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Article

Knowledge Based View of University Tech Transfer—A Systematic Literature Review and Meta-Analysis

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Abstract: Research and technology commercialization at research-intensive universities has helped to develop provincial economies resulting in university startups, the growth of other new companies and associated employment. University technology transfer offices (TTOs) oversee the process of technology transfer into the commercial marketplace and these organizational units can be considered in the context of enabling effective knowledge management. However, what enables productive TTO performance has not been comprehensively researched. Therefore, this research study adopted the knowledge-based view as the theoretical construct to support a comprehensive investigation into this area. This was achieved through employing a systematic literature review (SLR) combined with a robust meta-analysis. The SLR identified an initial total of 10,126 articles in the first step of the review process, with 44 studies included in the quantitative synthesis, and 29 quantitative empirical studies selected for the meta-analysis. The research study identified that the relationship between TTO knowledge management and knowledge deployment as well as startup business performance is where TTOs secure the strongest returns.

Keywords: university technology transfer; technology transfer; technology commercialization; patent licensing; systematic literature review (SLR); knowledge-based view (KBV)

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1. Introduction

The biologists Lubert Stryer (University of California, Berkeley, CA, USA) and Alexander Glazer (Stanford University) pioneered the use of phycobiliproteins found in marine algae as fluorescent markers. Six months later, Stanford University entered into a relationship with two private sector organizations to patent this invention and become involved in developing a critical tool for blood and cancer diagnostic screening. In the ensuing 30 years, research universities have been in the business of licensing patented inventions and entering into new business ventures (Wiesendanger 2000). There are many examples. The artifacts of this process are well known and university developed products and technologies include the following selected examples (see Table 1): MIT's solar power, (Eschner 2017), Georgetown University's CT (computed tomography) scans (Langer 2012), the University of Rochester Medical Center's pivotal flu vaccine (Hauser 2015; Wentzel 2008), Clark University's rocket technology (Clark University 2019), Cornell University Medical School's seat belts (Rong 2016), Indiana University's Breathalyzer (Woo 2002), and the University of Florida's Gatorade (Martin 2007).

Table 1. Examples of significant inventions/technologies originating at universities.

Year	Inventor	Invention	University	Source
1926	Robert Hutchings Goddard, Physicist	Rocket technology	Clark University	(Clark University 2019)
1940s	Maria Telkes, Biophysicist and engineer	Solar Power using the crystallization of a sodium sulfate solution	MIT	(Eschner 2017)
1954	Robert Borkenstein, Forensic Scientist	Breathalyzer test	Indiana University	(Woo 2002)
1955	Roger Griswald and Hugh DeHaven, Pilot	Three-point car seat safety belt	Cornell University Medical School	(Rong 2016)
1965	Robert Cade, Nephrologist	Gatorade	University of Florida	(Martin 2007)
1973	Robert S. Ledley, Physicist	Full Body CT Scanner	Georgetown University	(Langer 2012)
1983	David Smith, Pediatrician; Porter Anderson, Chemist; Richard Insel Pediatric Immunologist; and Medical Center Team	Flu Vaccine: Conjugate vaccine technology led to the creation of vaccines against Hemophilus influenzae type b (Hib), pneumococcus, and meningitis.	University of Rochester Medical Center	(Wentzel 2008; Hauser 2015)

Since the Morill Act of 1862 established land grant universities in the United States, they have served as research hubs, although this did not necessarily result in significant levels of technology being transferred from universities to industry. In 1980, the U. S. Congress passed the Bayh–Dole Act (U. S. Congress 1980), which allowed universities to obtain ownership titles to inventions created with government funded research. The process was typically managed by technology transfer offices (TTOs). These offices are tasked with the development of processes and policies regarding patenting and licensing of the university's inventions. Technology transfer can be regarded as a subset of technology management (Hamilton 2017a, 2017b). Besides TTOs, there are other organizational units involved in research administration, such as offices of sponsored programs, project management offices (PMOs), and research grant offices (RGOs).

In recent years, PMOs have been able to serve as advisory support to industry, academic, and end-user consortia. In this case, directive type PMOs assist with grant preparation, negotiation of intellectual property provisions, innovation management, research commercialization, and stakeholder management (Wedekind and Philbin 2018).

Since the role of TTOs is to enable the commercialization of technical innovations, a growing number of researchers have examined different aspects of this subject, including the effect of university policies and structures on academic entrepreneurship (Seashore Louis et al. 1989). More specifically researchers have investigated the following aspects of TTOs and the subject of tech transfer:

- The features of universities that generate the most spin-offs (Lockett and Wright 2005).
- Factors that enhance university tech transfer (Friedman and Silberman 2003).
- Whether or not internal and external factors explain the efficiency of university tech transfer (Siegel et al. 2003).
- The level of efficiency that university TTOs in the U.K. exhibit (Chapple et al. 2005).
- The difference between for-profit versus traditional non-profit TTOs, technology licensing for equity strategies, and sponsored research licensing strategies (Markman et al. 2005a).
- The optimal incubation models for academic spin-offs (Clarysse et al. 2007).
- The most efficient TTOs (Curi et al. 2012).
- What technology transfer specialists pay attention to (Hamilton 2015; Hamilton and Schumann 2016).
- Which TTOs are more likely to get better results (González-Pernía et al. 2013).

2. Literature Review

2.1. Resource Based View (RBV) of Competitive Strategy

Although there is an expansive level of TTO research, there remains significant ambiguity surrounding the determinants of TTO performance. For instance, one study showed that TTO performance in the creation of startups is strengthened by the presence of human capital (Van Looy et al. 2011), while another study found that the presence of human capital had little or no effect in relation to startup formations (Hülsbeck et al. 2013). This exemplifies the lack of clarity regarding the more likely enablers of strong TTO performance. Therefore, it is plausible that utilizing a theoretical framework, such as the resource-based view (RBV) of the firm (Barney 1991; Rumelt 1984; Warnerfelt 1984), will be useful in describing which TTO attributes are directly related to performance. The RBV posits that when organizations possess strategic resources that are valuable, rare, and hard to imitate, they are more likely to enhance performance and provide the basis for competitive advantage.

The RBV resource categories include tangible and intangible assets as well as organizational capabilities. Organizational capabilities refer to tangible and intangible assets that enable an organization (in this case the university) to take full advantage (also known as leveraging) of its other resources (Barney 1991). Within the context of technology transfer, strategic capabilities are research and development (R&D) policies, skills, and processes that incentivize commercialization. The resources that are most likely to underpin competitive superiority (referred to as strategic resources) are intangible assets and organizational capabilities as they are rare and inimitable (i.e., difficult to imitate). An organizational culture that embraces innovation and commercialization would be extremely difficult to replicate in the short term due to its causal ambiguity (i.e., how do they do it?) and path dependency (i.e., no short-cuts or quick fixes). Establishing such a culture requires that rivals would have to follow the same series of steps to match or imitate the organization's capability—it would take time and effort. For the same reason, forms of intellectual property (such as patents and trademarks) are potentially strategic resources (Barney and Asli 2001).

