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A COCHRANE METHOD SYSTEMATIC REVIEW OF UNIVERSITY TECH COMMERCIALIZATION RESEARCH

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Abstract

Since 1980 universities have been able to commercialize inventions that their faculty researchers create as per the 1980 Bayh-Dole Act (P.L. 96-517). Research universities can now own and license these inventions to small and well established companies. Since 1980, research universities have used tech commercialization to support their regional economies with product development and sales, and academic entrepreneurship resulting in university spin-offs and start-up business formations. This results in job creation. The technology transfer offices (TTOs) which were established at many research universities to manage this process have been studied quite extensively. However, the foundational elements that fuel successful TTO performance has not been studied comprehensively. Instead, there are numerous fragmented studies that date back to the early 1980s. In addition, there is no agreed upon common theory for studying university technology and how these elemental inputs related to performance outputs. Thus, herein it is advocated that the resource-based view (J. Barney, 1991) and theory on environmental munificence (Castrogiovanni, 1991, 2002) be used as a theoretical framework for researching university technology commercialization. Competitive resources in a more munificent environment can make it easier for an organization to survive and prosper.

Keywords

technology management, technology transfer, technology commercialization, systematic review, meta-analysis, management of innovation, management of new technologies, project and innovation management, R&D management, management of scientists and engineers

Introduction

Stanford cell biologist Lubert Stryer and U.C. Berkeley microbiologist Alexander Glazer researched the use of phycobiliproteins found in marine algae as fluorescent markers. Six (6) months later, Stanford licensed the invention to two (2) companies which is now an important tool for cancer detection and blood screening. And this is only one among many such success stories. In fact, for the past 30 years, universities have been in the business of selling research results by licensing technological innovations to well established corporations, small businesses, and/or to university start-up companies that they spin-off (Wiesendanger, 2000).

Since the Morrill Act of 1862, established land grant universities have acted as research hubs. In 1980, Congress passed the Bayh-Dole Act ("Bayh Dole Act," 1980) which allowed universities to obtain ownership title to inventions created with government funded research and established technology transfer offices (TTOs) to manage the process of patenting and licensing these inventions. Technology transfer is a subset of technology management (C. Hamilton, 2017a, 2017b). Because of the role of TTOs in enabling and commercializing innovations, a growing number of researchers have examined for example: whether university policies and structures have any effect on academic entrepreneurship (Seashore Louis, 1989); the features of universities that generate the most spin-offs (A. W. Lockett, Mike 2005); factors that enhance university tech transfer (Friedman, 2003); if internal and external factors explain the efficiency of university tech transfer (Siegel, 2003); the level of efficiency that university TTOs in the UK exhibit (Chapple, 2005); the difference between for profit versus traditional nonprofit TTOs, technology licensing for equity strategies and sponsored research licensing strategies (G. D. Markman, Phan, Phillip H., Balkin, David B., Gianiodis, Peter T., 2005); the best incubation models for academic spin-offs (Clarysse, 2007); the most efficient TTOs (Curi, 2012) ; what technology transfer specialists pay attention to (C. Hamilton, 2015; C. S. Hamilton, David, 2016); and which TTOs are more likely to get better results (González-Pernía, 2013).

Although there is a large and growing amount of TTO research, there is significant ambiguity surrounding the determinants of TTO performance. As an example, although one study showed that TTO performance in the creation of startups is strengthened by the presence of human capital (Van Looy, 2011), another study found the presence of human capital had little to no effect in relation to startup formations (Hülsbeck, 2013). This simply example suggests that it is unclear what resources are needed to enable strong TTO performance. Thus, the resource-based view (RBV) (J. Barney, 1991) may be useful in describing why key TTO attributes might be related to performance. The RBV asserts that when organizations possess strategic resources that are valuable, rare, and hard to imitate, higher performance can result. For example, patents are potentially strategic (J. B. A. Barney, A. M. , 2001). The RBV further outlines that human (e.g., scientists), organizational (e.g., positive reputation, plans, systems), and physical (e.g., labs and facilities) resources might be necessary, but not sufficient, for organizations to perform at high levels if they are easy to imitate (J. Barney, 1991). Although the RBV has been applied to university technology commercialization in prior research (J. B. Powers, 2003), findings from single studies often do not generalize to the overall population (Schmidt, 2015). In addition to the RBV, the environment external to the university is an important source of resources; and when environments are more munificent, it makes it easier for an organization to survive and prosper (Castrogiovanni, 1991, 2002). In the context of TTOs, munificent environmental are characterized by industry funding, total research funding, GDP, and regional R&D intensity. The meta-analysis allows findings from extant research to be combined so that sampling error is minimized, and that estimates of relationships more closely approximate those found in the population.

