitative findings

Table 6 demonstrates that licenses and royalties were identified as outputs of UITT by a substantial majority of TTO directors and university administrators. Managers and entrepreneurs also frequently mentioned licenses, but stressed informal aspects of UITT a bit more, as well as economic development outcomes. Scientists emphasized product development and surprisingly, failed to mention sponsored research agreements.

Another key finding is that there is considerable heterogeneity in stakeholder perspectives regarding UITT outputs. There appears to be a "Rashomon" effect, as evidenced by the numerous output categories identified by respondents and by the many significant differences between each class of interviewee (16 out of 30 Z statistics are significant at the 5% level).28 This is perhaps not surprising, as university management of intellectual property through a TTO is a recent and somewhat controversial development.

This raises the important issue of the tradeoffs associated with stimulating additional UITT, in terms of its impact on the sharing and dissemination of knowledge. Indeed, some interviewees perceived the mission of the TTO (protection and marketing of the university's intellectual property) as being inconsistent with the traditional "public domain" philosophy regarding the dissemination of information that pervades most research universities. This concern was articulated in a recent trenchant essay by Nelson (2001), who asserts that the cost of losing the culture of "open science" that exists at leading universities outweighs any benefits that might arise as a result of more rapid technological diffusion.

Table 7 shows that respondents in each stakeholder category mentioned personal relationships in UITT much more often than contractual relationships. One scientist said:

> I would say right now that I feel that the one-on-one interaction is somewhat more successful in effectively transferring technology [than is research formally sponsored by a consortium].

This raises the possibility that the formation of "social networks" could be important in UITT. These networks include academic and industry scientists, graduate students and post-doctoral fellows who conduct most of the experimental work in laboratories, former graduate students who have accepted positions in industry, entrepreneurs, and perhaps, university administrators and TTO directors. As defined by Liebeskind et al. (1996), social networks, like markets, involve exchanges between legally distinct entities. However, unlike markets, social networks support these exchanges without using competitive pricing or legal contracting. Instead, they rely on shared norms among the exchange partners, where information is the currency of exchange.29

Table 7 also indicates that knowledge transfer appears to work in both directions. For instance, 65% of the scientists noted that interacting with industry has had a positive influence on their experimental work. Some scientists explicitly mentioned that these interactions improved the quantity and quality of their basic research. A representative comment from a scientist was:

> There is no doubt that working with industry scientists has made me a better researcher. They help me refine my experiments and sometimes have a different perspective on a problem that sparks my own ideas. Also, my involvement with firms has allowed me to purchase better equipment for my lab, which means I can conduct more experiments.

This result is consistent with Zucker and Darby (1996), who found an increase in the scholarly output of “star” academic scientists after they were involved in commercialization efforts in biotechnology.30 This implies that the conventional wisdom regarding the existence of a tradeoff between UITT activity and research performance may be wrong.

As shown in Table 8, all three groups identified a lack of understanding regarding university/corporate/scientific norms as a barrier to effective UITT (90.0, 93.3, and 75.0%). It appears that these cultural and informational barriers are pervasive. That is, university scientists and administrators often do not understand or appreciate the industry environment, and vice versa. An illustrative comment from a scientist was:

> Industry has a lack of understanding of what an academic institution does and a lack of understanding of what a university faculty member’s responsibility is to their institution. There are some companies I don’t even deal with because their approach to dealing with an academic entity is so poor. They feel that basically we owe them by our position at the university because the state pays our salaries.

Our qualitative evidence is consistent with the view that UITT stakeholders operate under different organizational environments and cultures, implying that they have different norms, standards, and values. For example, Nelson (2001) noted how universities and firms differ in their perspective on the role of knowledge. Managers and entrepreneurs usually do not share the academic values of publishing results and sharing information with colleagues and the general public. Instead, new knowledge and technology is to be kept proprietary and exploited to achieve or sustain a competitive advantage.