According to a slightly different perspective, the RBV further proposes that human (e.g., scientists), organizational (e.g., positive reputation, plans, and systems), and physical (e.g., labs and facilities) resources may be necessary, but insufficient, for organizations to perform at high levels if they are easy to imitate (Barney 1991). Moreover, these resources are connected with processes to enable organizational capabilities. Using the RBV lens, a study of university-industry research collaboration revealed three types of collaboration capabilities, namely: (1) technical, including knowledge, facilities, and the awareness of how published research relates to industry needs; (2) commercial, including project management, intellectual property rights, and industrial research contracting skills; and (3) social, including leadership, trust, and negotiation skills (Philbin 2012). However, these capabilities and the corresponding resources also need to be managed, integrated, and deployed (Sirmon and Hitt 2003). They must be leveraged into organizational capabilities.

2.2. Evolution of the Knowledge-Based View of Strategy

Knowledge is defined as the continuous process of managing know-how in order to anticipate existing and future needs, exploit resources, and develop new opportunities (Price et al. 2013). This capability becomes internalized, shared, accumulated, and used in the process of knowledge integration. Once this capability is leveraged, an organization can achieve competitive advantage (Grant 1996a, 1996b) and this is the Knowledge-Based View (KBV) of strategy. Consequently, the current study examines the role of four contextual KBV variables to the management, integration, and deployment of technology transfer. The essential elements are proposed as follows: (1) knowledge management; (2) deployment of resources; (3) external financial investments for sponsored research and development; and (4) physical infrastructure locations for the R&Dto take place.

In the late 1970s, economic analysts and policy-makers were studying ways to improve data on the rates of return from industrial innovations. Examining 17 case studies, it was discovered that, for certain innovations, imitation can be much cheaper than innovation (Mansfield et al. 1977). Later in the 1990s, with regard to the development of the knowledge-based view, other researchers studied how firms can deter imitation by innovation. They developed a more dynamic view of how firms create new knowledge (Kogut and Zander 1992).

Knowledge flow is inherently a public good and the existence of technology-based research efforts by other firms may allow a firm to achieve results with less research effort. The importance of this spillover phenomenon was studied by looking at the average effect that other firms' R&D has on the productivity of a firm's own R&D. Circumstantial evidence revealed spillovers of R&D from several indicators of technological success (Jaffe and Trajtenberg 1996).

Further research on knowledge flow, technology, and absorptive capacity was conducted using data from 31 intensive case studies of research, development, and demonstration (RD&D) projects sponsored by an energy authority. These researchers developed a technology transfer process model and a technology absorption process model. Although the goal of these projects was hardware development, the output in most cases was new knowledge. The researchers found that the benefits from the use of new knowledge was higher than the benefits of using the hardware that was developed (Kingsley et al. 1996).

Building on the relational view, social capital, and knowledge-based theories, researchers defined technology commercialization as knowledge exploitation. They proposed that social capital facilitates external knowledge acquisition in key customer relationships and that knowledge mediates the relationship between social capital and knowledge exploitation for competitive advantage. Indeed, social capital has been found to be a key enabling factor to support the process of university-industry research collaboration (Philbin 2008). Moreover, Yli-Renko et al. (2001) surveyed 180 young tech-based firms in the U.K. The results indicate that social interactions and network ties are associated with greater knowledge acquisition; and knowledge acquisition is positively associated with knowledge exploitation. One finding was that the greater a young technology-based firm's knowledge acquisition forms a key customer relationship, the higher the number of new products developed by the young technology-based firm becomes as a result of that relationship (Yli-Renko et al. 2001).

Furthermore, researchers advanced the knowledge-based view of the firm by using a knowledge-based approach to integrate ideas about knowledge inheritance and employee entrepreneurship; and to construct a theory of spin-out formation and development. They investigated how industry incumbents' knowledge capabilities affected its spin-outs in the computer disk drive industry and found that incumbents with both strong technological and market pioneering know-how generate fewer spin-outs than firms with strength in only technological or market know-how. Also, an incumbent's knowledge capabilities at the time of a spin-out's founding positively affect the spin-out's knowledge capabilities and its probability of survival. The researchers concluded that firms need to strategically invest resources in both value creation and appropriation rather than specialize to the detriment of a complementary capability. In regard to startups, the researchers concluded that knowledge is inherited, and a firm's founder is the more effective agent of transfer than a hired employee (Agarwal et al. 2004).

Literature on knowledge integration was found to be primarily focused on product component technologies and considered the division of labor and division of knowledge (Brusoni et al. 2009, 2001; Takeishi 2002). This was extended to process component technologies when researchers considered the commercialization of new product innovation in the computer memory industry (Kapoor and Adner 2012). They assessed the effectiveness of firm boundary choices in solving this problem according to the speed with which firms solve this problem.

Nickerson and Zenger (2004) extended the comparative logic of transaction cost economics to the knowledge-based view with a problem-solving perspective of the theory of the firm (Nickerson and Zenger 2004). Kapoor and Adner (2012) extended Nickerson and Zenger's (2004) theory by arguing that firms may benefit from investments in the knowledge gained from outsourced activities; they also linked problem complexity to the nature of technological change underlying product innovation.

With respect to past applications of the knowledge-based view, none of these research studies have applied the knowledge-based view to a systematic literature review of university technology transfer. More importantly, these prior studies give credence to the position that the knowledge-based view is an ideal analytical lens to apply when studying the university technology commercialization phenomenon.

The structure of this paper is as follows. After the introduction and initial discussion of the role of the TTO as well as introductory material on the RBV and KBV strategy frameworks, there is further discussion of supporting theory along with hypothesis development. This is followed by the method, which is based on a systematic literature review (SLR) and includes data collection and meta-analysis. 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. This is followed by the results, conclusions, and future work.

3. Theoretical Framework and Hypotheses

A conceptual model was developed for university technology transfer success based on the KBV strategy framework (see Figure 1). The conceptual model's constructs, definitions and sample measures are shown in Table 2. The model shows inputs into the university technology transfer process. These are the resource inputs. A KBV of university technology transfer involves viewing the process from the lens that TTOs require knowledge management, knowledge deployment, knowledge integration, and external investments to succeed. It was imperative to identify research studies with empirical measurements of resources that might be important.