Hypotheses Development

A concept model was developed for university technology transfer success based on the RBV. The concept model's constructs, definitions and samples measures are shown in Exhibit 1. The concept model shows inputs into the university technology transfer process. These are resource inputs. A RBV of university technology transfer involves viewing the process from the lens that TTOs require human, organizational, and physical resources to succeed. It was imperative to find studies with empirical measurements of resources that might be important.

Regarding *human capital resources*, studies were found which empirically measured TTO staff sizes in terms of full time equivalents (FTEs) (Carlsson, 2002; Chapple, 2005; Hülsbeck, 2013; G. D. G. Markman, Peter T.; Phan, Phillip H.; Balkin, David B. , 2005; J. B. M. Powers, Patricia 2005; Siegel, 2003; Van Looy, 2011); TTO legal expenditures (Chapple, 2005; Siegel, 2003); and TTO age (Chapple, 2005; G. D. G. Markman, Peter T.; Phan, Phillip H.; Balkin, David B. , 2005; J. B. M. Powers, Patricia 2005). With regard to *organizational resources*, invention disclosures (Cardozo, 2011; Carlsson, 2002; Chapple, 2005; Hülsbeck, 2013; Rogers, 2000; Siegel, 2003; Sine, 2003; Swamidass, 2009); patent applications filed by the TTO (Cardozo, 2011; Carlsson, 2002; Ho, 2014; Rogers, 2000; Swamidass, 2009) and university owned patents (Cardozo, 2011; Hülsbeck, 2013; J. B. M. Powers, Patricia 2005; Van Looy, 2011) have been measured.

With respect to *physical resources*, the presence of medical schools and incubators has also been studied (G. D. Markman, Phan, Phillip H., Balkin, David B., Gianiodis, Peter T., 2005; J. B. M. Powers, Patricia 2005; Van Looy, 2011). Further, the theory of environmental munificence (TEM) applies since the environment external to an organization such as a university is an important source of resources, and when environments are more munificent, it makes it easier for an organization to survive and prosper (Castrogiovanni, 1991, 2002). In the context of TTOs, munificent environmental are characterized by total research funding (Chapple, 2005; Ho, 2014; Hülsbeck, 2013; A. S. Lockett, Donald; Wright, Mike; Ensley, Michael D., 2005; J. B. M. Powers, Patricia 2005; Van Looy, 2011), regional GDP (Chapple, 2005; Hülsbeck, 2013), regional R&D intensity (Chapple, 2005; A. S. Lockett, Donald; Wright, Mike; Ensley, Michael D., 2005) and industry funding (Ho, 2014; J. B. M. Powers, Patricia 2005). These are empirical studies of external resources with respect to university technology transfer.

Exhibit 1 also shows the outputs of the university technology transfer process. These outputs are entrepreneurial spin-off businesses that may be formed (Hülsbeck, 2013; G. D. Markman, Phan, Phillip H., Balkin, David B., Gianiodis, Peter T., 2005; J. B. M. Powers, Patricia 2005; Rogers, 2000; Van Looy, 2011) and related licensing agreements (Chapple, 2005; J. B. Powers, 2003; J. B. M. Powers, Patricia 2005; Rogers, 2000; Siegel, 2003; Sine, 2003; Swamidass, 2009). There may also be licensing deals with established small business enterprises or larger corporations. The primary performance measures for TTOs are licensing revenues (Carlsson, 2002; Chapple, 2005; Ho, 2014; A. S. Lockett, Donald; Wright, Mike; Ensley, Michael D., 2005; G. D. Markman, Phan, Phillip H., Balkin, David B., Gianiodis, Peter T., 2005; J. B. Powers, 2003; J. B. M. Powers, Patricia 2005; Rogers, 2000; Siegel, 2003).