Table 8 also indicates widespread belief that there are insufficient rewards for faculty involvement in UITT. Sixty percent of administrators and 70% of scientists reported this as a barrier. In their comments, administrators and scientists specifically referred to tenure and promotion policies and the university’s royalty and equity distribution formula. The latter refers to the split in licensing or equity income among the inventor(s), the department or college of the inventor(s), and the TTO or another general research fund within the university. For example, at one school, the formula was 40% inventor, 40% inventor’s department, and 20% “invention management fund” which is managed by the TTO.31 An administrator at a school with a relatively low payout rate to inventors noted that:

> Some faculty members have complained about the low share of revenue they receive. They may be right. We hope to bring that up to say 40% in the near future. I think we'll have much of a struggle on that one.

The vast majority of interviewees also specifically commented on the fact that tenure and promotion decisions continued to be made almost strictly on the basis of publications and grants. For example, one scientist remarked:

> Technology transfer has not played a role in the performance evaluation process. Performance evaluation is based on publications.

From this scientist's perspective, the existing reward structure at his university is inconsistent with the organizational objective of increasing UITT, a goal that is featured prominently in that university's mission statement and promotional brochures.

Managers/entrepreneurs (80%) and scientists (70%) also frequently pointed to university bureaucracy and inflexibility as barriers to effective UITT. Many scientists and managers provided us with examples of rigid, cumbersome, and unclear policies and procedures that impede UITT. Faculty members who had tried to form startup companies were especially vocal on this point. A typical remark from a scientist was:

> I don't think they understand the flexibility within the framework and what they can do. I think they have a set of forms and a set of ways of doing things, and if it doesn't fit nicely into that, then they make you go through a whole bunch of hoops.

Although some of these complaints may be self-serving, universities that wish to enhance UITT productivity should address such negative perceptions.

Staffing practices in the TTO are also a matter of concern. Recall that a university technology licensing officer is responsible for coordinating the activities that result in a formal agreement between the university (and its scientists) and a firm. Fifty-five percent of the managers and entrepreneurs we interviewed expressed dissatisfaction with the marketing and negotiation skills of TTO personnel. An intellectual property manager stated:

> These guys (TTOs) need to be marketing facilitators rather than lawyers. They need to be able to step into the company and into their customer's shoes and look back.

A lack of requisite business skills and expertise could have a significant deleterious effect on TTO productivity. Other respondents noted that TTOs are either too narrowly focused on a small set of technical areas, or too concerned with the legal aspects of licensing.

There is also a strong belief on the part of industry (80%) that universities are exercising their intellectual property rights too aggressively. One manager stated:

> I think the frustration for commercial licensees who go to a university is that it seems as though the attitude they are hitting at the university is 'oh we've got this wonderful thing and we're going to drag every nickel out of you that we can get for it'.

One interpretation of this perception is that it is self-serving and merely a reflection of the inherently adversarial nature of negotiations. However, this attitude, in conjunction with the concerns raised earlier regarding university bureaucracy and inflexibility, has led some firms to completely avoid working with TTOs. Thus, when an invention is publicly disclosed, some firms will contact scientists and arrange to work with them via informal technology transfer, through consulting or a sabbatical leave. A scientist reported on the attitude of firms he was working with:

> In fact a lot of firms will come to us and say we don't want to go through the university … we'll just pay you on the side.

Table 9 presents some suggested improvements to the UITT process. These recommendations are fairly consistent with the impediments identified in Table 8. With virtual unanimity, respondents suggested that universities and firms should devote more effort to developing better mutual understanding. Several respondents noted that this could easily be achieved through such events as "Town Hall" meetings involving the three stakeholder groups, as well as by targeting each individual group with additional information to help facilitate UITT. For example, one university scientist pointed out that new faculty orientations at his university did not include a module on UITT issues:

> It’s appalling that new faculty members don’t receive any information on how to get involved in technology transfer at their orientation sessions. What does that tell you about this school’s priorities?

Another consistent theme was that universities should align reward systems with UITT goals. Although we lack measures of the intensity of feeling on a particular theme, our analysis of the transcripts reveals that recommendations regarding changes in reward systems were by far the most direct and vivid of the suggested improvements to the UITT process. Many university administrators specifically mentioned the need to reward UITT more in promotion and tenure decisions. One department chair phrased it as follows:

> It’s the height of hypocrisy for universities to claim that they value technology transfer, or that it’s supposed to be a top institutional priority, and then fail to reward it in their promotion and tenure decisions. At some point, we’ve got to resolve this discrepancy.