Table 2 provides details on the inputs and outputs of the university technology transfer process. These outputs are entrepreneurial spin-off businesses (i.e., startups) that may be formed (Hülsbeck et al. 2013; Markman et al. 2005a; Powers and Patricia 2005; Rogers 2000; Van Looy et al. 2011) and related licensing agreements (Chapple et al. 2005; Powers 2003; Powers and Patricia 2005; Rogers 2000; Siegel et al. 2003; Sine et al. 2003; Swamidass and Venubabu 2009). There may also be licensing deals with established small business enterprises or larger corporations. Indeed, the primary performance measures for TTOs have traditionally been licensing revenues (Carlsson and Fridh 2002; Chapple et al. 2005; Ho et al. 2014; Lockett et al. 2005; Markman et al. 2005a; Powers 2003; Powers and Patricia 2005; Rogers 2000; Siegel et al. 2003).

The context and population in the following research questions for this study is the university TTOs and their staffs, respectively. According to the KBV, the following hypotheses were tested with the meta-analytical systematic literature review (SLR) reported in this paper:

- *Research Question 1*: Is *Knowledge Management* positively related to TTO performance in the areas of patenting, licensing, and generating startups?
- *Research Question 2*: Is *Knowledge Deployment* positively related to TTO performance in the areas of patenting, licensing, and generating startups? Resources such as invention disclosures, patent applications, and patents are evidence of knowledge deployment.
- *Research Question 3*: Is *Knowledge Infrastructure* positively related to TTO performance in the areas of patenting, licensing, and generating startups? Herein, knowledge infrastructure includes having the presence of incubators and medical schools.
- *Research Question 4:* Are *External Investments* positively related to TTO performance in the areas of patenting, licensing, and generating startups?

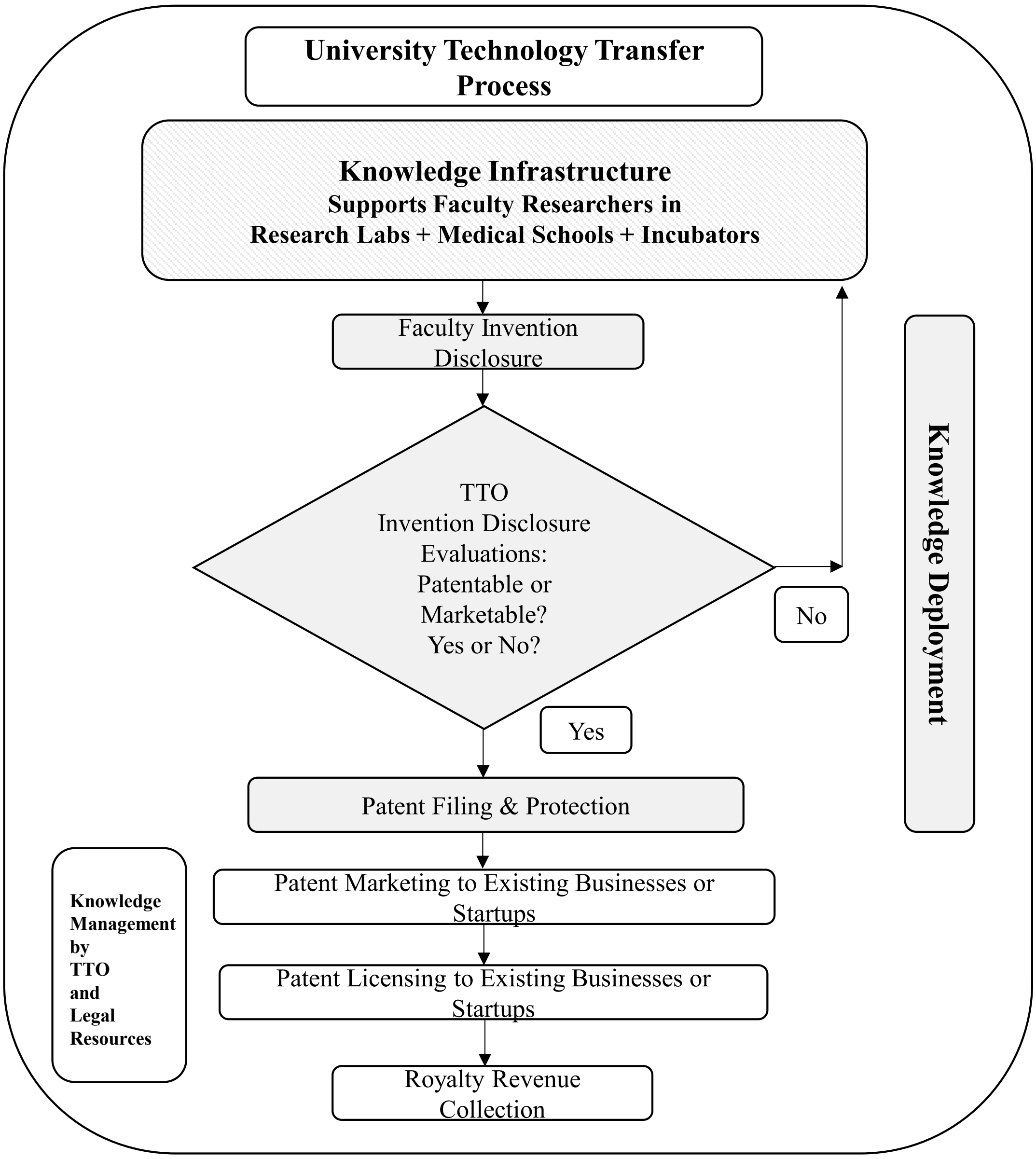

Figure 1. Conceptual Model for University Technology Transfer based on the Knowledge Based View (KBV).

The existing literature is extended by testing the four hypotheses related to these research questions. Regarding *Knowledge Management*, studies were found which empirically measured TTO staff sizes in terms of: full time equivalents (FTEs) (Carlsson and Fridh 2002; Chapple et al. 2005; Hülsbeck et al. 2013; Markman et al. 2005b; Powers and Patricia 2005; Siegel et al. 2003; Van Looy et al. 2011); TTO legal expenditures (Chapple et al. 2005; Siegel et al. 2003); and TTO age (Chapple et al. 2005; Markman et al. 2005b; Powers and Patricia 2005). It has been identified that there is an adverse effect on managing a high volume of technology and the ability of the TTO to commercialize such a high volume of activity when the number of invention disclosures per TTO staff members were investigated (Sine et al. 2003). It has also been reported that not surprisingly hiring more TTO staff leads to both a higher number of licenses and increased licensing activity (Chapple et al. 2005; Swamidass and Venubabu 2009). Yet, spending more on external legal assistance had an insignificant impact on the number of licenses while generating a positive impact on licensing revenue generation (Chapple et al. 2005). Moderate correlations have been reported between invention disclosures and TTO size (Hülsbeck et al. 2013).