Method

There’s a large body of university technology transfer research dating back to the 1970s. Between September – November 2014, an evidence-based systematic review of university technology transfer literature was conducted to identify, select, appraise and synthesize results from similar separate studies. The review was updated between August and September of 2017. Systematic reviews focus on a specific research question or set of questions. Here, the systematic review was used to test the hypotheses.

Exhibit 1. Definitions and Sample Measures of RBV constructs

Constructs impacting the Tech Transfer process	Definitions	Sample Measures
INPUT		
Human (H)	Universities’ TTO staff and legal resources	TTO staff size (FTEs); TTO age; TTO legal expenditure
Organizational (O)	Universities’ internal organizational resources	Invention disclosures; Patent applications filed; Patents owned
Physical (P)	Universities’ internal physical resources	Presence of an Incubator; Presence of a medical school
External environment (E)	Regional external resources	Regional GDP; Regional R&D intensity; Total research funding; Industry funding
OUTPUT		
Performance (Perf)	Outcomes of the university TTO’s activities	Overall performance including Licenses executed; Licensing revenues; Startups formed
License (Lic)		Licenses executed; Licensing revenues
Startups (Start)		Startups formed

Systematic reviews differ from traditional narrative reviews because systematic reviews require the use of a pre-planned standard format and scientific method. In a traditional review, the researchers would generally look for research papers that support or not support the researchers’ hypotheses. With regard to the scientific method, there are four (4) steps that differentiate a systematic review from a traditional narrative review. The traditional reviewer: (1) identifies all evidence on the topic; (2) selects evidence that meets inclusion/ exclusion criteria; (3) appraises the quality and validity of the evidence; and (4) summarizes the results. In comparison to the traditional review, in the systematic review, a standard format is used in an effort to conduct a higher quality, more sophisticated, comprehensive, extensive and unbiased review. There is a clearly specified method of identifying, selecting, validating and including information so that it is clear, transparent, recordable and reproducible. The transparency is in the process documented in the protocol for the systematic review. Using a clear and transparent process helps minimize bias and systematic errors in summarizing the evidence. There is also a quantitative synthesis to integrated the information from multiple studies.

The Cochrane Collaborative is a leading international group of medical researchers that conduct systematic reviews on biomedical research. Using their *Cochrane Handbook for Systematic Reviews*, the first step in this systematic review was to develop a protocol which outlined the steps for doing the systematic review based on the Cochrane Method (*Cochrane Handbook for Systematic Reviews of Interventions*, 2011). The protocol included data collection, screening the results, abstracting data, appraising the risk of bias, synthesizing the findings, and interpreting the results.

Data Sources

In this systematic review, a comprehensive list of phenomenon-specific search keywords was created. Keywords were selected using the Cochrane Collaboration recommended PICO strategy in medical research. The benefit of using the PICO strategy is to ensure a well formulated research question (*Cochrane Handbook for Systematic Reviews of Interventions*, 2011). In PICO, research questions are broken down into concepts which include the research *Population*, medical *Interventions*, *Comparisons* and research *Outcomes*. In this study, keywords include concepts related to this study's newly coined 'PRO' which stands for research *Population*, *Resources*, and *Outcomes*: The studies collected for this systematic review have the following PRO components:

P = technology transfer office staffing Populations

R = human, organizational, and physical Resources

O = patenting, patent licensing and startup formation performance Outcomes

In addition, the Cochrane Collaborative recommends that well formulated research questions in biomedical systematic reviews describe the medical exposure or intervention, outcome, setting and population. The setting and population in the following research questions for this study is the university TTOs and their staffs respectively. According to RBV and TEM, the following hypotheses were tested with this meta-analytical systematic review:

- *Research Question 1*: Are human resources positively related to TTO performance in the areas of patenting, licensing, and generating startups?
- *Research Question 2*: Are organizational resources positively related to TTO performance in the areas of patenting, licensing, and generating startups? These resources are invention disclosures, patent applications and patents.
- *Research Question 3*: Are physical resources positively related to TTO performance in the areas of patenting, licensing, and generating startups? These physical resources include incubators and medical schools.
- *Research Question 4*: Are external environmental munificence positively related to TTO performance in the areas of patenting, licensing, and generating startups?