Several managers/entrepreneurs and administrators also discussed the need for incentive compensation for TTO staff. A representative comment from a manager was:

> The TTO people need to push the deals through …. You’ve got to look at how they are rewarded. Perhaps if they were paid on the basis of the number of deals they complete or the revenue they generate for the university, you would see more technologies licensed. I guess that they are so terrified of negative publicity if a bad deal goes through, that they’re afraid to make this change.

Our respondents noted that some private schools, and even some public ones, such as the University of Washington and Wayne State, recently instituted incentive compensation plans in the TTO. Other schools are contemplating implementing these programs. Such efforts might reduce the high rate of turnover among TTO staff and enhance productivity.32

Table 9 also demonstrates that, to a lesser extent, there was support for the notion that universities should devote additional resources to UITT, although most of these recommendations were somewhat nebulous. Many respondents also suggested that universities provide more education and/or community outreach to overcome informational and cultural barriers. A predictable recommendation from managers and entrepreneurs is that universities should be less aggressive in exercising intellectual property rights.

7. Conclusions and suggestions for additional research

In this paper, we present quantitative and qualitative evidence on several aspects of UITT. A stochastic production function framework is used to assess the relative productivity of university TTOs. The parameter estimates of the stochastic frontier imply that licensing activity, our proxy for UITT, is characterized by constant returns to scale. The deviations from the frontier, which represent technical inefficiency, are assumed to be a function of a vector of environmental and institutional factors. We find that these variables explain a portion of the variation in relative productivity across universities.

We hypothesize that some of the remaining variation in relative efficiency can be attributed to organizational practices in university management of intellectual property. Unfortunately, this hypothesis cannot be formally tested because there are no systematic measures of these factors. Thus, an analysis of UITT organizational practices is fertile ground for an inductive, exploratory field study. As a first step towards identifying these practices, we conducted 55 face-to-face interviews of 98 key UITT stakeholders at five research universities. This fieldwork also greatly improved our ability to model the UITT process, by providing a critical reality check on the specification of the econometric model. Based on our qualitative evidence, we believe that the most critical organizational factors are reward systems for faculty involvement in UITT, compensation and staffing practices in the TTO, and actions taken by administrators to extirpate informational and cultural barriers between universities and firms. More specifically, it appears that the propensity of faculty members to disclose inventions, and thus, increase the "supply" of technologies available for commercialization, will be related to promotion and tenure policies and the university's royalty and equity distribution formula. TTO compensation practices could also be relevant because UITT activity will depend on the efforts of technology licensing officers to elicit invention disclosures and market them effectively to private companies. Thus, we expect that, ceteris paribus, licensing activity will be higher at universities that have implemented some form of incentive compensation plan for technology licensing officers.33

Staffing practices in the TTO may also help explain why some universities are more proficient than others in managing intellectual property. According to Parker and Zilberman (1993), TTOs usually hire either a mix of scientists and lawyers or a mix of scientists and entrepreneurs/businessmen. In the former case, legal functions, such as the adjudication of disputes involving intellectual property rights and the negotiation of licensing agreements, are performed in-house. In the latter case, such functions are usually outsourced. Parker and Zilberman hypothesize that the entrepreneur/business model for TTOs may be more conducive to helping scientists form their own startups. It also seems reasonable to assume that TTOs staffed in this manner would be more effective in the marketing phase of UITT. A substantial percentage of managers suggested that universities hire more licensing professionals with stronger marketing and business skills.

Our findings regarding informational and cultural barriers suggest that “boundary spanning” could be an important skill for university technology licensing officers. Boundary spanning behavior has been studied extensively in the management literature (Katz and Tushman, 1983). In the context of UITT, boundary spanning refers to actions taken by university technology managers to serve as a bridge between “customers” (entrepreneurs/firms) and “suppliers” (scientists), who operate in distinctly different environments. Without effective boundary spanning, the needs of customers may not be adequately communicated to suppliers. Similarly, the capabilities and interests of suppliers may not be adequately communicated to customers. Effective boundary spanning by a TTO would involve adept communication with both stakeholder groups, in an effort to forge alliances between scientists and firms.