Moreover, patenting experience and TTO staffing has been found to be positively correlated with startup business formations (Lockett and Wright 2005).

Table 2. Definitions and Sample Measures of KBV constructs.

Constructs Impacting the Tech Transfer Process	Definitions	Sample Measures	Studies
	INPUT		
Knowledge Management (KM)	Universities' TTO staff and legal resources which support knowledge management	TTO staff size (FTEs)	(Carlsson and Fridh 2002) (Chapple et al. 2005) (Hülsbeck et al. 2013) (Markman et al. 2005b) (Powers and Patricia 2005) (Siegel et al. 2003) (Van Looy et al. 2011)
		TTO age	(Chapple et al. 2005) (Markman et al. 2005b) (Powers and Patricia 2005)
		TTO legal expenditure	(Chapple et al. 2005) (Siegel et al. 2003)
Knowledge Deployment (KD)	Universities' internal organizational resources which support knowledge deployment	Invention disclosures	(Sine et al. 2003) (Cardozo et al. 2011) (Carlsson and Fridh 2002) (Chapple et al. 2005) (Hülsbeck et al. 2013) (Rogers 2000) (Siegel et al. 2003) (Swamidass and Venubabu 2009)
		Patent applications filed	(Cardozo et al. 2011) (Carlsson and Fridh 2002) (Ho et al. 2014) (Rogers 2000) (Swamidass and Venubabu 2009)
		Patents owned	(Cardozo et al. 2011) (Hülsbeck et al. 2013) (Powers and Patricia 2005) (Van Looy et al. 2011)
Knowledge Infrastructure (KI)	Universities' internal infrastructure resources which support knowledge integration	Presence of an Incubator Presence of a medical school	(Markman et al. 2005b) (Powers and Patricia 2005) (Van Looy et al. 2011)
External Investments (EI)	Regional external investments	Regional GDP	(Chapple et al. 2005) (Hülsbeck et al. 2013)
		Regional R&D intensity	(Chapple et al. 2005) (Lockett et al. 2005)
		Total research funding	(Chapple et al. 2005) (Ho et al. 2014) (Hülsbeck et al. 2013) (Lockett et al. 2005) (Powers and Patricia 2005) (Van Looy et al. 2011)
		Industry funding	(Ho et al. 2014) (Powers and Patricia 2005)
	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	(Chapple et al. 2005) (Swamidass and Venubabu 2009)
Startups (Start)		Startups formed	

Hypothesis 1 (H1). *Knowledge Management is positively related to TTO performance in the areas of patent licensing and generating startups. Knowledge Management is characterized by the TTO FTEs, TTO age, and TTO expenditures for legal assistance.*

In regard to the *Knowledge Deployment* of organizational resources, invention disclosures (Cardozo et al. 2011; Carlsson and Fridh 2002; Chapple et al. 2005; Hülsbeck et al. 2013; Rogers 2000; Siegel et al. 2003; Sine et al. 2003; Swamidass and Venubabu 2009); patent applications filed by the TTO (Cardozo et al. 2011; Carlsson and Fridh 2002; Ho et al. 2014; Rogers 2000; Swamidass and Venubabu 2009) and university owned patents (Cardozo et al. 2011; Hülsbeck et al. 2013; Powers and Patricia 2005; Van Looy et al. 2011) have been measured.

Hypothesis 2 (H2). *Knowledge Deployment is 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.*

With respect to *Knowledge Infrastructure*, the presence of medical schools and incubators has also been studied (Markman et al. 2005a; Powers and Patricia 2005; Van Looy et al. 2011). As expected, invention disclosures have been found to be explained primarily by total research funding (Carlsson and Fridh 2002). Moreover, invention disclosures have been found to have the expected positive and high magnitude correlations with licensing revenue generation (Siegel et al. 2003; Sine et al. 2003). However, TTO FTEs were found to be statistically insignificant with respect to invention disclosures. Nevertheless, it has been reported that higher levels of invention disclosures or total research funding leads to higher numbers of licenses or higher licensing income (Chapple et al. 2005). Previous research has indicated that there is no relationship between the revenue a university's TTO generates and the patent applications and invention disclosure ratio (Cardozo et al. 2011). However, patent applications have been found to be positively related to funding and to licensing (Ho et al. 2014).

Close physical proximity has been found to be a strong predictor of interdisciplinary co-authorship and co-invention ties (Claudel et al. 2017). Therefore, measuring the co-authorship of scientific papers, it was found that policies that encourage interdisciplinary collaborations in a cancer research center are successful when coupled with mentorship and pilot funding. Thus, financial investments are also important (Fagan et al. 2018). In addition, it has been suggested that university spinoffs can benefit from having access to university resources, knowledge and support when these firms maintain linkages to the university. In a study of 551 spinoffs from Italian universities, it was discovered that geographic proximity moderates the impact of university equity ownership linkages on market performance. There was evidence that increasing geographic proximity strengthens the positive effect of university equity ownership in these spinoffs (Bolzani et al. 2020).

With respect to university equity ownership, a study of linkages between university and start-up activity at 116 universities provided evidence that university equity policy and policies regarding the distribution of royalties have a significant impact on start-up activity. Yet the presence of an incubator did not have an impact on start-up activity (Di Gregorio and Scott 2003). Further, with regard to proximity, in a case study of nine (9) organizations in Italy, There were 54 interviews with 54 employees in the academic research and university-industry arena This qualitative study revealed evidence that TTOs, university incubators, and collaborative research centers relied on activities that increased different dimensions of proximity between their actors. The research also showed that the complexity of the knowledge being transferred may influence the type of activities that different intermediary organizations implement (Villani et al. 2017).

Hypothesis 3 (H3). *Knowledge Infrastructure is positively related to TTO performance in the areas of patenting, licensing, and generating startups. Again, Knowledge Infrastructure is indicated by the presence of incubators and medical schools.*

Within the context of TTOs, *External Investments* are characterized by total research funding (Chapple et al. 2005; Ho et al. 2014; Hülsbeck et al. 2013; Lockett et al. 2005; Powers and Patricia 2005; Van Looy et al. 2011), regional GDP (Chapple et al. 2005; Hülsbeck et al. 2013), regional R&D intensity (Chapple et al. 2005; Lockett et al. 2005) and industry funding (Ho et al. 2014; Powers and Patricia 2005). Past research has indicated that research-intensive universities that secure more research funding generate more TTO income; and that TTO age has been found to be positively associated with research funding (Cardozo et al. 2011). In this regard, Cardozo et al. (2011) found that institutions with medical schools received twice the amount of research funding. The presence of a medical school has been found to be positive and significant for licensing income generation (Chapple et al. 2005).