These research questions were translated into the following general Boolean format that a database could understand: (Population OR synonym1 OR synonym2) AND (Resource1 OR synonym1 OR synonym2) AND (Outcome1 OR synonym1 OR synonym2). Thus, a sample initial search for Research Question 1 would be: (TTO OR "tech transfer" OR "technology management" OR "technology commercialization" OR "technology licensing") AND ("human resource" OR staff OR employee OR "licensing specialist" OR "tech transfer specialist") AND (performance OR licens OR patent OR startup).

The goal was to use the fewest number of concepts as possible to maintain a manageable set of results in the keyword searches. Keyword searches are any type of free text searching conducted to look for words in abstracts and other database fields. Since it takes an extensive amount of time to hand search all of the literature, a search strategy for databases is estimated and this is augmented with enough hand searching to ensure that the systematic review is being conducted in a full and comprehensive manner. Searches were conducted in databases such as *Web of Science*, *Scopus*, *Business Source Complete*, *JSTOR*, *EBSCO Academic Search*, *Social Science Research Network (SSRN)* and *Google Scholar*. The search strategy was iterative in that a table was created listing the keywords listed in each study; and as new keywords were found, the search strategy was revised using those terms. The search was rerun and documented. The goal was to create an optimal search strategy in order to retrieve useful citations. This process was done for each database. This was a comprehensive systematic literature review of TTO empirical studies.

Thousands of TTO empirical studies were found. Many used data from the Association of University Technology Management (AUTM) Statistics Access for Technology Transfer (STAT) database. Thus, although the Cochrane Method is typically used in the field of medical research, in this study of university technology commercialization, the universities' patenting and licensing may include medical, engineering, basic science, or computer science and other research areas.

The database search for empirical studies was augmented with hand searching that included the reference list of each study. This is called snowballing. Gray literature including dissertations were also searched. This

electronic search was evaluated against the Sampson (2008) seven (7) key criteria for assessing search quality (Sampson, 2008): “(1) accurate translation of the research question into search concepts; (2) correct choice of Boolean operators; (3) accurate line numbers and absence of spelling errors; (4) an appropriate text word search; (5) inclusion of relevant subject headings; (6) correct use of limits and filters; and (7) search strategy adaptations”. The original search for this study was conducted in 2014. In 2016, the seventh of the key criteria was removed as a highly recommended criterion and is now required at the search strategist’s discretion (McGowan, 2016). Further, personal contacts in the university technology transfer were used to help identify and find additional empirical studies that should be included in the data. This thorough methodology is required in comprehensive systematic reviews.

Data Collection

To record all of this data for the systematic review and meta-analysis, the PRISMA method of transparent reporting was used. PRISMA was used to ensure a high quality rigorous review (Moher, 2009). This reporting strategy includes a 27 step checklist which was implemented for the reporting of this study. The PRISMA information flow chart is provided in Exhibit 2. Data was added to a table which included the data that a reference was found and the source of the data (i.e. the database, hand search, internet search or personal contact recommendation). The search strategy used to find each reference (i.e. keywords); and the name of the reference and findings were noted. In order to minimize bias, peer reviewed publications were selected. It was assumed that internal validity, external validity, originality and ethics would have been assessed in the peer review process.

Meta-Analysis

After completion of the systematic literature review, a meta-analysis was conducted to aggregate the evidence to reveal whether and to what extent the hypothesized relationships exists. A meta-analysis is a statistical analysis of a large collection of results from individual studies. Meta-analyses are useful when seeking to find trustworthy information when there is seemingly too much information. These analyses facilitate the efficient integration of information and can help university technology commercialization managers make better, rational decisions based on the totality of the available evidence. A meta-analysis yields a weighted average effect of the size of a relationship (Schmidt, 2015). The observed effects are correlations between any two variables and they vary randomly around the population ‘real’ effect.