The most natural extension of our exploratory study would be to survey UITT stakeholders at each university in an attempt to measure the organizational factors we have identified.34 Some variables, such as the university’s royalty and equity distribution formula are easy to measure with a survey and may even be available on the worldwide web. Other variables, such as measures of the skills of TTO personnel, tenure and promotion policies, and other policy variables will be more perceptual in nature. In designing these surveys, we need to be mindful of the considerable heterogeneity in stakeholder perspectives on UITT that was revealed in our interviews. This finding underscores the importance of surveying scientists, managers/entrepreneurs, and administrators separately to generate a more accurate and unbiased view of the organizational environment.

Taking stock of organizational practices in university management of intellectual property will be useful in several respects. First, given the somewhat embryonic nature of the TTO enterprise as an organizational form, there is a need to simply document the nature of these practices.35 Many administrators expressed a strong interest in benchmarking their intellectual property management practices relative to peer institutions. Perhaps the most important benefit of collecting this information is that it can be used to determine the fraction of the variance in relative productivity that can be attributed to organizational factors. We can also identify specific practices that enhance UITT productivity. Finally, these data could be used to assess the performance effects of the adoption of complementary organizational practices. Recent theoretical (Athey and Stern, 1998) and empirical (Ichniowski et al., 1997) studies highlight the importance of clusters or “mixes” of complementary organizational practices in enhancing productivity, due to interaction effects. It would be interesting to see if such synergies arise in the context of UITT.

Possible extensions to the econometric analysis include adding more environmental and institutional factors as explanatory variables in the inefficiency equation, such as measures of the strictness of state and university technology transfer policies, local venture capital activity, and more detailed data on regional R&D. It might also be useful to employ a more general, "flexible" functional form for the production function, such as the Generalized Leontief specification (see Morrison and Siegel, 1997). Access to more comprehensive data might also allow for an analysis of variation in licensing practices and impediments by technology field (e.g. physical versus life sciences).36 Another extension to the empirical analysis would involve incorporating multiple outputs of UITT, such as the number of startups and sponsored research agreements resulting from UITT. This requires the use of a "distance" function approach, which has been implemented in recent studies in the stochastic frontier literature.37

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1 For instance, as noted in Cohen et al. (1998), NSF has established Science and Technology Centers and other programs that require universities to attract matching funds from industry. See

David and Hall (2000), Klette et al. (2000), and Martin and Scott (2000) for more general theoretical and empirical considerations of public–private partnerships in the realm of R&D.

2 Gallini and Scotchmer (2001) provides an excellent discussion of issues related to appropriate intellectual property regimes in this context.

3 See Geroski (2000) for an excellent review article of models of technology diffusion.

4 “We came to the realization that this failure to move from abstract research into useful commercial innovation was largely a result of the government’s patent policy and we sought to draft legislation which would change this policy in a way to quickly and directly stimulate the development and commercialization of inventions” (Bayh, 1996).

5 Mowery et al. (2001) challenge this causal interpretation of the impact of Bayh–Dole on UITT. The authors analyze pre- and post-Bayh–Dole UITT licensing and patenting at the University of California, Columbia, and Stanford, and conclude that Bayh–Dole was only one of several factors inducing a rise in UITT.

6 Exceptions are papers by Thursby and Thursby (2000) and Bercovitz et al. (2001). The former is a quanitative study, based on AUTM data, which examines the productivity of university licensing. The latter is a qualitative study of the relationship between organizational structure and UITT performance at Duke, Johns Hopkins, and Penn State.

7 Also, university technology managers tend to view patents as both an input and output of UITT (see AUTM, 1997, pp. 20–21).

8 This amount includes expenditures in support of prosecution, maintenance, litigation, and interference costs relating to patents and/or copyrights (see AUTM, 1997).

9 Battese and Coelli (1995) have recently extended this model to incorporate panel data.

10 An alternative is to use MSA-level R&D data on industrial innovations and R&D employment, provided in Anselin et al. (1997). Unfortunately, these data (from 1982) do not correspond to our sample period.