Hypothesis 4 (H4). *External Investments are positively related to TTO performance in the areas of patent licensing and generating startups.*

4. Prior Literature Reviews

Over the past 20 years, there have been several literature reviews related to university technology transfer; Bozeman (2000); Agrawal (2001); Rothaermel et al. (2007); O'Shea (2007); O'SheaO'Shea et al. (2008); Djokovic and Vangelis (2008); Geuna and Alessandro (2009); Grimaldi et al. (2011); Perkmann et al. (2013); Kirchberger and Larissa (2016); Kochenkova and Rosa (2016); Schmitz et al. (2017); Miranda et al. (2018); Fini et al. (2018); Mathisen and Rasmussen (2019); Fini et al. (2019); and Bengoa et al. (2020). Rothaermel et al. (2007) studied 173 articles in 28 academic journals between 1981 and 2005. However, while Rothaermel's very comprehensive 100-page study included a brief discussion of the productivity of technology transfer offices, it is now dated and primarily only focused on academic entrepreneurship. Other reviews of academic spin-offs and entrepreneurs include Djokovic and Vangelis (2008); Grimaldi et al. (2011); Schmitz et al. (2017); Miranda et al. (2018); and Mathisen and Rasmussen (2019). Note that technology transfer occurs primarily in three ways: (1) transfer of technology to an academic entrepreneur's start-up; (2) transfer to non-academic-entrepreneur's start-up; and (3) transfer to a well-established business entity. Thus, the review studies of academic entrepreneurs and spin-offs do not capture all of the possible transfers of technology.

Further, Perkmann et al. (2013) conducted a review of the literature which broadly included research engagements defined as research collaborations more generally. One of the future research agendas discovered in the Grimaldi et al. (2011) review was the need for answering how indications of performance combine "within an institution to obtain [a] complete view of research commercialization". Schmitz et al. (2017) noted that a number of past studies have indicated a need for "more systematic and holistic studies". Fini et al. (2018) noted that there is already extensive, available university technology commercialization data. However, there is a need for "more systematic and rigorous research on the societal impact of science commercialization ... and societal returns to public investment in science" (Fini et al. 2018). An investigation of these investments in can be achieved with the combination of the knowledge-based view theoretical framework, a systematic literature review and empirical meta-analysis.

Although the past review studies make valuable contributions, the limitations of the previous reviews are noted in Table 3. Thus, there is justification for the need for this new systematic literature review and meta-analysis.

Table 3. Summary of methods used in past reviews of the literature.

Authors (Year)	Time Period Analyzed	Number of Articles Reviewed	Database(s)	Shortcomings
Bozeman (2000)	1987–1999	75 references	No mention	This seminal, traditional literature review is now dated and focuses primarily on "particularly important findings but also more recent ones ... [and] chiefly on empirical research". Thus, this approach is a biased selection.
Agrawal (2001)	1979–2000	26 references	No mention	This traditional literature review is now dated and was not systematic and did not include a meta-analysis.
Rothaermel et al. (2007)	1981–2005	173 records	Proquest ABI/ Inform, Business Source Premier, EconLit	This traditional literature review is now dated and focuses primarily on academic entrepreneurship; it also does not include an empirical meta-analysis.
O'Shea (2007); O'Shea et al. (2008)	1988–2005	24 references	No mention	This is not a review article. However, it is an empirical study of university spinoffs and includes a seminal traditional literature review of university spinoff literature.
Djokovic and Vangelis (2008)	1990–2006	102 records (60 primarily focused on spin-offs and 42 secondarily including tech transfer and other tech based firms)	ABI/Inform, Business Source Premier, Science Direct	This study is now dated and focuses primarily on academic entrepreneurship; and does not include an empirical meta-analysis.
Geuna and Alessandro (2009)	1982–2009 (based on the publication dates of references)	86 references were included	No mention	This study is entitled a 'critical' review of the literature; but did not use an unbiased systematic methodology; it does not include an empirical meta-analysis and is now dated.
Cardozo et al. (2011)	1986–2011 (based on the publication dates of references)	102 references were assessed	No mention	This study is an assessment of academic entrepreneurship research did not use an unbiased systematic methodology; it does not include an empirical meta-analysis and is now dated.
Perkmann et al. (2013)	1980–2011	413 found records filtered to 36	EBSCO (EconLit); and manual search of Research Policy, Journal of Technology Transfer and Technovation for years 1989-2011	While this is a systematic literature review, only one database was included; the manual search of 3 journals can be construed as arbitrary and biased; it does not include an empirical meta-analysis and the study is now dated.

Table 3. *Cont.*

Authors (Year)	Time Period Analyzed	Number of Articles Reviewed	Database(s)	Shortcomings
Kirchberger and Larissa (2016)	1987–2013	144 records	Searched relevant journals and Google Scholar	While this is a systematic literature review, only one database was included and it does not include an empirical meta-analysis.
Kochenkova and Rosa (2016)	2003–2013	46 records	Scopus, Google Scholar, and Proquest	Does not include a meta-analysis and included only knowledge transfer public policy "studies with in-depth investigations of specific, single policy measures or a wide set of measures oriented toward technology transfer but excluded studies that mentioned policy measures only marginally"; it also does not include an empirical meta-analysis.
Schmitz et al. (2017)	1974-2015	872 found records filtered to 36	Web of Science Core Collection	While a systematic literature review, only one database was used and is focused on academic innovation and entrepreneurship; it does not include an empirical meta-analysis.
Miranda et al. (2018)	1997–2016	268 records	Web of Science Core Collection (specifically analyzed articles published in journals in the Social Sciences Citation Index, SSCI)	While a systematic literature review, only one database was used and is focused on university spin offs; it does not include an empirical meta-analysis.
Mathisen and Rasmussen (2019)	2000–2016	105 records after filtering	Web of Science	While a systematic literature review, only one database was used and is focused on university spin offs; it does not include an empirical meta-analysis.
Fini et al. (2018)	1987–2018 excluding a 1945 outlier (based on the publication dates of references)	134 references were included	No mention	While this is a valuable summary of the state of the art of literature, it is not an unbiased systematic review; it does not include an empirical meta-analysis.