Fortunately, meta-analyses minimize the impact that sampling and measurement error have on any given study’s results because meta-analyses aggregate effects sizes from multiple studies so that small samples do not distort the overall findings and measurement errors are minimized (Schmidt, 2015). The goal is to consider whether the extent of the effects is large enough to matter to TTOs, faculty researchers, other research administrators and research university leaders.

Inclusion-Exclusion Criteria. To be included in the meta-analysis, each study had to contain a correlation among a resource or external environmental munificence measure and a performance measure. As a systematic reviewer, decisions had to be made about which of the studies were similar enough that they could be combined in a meta-analysis so that it could be determined whether or not an effect exists.

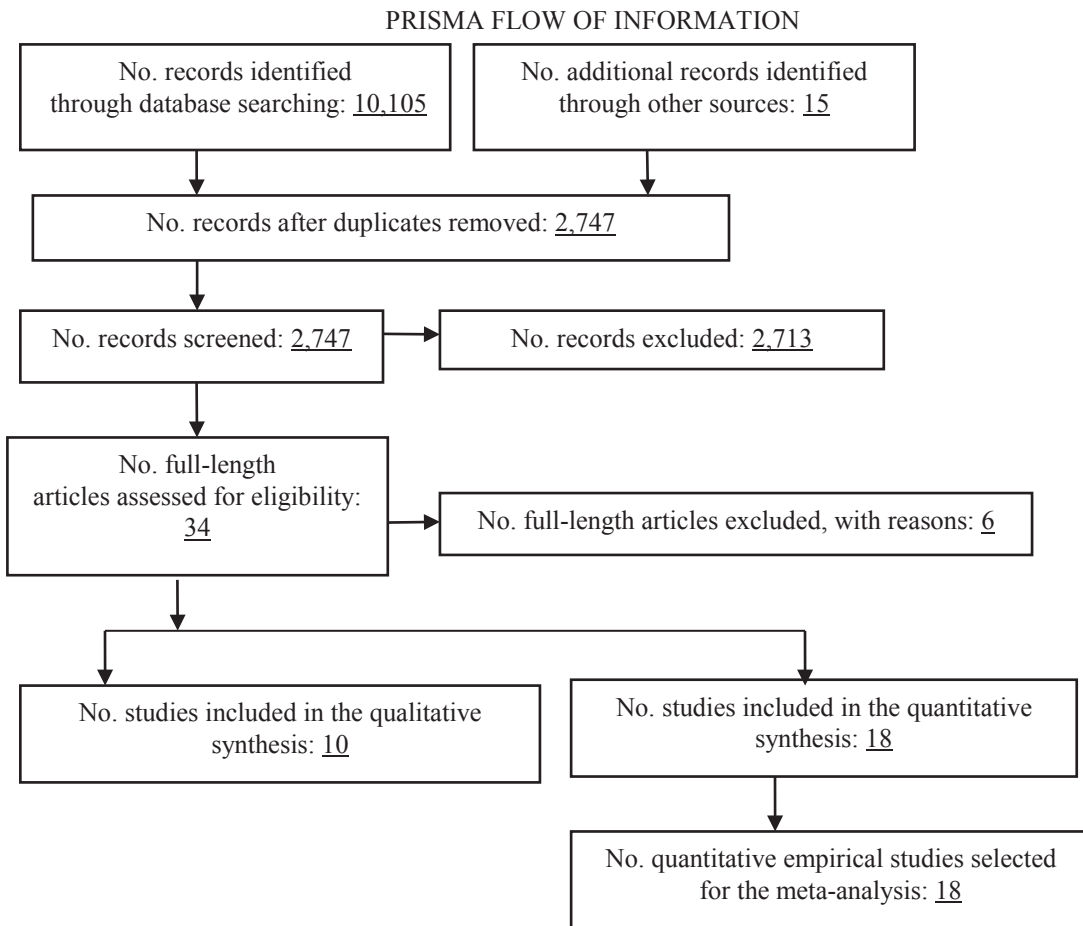
It is well known that there will be characteristics that differ in a set of research studies on a similar topic. For example, the characteristics of the study design, study participants, and outcomes may differ. The selected studies have to be similar in some way and the systematic reviewer has to decide whether they are similar enough. The systematic reviewer is also required to decide whether the studies are estimating in whole or in part a common effect. The goal is to combine the results quantitatively to obtain a single summary result. To ensure quality control, duplicate screening was used by having a second researcher independently review the studies as well. Among thousands of TTO studies extracted and screened as noted in Exhibit 2, 18 studies met the criteria. There were 24 studies identified as having relevant measures. However, only the 18 studies that measured TTO human, organizational and physical resources correlated to performance outcomes of licenses executed, licensing revenue and/or startup companies formed were included in this systematic review’s meta-analysis. Also note that Carlsson 2002a and 2002b; and Ho 2014a and 2014b are designated as having two (2) studies each because each research team studied two (2) distinct study groups.