11 Source: Carnegie Foundation for the Advancement of Teaching—to qualify for Research 1 status, a university must award 50 or more doctoral degrees and receive at least US$ 40 million annually in federal research grants.

12 Unfortunately, AUTM does not ask TTOs to split out information on exclusive and non-exclusive licenses.

13 Source: NSF (1991) Research and Development in Industry (1991–1996), US BEA (1999) Gross State Product data reported in Fixed Reproducible Tangible Wealth.

14 A similar problem is encountered with patents. Jaffe et al. (1993), Trajtenberg et al. (1997), and Henderson et al. (1998) weight patents on the basis of the number of citations they receive.

15 Although there is no direct diagnostic test for multi-collinearity, we do not observe any of the key symptoms of this problem: (1) high R2 but few significant t ratios; (2) high pairwise and partial correlations among explanatory variables (see Table 2). Thus, we conclude that there does not appear to be a multi-collinearity problem.

16 Coelli (1994) points out that, except for the intercept term, the OLS estimates are consistent, albeit inefficient.

17 We are indebted to an anonymous referee for this salient point.

18 That is, the mean technical efficiency is closer to one when we include these variables in the stochastic frontier model (0.06/(1−0.77)=0.261 and 0.04/(1−0.76)=0.167).

19 This is by no means an exhaustive list of such concerns. For a comprehensive review of qualitative research methods, see Miles and Huberman, 1994 and Yin, 1989.

20 That is, some institutions are close to the frontier, while others are highly inefficient.

21 Although there were only 55 face-to-face meetings, we actually interviewed 100 individuals, since multiple respondents were present at some meetings (Siegel et al., 2001).

22 Typically, the TTO director reports to a Vice President, Vice Provost, or Vice Chancellor for Research.

23 In one region, a facilitator had published a voluminous report on UITT, which contained the names, phone numbers, and addresses of these potential respondents.

24 Five professors (two management professors and three economists) conducted the 55 interviews (Siegel, 1999).

25 According to Yin (1989), this serves two useful purposes. First, it indicates the researchers' concern and respect for the value of the respondent's time. Second, it reduces uncertainty and suspicion regarding the intentions of the researchers.

26 We also followed the advice of Miles and Huberman (1994) by having multiple assessors of interview transcripts. The authors assert that the use of multiple assessors reduces the degree of bias in interpreting such transcripts.

27 These methods are similar to those employed by Butterfield et al. (1996), who identified unique "thought units" pertinent to their subject of interest (employee discipline).

28 For the benefit of Research Policy readers who are cinematically deprived, Rashomon is a famous Japanese movie, directed by Akira Kurosawa. It portrays four vastly different views of

the same heinous crime. In coining this phrase, we wish to suggest that the three stakeholders (academic scientists, university administrators, and managers/entrepreneurs) may have starkly different perspectives on the same events/process.

29 Powell (1990) argued that social networks are the most efficient organizational arrangement for sourcing information because information is difficult to price and communicate through a hierarchical structure.

30 Mansfield (1995) reported similar results for a variety of scientific fields.

31 Jensen and Thursby (2001) surveyed 62 TTOs and found that the mean payout rate to inventors is 40%. See Beath et al., 2000 for an analysis of the optimal payout rate for scientists.

32 Several firms were frustrated by the high rate of turnover in the TTO, which was perceived to be detrimental to relationship building and organizational learning.

33 Lazear (1999) and Ichniowski et al. (1997) report a positive correlation between incentive compensation and worker and plant productivity, respectively.

34 There is an existing survey instrument to measure boundary-spanning skills (Caldwell and O'Reilly, 1982).

35 Although TTOs were established many years ago at some elite institutions, our discussion relates to TTOs at more representative universities.

36 In this regard, Owen-Smith and Powell (2001) report some interesting differences in the perceptions of academics in the physical and life sciences regarding patent outcomes.

37 As described in Grosskopf et al. (1997), this class of models assumes that the relationship between output and inputs can be represented by a transformation function T, where $0=T(x,y)$ and y denotes a vector of outputs ($0=y-f(x)$ for the single output case).