Table 3. *Cont.*

Authors (Year)	Time Period Analyzed	Number of Articles Reviewed	Database(s)	Shortcomings
Fini et al. (2019)	2004–2019	40 records	Searched leading, empirical management journals including Academy of Management Journal, Journal of Management, Journal of Management Studies, Management Science, Organization Science and Strategic Management Journal	While this is a valuable summary of the state of the art of literature, it is not an unbiased systematic review; it also does not include an empirical meta-analysis
Bengoa et al. (2020)	1969–2018	3218 records	Web of Science	This is a bibliometric review of only one database and does not include an empirical meta-analysis.

5. Method

There is a large body of university technology transfer research dating back to the 1970s. Therefore, between September and November 2014, an evidence-based systematic review of university technology transfer literature was conducted to identify, select, appraise, and synthesize results from similar but separate studies (Hamilton and Crook 2015). The review was updated between August and September of 2017 using the RBV (Hamilton 2018). The review was again updated between 2018 and 2020 using the KBV. Systematic literature reviews focus on a specific research question or set of questions. Here, the systematic literature review was used to test the aforementioned hypotheses from the perspective of the KBV.

Systematic literature reviews differ from traditional narrative literature reviews in that systematic literature reviews require the use of a pre-planned standard format and robust scientific methodology. For recent examples of systematic literature reviews that have been employed to support a rigorous investigation of a defined area of interest, see the work of Liao et al. (2017); Chauhan et al. (2018) and Ahmed and Philbin (2020). In a traditional literature review, the researchers would generally look for research papers that support or do not support the researchers' hypotheses. With regard to the scientific method, there are four steps that differentiate a systematic literature review from a traditional narrative literature review. The traditional literature 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 (this final stage can also be used to support synthesis of research findings along with identification of proposed areas of future research).

As a comparison, the systematic literature review employs a standard format in an effort to conduct a higher quality, more comprehensive, extensive, and unbiased literature review. There is a clearly specified method of identifying, selecting, validating, and including information from the literature so that it is clear, transparent, recordable and reproducible. The transparency in the process is documented in the protocol for the systematic literature review. Using a clear and transparent process helps minimize bias and systematic errors in summarizing the evidence, thereby enhancing the validity of the research findings. There is also a quantitative synthesis to integrate the information from multiple studies identified from the literature.

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 conducting the systematic literature review based on the Cochrane Method (Higgins and Green 2011). The protocol included data collection, screening the results, abstracting data, appraising the risk of bias, synthesizing the findings, and interpreting the results.

5.1. Data Sources

In the systematic literature review in this research study, 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 (Higgins and Green 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 'KROP', which stands for research *Knowledge Resources, Outcomes*, and *Populations*: The studies collected for this systematic review have the following KROP components:

KR = *Knowledge Resources,* including knowledge management, deployment, infrastructure, and external investments.

O = *Outcomes*, including patenting and patent licensing as well as startup formation performance.

P = *Populations*, including technology transfer office staffing.

In addition, the Cochrane Collaboration recommends that well formulated research questions in biomedical systematic reviews describe the medical exposure or intervention, outcome, setting, and population. Thus, the 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). As aforementioned, knowledge management is comprised of "human resources" such as the TTO staff and legal assistance.

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. Literature searches were conducted in several databases, including the following: *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 from the literature. This process was carried out for each database. Therefore, this work represented a comprehensive systematic literature review of TTO empirical studies.

The systematic literature review identified more than 10,000 TTO empirical studies. Many of the studies employed data from the Association of University Technology Management (AUTM) Statistics Access for Technology Transfer (STATT) 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. Nevertheless, the systematic literature review employed in this study that was based on the Cochrane Method provided a state-of-the-art perspective on tech transfer.

The database search for empirical studies was augmented with hand searching that included the reference list of each study. This is called snowballing. Grey literature including dissertations were also searched. This electronic search was evaluated against the Sampson et al. (2008) seven key criteria for assessing search quality (Sampson et al. 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 et al. 2016). Furthermore, personal contacts from the university technology transfer sector were used to help identify and find additional empirical studies that should be included in the data. This thorough research methodology is required in comprehensive systematic reviews.

5.2. Data Collection

In order to record all of this data for the systematic literature review and meta-analysis, the PRISMA method of transparent reporting was used. PRISMA was used to ensure a high-quality rigorous review (Moher et al. 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 Figure 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, only 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.