Many of the university technology transfer resources are gathered annually during the Association of University Technology Managers (AUTM) annual licensing survey. These human and organizational resources include, but are not limited to inputs such as TTO staff size, licensing legal budgets; and outputs such as the number of patents, licensing deals, licensing revenues and the number of start-up companies formed as the result of the TTO

licensing patented inventions to them. Physical resources include, but are not limited to, the presence of a medical school and incubator. The external environmental resources include GDP, R&D intensity and sponsored research funding.

This data was aggregated using a meta-analysis technique to reveal relationships between these resources. Weighted average effect of the size of relationships are found (Schmidt, 2015). The meta-analysis method was chosen because it reduces the impact that measurement error and sampling error have on empirical research results. A meta-analysis can be used to accumulate evidence within a macro research stream; and as a motivator to re-evaluate established theories and develop new theories (Combs, 2011). Thus, the first step in the research method was the completion of a comprehensive literature review of TTO empirical studies. Each study had to contain (1) a measure of a university TTO resource or environmental munificence attribute (e.g., university research budget, industry funding, equity licensing, cash licensing, invention disclosures, patents, staff, staff experience, patenting legal expenditures, age of the TTOs, incubators), (2) a measure of performance (e.g., number of startups, licensing), and (3) an effect size estimate (e.g., correlation) of the relationship between an attribute and performance. A search for observed effects pertaining to human (H), organizational (O), physical (P) resources was conducted; and specific organizational resources related to external resources (E) also known as environmental munificence in relation to overall TTO performance (Perf), licensing as a type of performance (Lic) and startups (S) as a type of performance measure. Lic observed effects involved either executed licensing contracts or licensing revenues that were generated.

Exhibit 2. PRISMA Information Flow Chart



Statistical Analysis. The 18 studies were coded to include identifying data (e.g. author names, publication, year of publication), N sample size and level of study, independent variables (IV), dependent variables (DV) and correlations (r). *Comprehensive Meta-Analysis* (CMA) software was used (Borenstein, 2005). Estimates of the

effect sizes were calculated as the mean of the studies' sample size weighted correlations (\bar{r}). This provides a more accurate estimate since positive and negative sampling errors average out (Crook, 2008; Schmidt, 2015). Confidence intervals were used to facilitate hypothesis testing. The predictions were directional and two-tailed tests of the null were used. The effects described in the hypotheses were tested by whether the confidence intervals for \bar{r} included zero.

Results

Effect sizes are estimates of a relationship's magnitude. A relationship such as a correlation r has a large effect if the observed $r = 0.50$ or higher (Cohen, 1977). From the 18 studies found in the literature review, the weighted average effects and weighted average corrected effects were computed using a fixed effects model and are listed in Exhibit 3. The large effect sizes are highlighted in Exhibit 3. In addition, Exhibit 4 provides a comparison of results using the fixed effect model versus a random effects model. Heterogeneity is variation underlying the effects. The random effects model for meta analyses makes allowance for heterogeneity because it assumes there is a distribution of true effects.