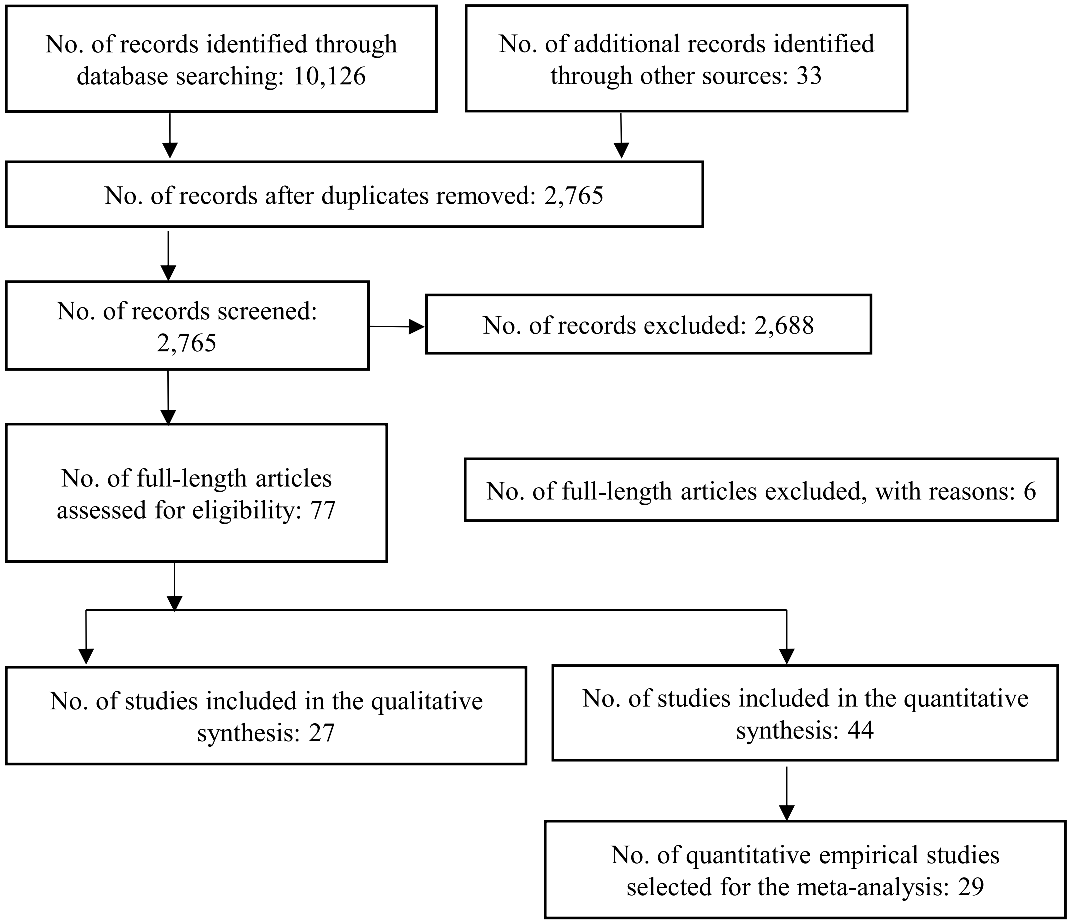

Figure 2. PRISMA Information Flow Chart.

5.3. 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 in this case can help university technology commercialization managers make improved, 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 and Hunter 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 and Hunter 2015). The goal is to consider whether the extent of the effects is large enough to matter to TTOs and key stakeholders, such as faculty members and researchers, other research administrators, and university senior leadership.

5.4. Inclusion-Exclusion Criteria

In order to be included in the meta-analysis, each study had to contain a correlation among a resource and a performance measure. As a systematic literature 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 subsequently 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 literature 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. In order to ensure quality control, duplicate screening was used by also having a second researcher independently review the studies.

Among the thousands of TTO studies extracted and reviewed for whether the studies contained effect sizes in the form of correlations, there were 44 studies that were identified as having relevant measures. From the 44 studies there were 29 studies that included relevant measures (i.e., TTO knowledge management, TTO knowledge deployment, TTO knowledge infrastructure, and TTO external investment resources) and were correlated to the performance outcomes (i.e., licenses executed, licensing revenue and/or startup companies formed). Thus, 29 studies were included in the systematic review's meta-analysis (see Table 4) (Alhomayden 2017; Calcagnini et al. 2014; Cardozo et al. 2011; Carlsson and Fridh 2002; Cesaroni and Andrea 2016; Chapple et al. 2005; Civera et al. 2020; Cunningham et al. 2019; Fini et al. 2016; Goble et al. 2017; Ho et al. 2014; Horta et al. 2015; Huyghe et al. 2016; Jung and Kim 2018; Lockett et al. 2005; Markman et al. 2005a, 2005b; Powers 2003, 2005; Rogers 2000; Seashore Louis et al. 1989; Siegel et al. 2003; Sine et al. 2003; Swamidass and Venubabu 2009; Tseng et al. 2018; Van Looy et al. 2011; Wang et al. 2015). The remaining 15 studies did not have correlations to this study's performance measures and were not included in the meta-analysis (Aldridge and David 2011; Bellucci and Luca 2014; Bolzani et al. 2020; Cattaneo et al. 2016; Chirgui et al. 2018; Comacchio et al. 2012; Curi et al. 2012; Friedman and Silberman 2003; Gubitta et al. 2015; Hülsbeck et al. 2013; Huyghe et al. 2016; Kirkman 2016; Munari et al. 2018; Owen-Smith 2003; Tang 2017). It should be noted that Carlsson and Fridh (2002) and Ho et al. (2014) are designated as having two studies each because each research team studied two distinct study groups.

Many of the university technology transfer resources data are gathered annually during the Association of University Technology Managers (AUTM) annual licensing survey. These knowledge management and knowledge deployment measures 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 the presence of a medical school and incubator. The external environmental resources include GDP (gross domestic product), R&D intensity, and sponsored research funding.

Table 4. Studies used in the meta-analysis.

	Publication	Study First Author, Year	Used
1	Research Policy	(Aldridge and David 2011)	-
2	University of Queensland PhD Thesis	(Alhomayden 2017)	x
3	Institut fur Angewandte Wirtschaftsforschung (IAW), Tubingen: Working Paper	(Bellucci and Luca 2014)	-
4	Journal of Technology Transfer	(Bolzani et al. 2020)	-
5	Journal of Technology Transfer	(Calcagnini et al. 2014)	x
6	Journal of Technology Transfer	(Cardozo et al. 2011)	x

Table 4. *Cont.*

	Publication	Study First Author, Year	Used
7	Journal of Evolutionary Economics	(Carlsson and Fridh 2002) a	x
8	Journal of Evolutionary Economics	(Carlsson and Fridh 2002) b	x
9	Journal of Technology Transfer	(Cattaneo et al. 2016)	-
10	Journal of Technology Transfer	(Cesaroni and Andrea 2016)	x
11	Research Policy	(Chapple et al. 2005)	x
12	Journal of Technology Transfer	(Chirgui et al. 2018)	-
13	European Economic Review	(Civera et al. 2020)	x
14	Journal of Technology Transfer	(Comacchio et al. 2012)	-
15	Journal of Technology Transfer	(Cunningham et al. 2019)	x
16	Cambridge J Economics	(Curi et al. 2012)	-
17	Small Business Economics	(Fini et al. 2016)	x
18	Journal of Technology Transfer	(Friedman and Silberman 2003)	-
19	World Scientific Reference on EntrepreneurshipBook Ch 5 Organizing for Innovation	(Goble et al. 2017)	x
20	Economic Development Quarterly	(Chapple et al. 2005)	x
21	Journal of Technology Transfer	(Gubitta et al. 2015)	-
22	Journal of Technology Transfer	(Ho et al. 2014) a	x
23	Journal of Technology Transfer	(Ho et al. 2014) b	x
24	Druid Conference	(Horta et al. 2015)	x
25	Journal of Technology Transfer	(Hülsbeck et al. 2013)	-
26	Small Business Economics	(Huyghe et al. 2016)	-
27	Journal of Technology Transfer	(Jung and Kim 2018)	x
28	Administrative Issues	(Kirkman 2016)	-
29	Research Policy	(Lockett and Wright 2005)	x
30	Journal of Business Venturing	(Markman et al. 2005a)	x
31	Research Policy	(Markman et al. 2005b)	x
32	Technology Forecasting and Social Change	(Munari et al. 2018)	-
33	Research Policy	(Owen-Smith 2003)	-
34	Research Policy	(Powers and Patricia 2005)	x
35	Journal of Higher Education	(Powers 2003)	x
36	Journal Association University Tech	(Rogers 2000)	x
37	Administrative Science Quarterly	(Seashore Louis et al. 1989)	x
38	Research Policy	(Siegel et al. 2003)	x
39	Management Science	(Sine et al. 2003)	x
40	Journal of Technology Transfer	(Swamidass and Venubabu 2009)	x
41	Open Journal of Social Science	(Tang 2017)	-
42	Journal of Technology Transfer	(Tseng et al. 2018)	x
43	Research Policy	(Van Looy et al. 2011)	x
44	Scientometrics	(Wang et al. 2015)	x

KBV studies with relevant measures, Legend: 44 Studies with relevant measures; 29 Studies with relevant measures and with correlations to this study's performance measures (x); 15 Studies without correlations to this study's performance measures (-).