Exhibit 3. University technology transfer meta-analysis results using a fixed effects model

E	E	E	P	P	P	O	O	O	H	H	H	IV
Start	Lic	Perf	Start	Lic	Perf	Start	Lic	Perf	Start	Lic	Perf	DV
1010	2632	1078	157	656	813	1366	3489	4711	674	2153	2827	N
12	26	38	2	6	8	15	40	53	10	26	36	K
0.517	0.231	0.317	0.147	0.056	0.073	0.740	0.444	0.532	0.629	0.363	0.435	Obs. r
0.572	0.236	0.328	0.148	0.056	0.074	0.950	0.478	0.593	0.740	0.381	0.466	Corrected r
0.452	0.183	0.278	-0.062	-0.046	-0.018	0.706	0.408	0.504	0.564	0.313	0.394	99% CI Lower
0.561	0.268	0.347	0.298	0.133	0.142	0.763	0.471	0.552	0.674	0.400	0.465	99% CI Upper

Exhibit 4. University technology transfer meta-analysis results comparing fixed effects model and random effects model

E	E	E	P	P	P	O	O	O	H	H	H	IV
Start	Lic	Perf	Start	Lic	Perf	Start	Lic	Perf	Start	Lic	Perf	DV
0.517	0.231	0.317	0.147	0.056	0.073	0.740	0.444	0.532	0.696	0.363	0.435	Fixed Pt Est
0.530	0.337	0.403	0.147	0.042	0.067	0.818	0.583	0.644	0.652	0.422	0.495	Random Pt Est
0.469- 0.561	0.194- 0.268	0.287- 0.249	-0.012- 0.298	-0.022- 0.133	0.004- 0.142	0.714- 0.763	0.417- 0.471	0.511- 0.532	0.580- 0.674	0.325- 0.400	0.404- 0.465	Fixed LL-UL
0.320- 0.690	0.137- 0.510	0.347- 0.538	-0.012- 0.298	-0.107- 0.189	-0.050- -0.182	0.703- 0.892	0.390- 0.727	0.505- 0.751	0.430- 0.799	0.211- 0.595	0.332- 0.629	Random LL-UL
93.74	96.60	96.26	0.00	72.49	63.575	96.02	98.19	98.03	93.55	96.50	96.18	I ²

It includes fixed effect point estimate sizes (Fixed Pt Est) for the effects and 95% confidence intervals. Exhibit 4 also includes random effect point estimate sizes (Random Pt Est) for the effects and 95% confidence intervals. The confidence intervals for the fixed effect model results are narrower than the random effects model results. Also, the large studies have more impact under the fixed effect model than in the random effects model.

It is important to note that the effect sizes vary from study to study and these dispersions may be due to chance, sampling error or real differences in the effect sizes from one study to the next. Thus, the dispersion in

effect sizes was analyzed for whether or not it is due to sampling error, chance or real differences in the correlations. The I-squared value is a measure of heterogeneity and it is listed in Exhibit 4. I^2 indicates the proportion of the observed variance that reflects the real difference in the studies.

The fixed effects model is based on the assumption that all of the studies are identical and have the same underlying true effect size; i.e. a single common effect. It assumes that any dispersion is due to sampling errors. In the first example of environmental factors correlated to start-up business formations, I^2 was 93.74. This indicates that the variance of dispersion would be 94% as wide as depicted in the forest plots generated by the CMA software. So, the dispersion would be reduced but not by very much. Given that there are high I^2 values, there is likely dispersion which is due to more than just sampling error. Thus, the random effects model is the best model's results are the best results to use.

In addition, Q, degrees of freedom (df) and p values to test the hypothesis of homogeneity were evaluated. The studies have heterogeneity and it is unlikely that dispersion is due to chance. When there is statistical heterogeneity, the random effects model may be useful to give a more conservative results due to the wider confidence intervals. However, this was not the basis for deciding whether to use the fixed effect model results rather than the random effects model results. That decision is based on the sampling method. Since this systematic review involved going to the literature, extracting studies, and culminated in the selection of 18 studies, these studies are obviously not identical and the effect size really does vary from one study to the next. Thus, the random effect model results are the more plausible. As shown in Exhibit 4, the only difference between the random model results and the fixed effect model results is that organizational inputs to licensing performance outputs have a large effect (unlike the results of the fixed effect model).

The existing literature is extended by testing four (4) hypotheses related to human, organizational, physical and external environmental resource inputs of TTO output performance. A discussion of the results related to each of the four (4) hypotheses follows:

- *Hypothesis 1.* Human resources are positively related to TTO performance in the areas of patent licensing and generating startups. Human resources are characterized by the TTO FTEs, TTO age and TTO legal expenditures for legal help.

As shown in Exhibit 4, the select human resources characterized by TTO age, TTO size and TTO expenditure on legal help measures had an observed and Fischer corrected correlation r greater than 0.5 in relation to university start up business formation. However, the study results do not show a large effect size between TTO human resources and licensing performance. The overall effect of these human resources was near significant as evidenced by weighted average correlations just under the value of 0.5. Thus, Hypothesis 1 is supported in part.

- *Hypothesis 2.* Organizational resources are positively related to TTO performance in the areas of patenting, licensing, and generating startups. These resources are faculty invention disclosures, university patent applications and university patents owned.

The university organizational resources researched in the selected studies for this systematic review included invention disclosures, patent applications and university patents owned. With respect to the evaluation of these organizational resources' relationship to overall technology transfer performance. Hypothesis 2 was not supported. These select organizational resources were positively related to overall performance and to university start up business formation. This was expected because without these resources, it is very difficult to execute intellectual property licenses and generate licensing revenue. It would also be difficult to increase start up business formations since a common university start-up business model is to license a university owned patent to the start up for cash or equity for the purpose of commercializing the patented invention. Thus, without the invention disclosures, patent applications and issued patents, this approach to technology transfer would not work.

- *Hypothesis 3.* Physical resources are positively related to TTO performance in the areas of patenting, licensing, and generating startups. These physical resources include incubators and medical schools.

The weighted average correlations for university physical resources including incubators and medical schools in relationship to overall technology commercialization performance in startup business formation and patent licensing were not large effects. Thus, Hypothesis 3 was not supported.

- *Hypothesis 4.* External environmental munificence is positively related to TTO performance in the areas of patent licensing and generating startups.

The external environmental resources of research funding by industry and governmental agencies, GDP and regional R&D intensity did not have a positive relation on the overall performance of technology transfer as defined by patent licenses executed, licensing revenues and startup business formations. However, when investigating the relationship of the environmental resources on licensing separate from start-up business formations, there was no positive relationship between environmental resources and licensing (i.e. executed patent licenses and licensing income). Yet, there was a positive relationship between the external environment and start up business formations. Thus, this systematic review provides confirmation that start-up business formations are positively correlated to the availability of external research and development sponsored funding, GDP and regional R&D intensity.

Conclusion

Unfortunately, prior research contains conflicting evidence surrounding how key TTO resources attributes and characteristics of the environment relate to performance. Given the importance of TTOs, the lack of a comprehensive study, and that little theory has been leveraged to understand central TTO-performance relationships, insights from extant research was combined via this systematic review and meta-analysis to tell a more complete story.

Here, the *Resource Based View* and *Theory of Environmental Munificence* were applied and we find that the relationship between TTO human and organizational resources and start up business performance is where TTOs get the strongest returns. It was discovered that human and organizational resources are significant relative to start-up business formations, patents, and licensing activities. The strongest effects were among the organizational and human inputs relative to licensing activities. The *Resource Based View* (RBV) teaches that when resources are hard to imitate, are valuable and rare, such as patented inventions, then they provide an organization with a competitive advantage. External environmental munificence also relates to TTO performance. The *Theory on Environmental Munificence* (TEM) (Castrogiovanni, 1991, 2002) teaches that environment external to the university is an important source of resources, and when environments are more munificent, it makes it easier for an organization to survive and prosper. Combined, the RBV and TEM explains the results of this meta-analysis research.

This analysis is useful because it can steer TTO managers and leaders into the direction of bolstering their human and organizational resources with their limited financial investments, rather than physical resources in order to improve performance success. Doing so will not only reconcile conflicting findings in extant research, but also will enable university leaders to optimize the use of their scarce resources.

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