This data was aggregated using a meta-analytic technique to reveal relationships between the resources. The weighted average effect of the size of relationships were found (Schmidt and Hunter 2015). The meta-analysis method was chosen because it reduces the impact that both measurement error and sampling error have on empirical research results. Within a macro-research stream, a meta-analysis may yield evidence to corroborate or re-evaluate established theories (Combs et al. 2011). Thus, the first step in the research method was the completion of a systematic literature review of TTO empirical studies. Each study had to contain (1) a measure of a university TTO resource (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. Observed effects pertaining to Knowledge Management (KM), Knowledge Deployment (KD), Knowledge Infrastructure (KI) resources were chronicled. Next were measures of specific organizational resources related to External Investments (EI) relation to overall TTO performance (Perf), licensing as a type of performance (Lic) and startups (S) as a type of performance measure. The Lic observed effects involved either executed licensing contracts or licensing revenues that were generated.

5.5. Statistical Analysis

The 29 qualifying 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 provided a more accurate estimate since positive and negative sampling errors averaged out (Crook et al. 2008; Schmidt and Hunter 2015). Confidence intervals were used to facilitate hypothesis testing. The predictions were directional and two-tailed tests of the null hypothesis were used. The effects described in the hypotheses were tested by whether the confidence intervals for $\bar{r}$ included zero.

6. 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). Among the 29 studies the weighted average effects and weighted average corrected effects were computed using a fixed effects model and are listed in Table 5. In addition, Table 6 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.

Table 5. University technology transfer meta-analysis results using a fixed effects model.

EI	EI	EI	KI	KI	KI	KD	KD	KD	KM	KM	M	IV
Start	**Lic**	**Perf**	**Start**	**Lic**	**Perf**	**Start**	**Lic**	**Perf**	**Start**	**Lic**	**Perf**	**DV**
3033	3170	5585	303	1086	1389	2448	4185	6488	1164	2594	3758	**N**
21	33	48	4	10	14	23	50	72	16	34	50	**K**
0.137	0.153	0.193	−0.022	0.151	0.123	0.408	0.249	0.336	0.4	0.274	0.314	**r**
0.090	0.107	0.159	−0.071	0.073	0.053	0.363	0.211	0.307	0.333	0.226	0.275	**99% CI Lower**
0.183	0.198	0.226	0.128	0.227	0.191	0.451	0.287	0.365	0.463	0.321	0.358	**99% CI Upper**

Table 6. University technology transfer meta-analysis results comparing the fixed effects model and a random effects model.

EI	EI	EI	KI	KI	KI	KD	KD	KD	KM	KM	KM	IV
Start	**Lic**	**Perf**	**Start**	**Lic**	**Perf**	**Start**	**Lic**	**Perf**	**Start**	**Lic**	**Perf**	**DV**
0.137	0.153	0.193	−0.022	0.151	0.123	0.408	0.249	0.336	0.400	0.274	0.314	**Fixed Pt Est**
0.271	0.292	0.350	−0.040	0.081	0.061	0.517	0.264	0.366	0.469	0.344	0.386	**Random Pt Est**
0.900–0.183	0.107–0.198	0.159–0.226	−0.071–0.128	0.073–0.227	0.053–0.191	0.363–0.451	0.211–0.287	0.307–0.365	0.333–0.463	0.226–0.321	0.275–0.353	**Fixed LL-UL**
0.026–0.486	0.016–0.526	0.163–0.513	−0.404–0.336	−0.268–0.411	−0.216–0.329	0.148–0.760	−0.058–0.536	0.127–0.564	0.140–0.705	0.089–0.705	0.089–0.557	**Random LL-UL**
96.12	97.26	96.84	84.74	94.975	93.64	98.37	98.44	98.33	95.42	96.20	95.96	$\mathbf{I^2}$

The model includes fixed effect point estimate sizes (Fixed Pt Est) for the effects and 99% confidence intervals. Table 6 also includes random effect point estimate sizes (Random Pt Est) for the effects and 99% 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 Table 6. 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 startup business formations, I^2 was 96.12. This indicates that the variance of dispersion would be 96%, as this was 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 optimal model's results and therefore, represent the highest quality results to analyze.

Q, degrees of freedom (df), and p values were used to test the hypothesis of homogeneity. 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 result 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 was based on the sampling method. Since this systematic literature review involved searching the literature, extracting studies, and culminated in the selection of 29 studies, these studies were obviously not identical and the effect size really did vary from one study to the next. Thus, the random effect model results are the more plausible. As shown in Table 6, 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).

7. Discussion

The final stage of the analysis was to test the four hypotheses as previously set forth.

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

As shown in Table 6, the knowledge management resources are characterized by TTO age, TTO size, and TTO expenditure on legal help measures had no observed and Fischer corrected correlation r greater than 0.5 in relation to university start up business formation or licensing. However, the study results do not show the largest effect size between TTO knowledge management and startup performance. Thus, Hypothesis 1 was not supported.

- *Hypothesis 2.* Knowledge deployment is 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 knowledge deployment researched in the selected studies for this systematic review included invention disclosures, patent applications, and university patents owned. With respect to the evaluation of knowledge deployment's relationship to overall technology transfer performance, Hypothesis 2 was supported in part. These selected organizational resources were positively related to university startup 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 startup business formations since a common university startup business model is to license a university owned patent to the startup 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 be possible.

- *Hypothesis 3*. Knowledge infrastructure is positively related to TTO performance in the areas of patenting, licensing, and generating startups. Herein, knowledge infrastructure is defined to include physical infrastructure that supported integration such as 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. They revealed the lowest effect sizes. Thus, Hypothesis 3 was not supported.

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

The external investments 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 investments on licensing separate from startup business formations, there was no positive relationship between environmental investments and licensing (i.e., executed patent licenses and licensing income). Thus, Hypothesis 4 was not supported.

8. Conclusions

Prior research contains conflicting evidence regarding how key TTO resource attributes and characteristics of the organizational environment relate to the performance of technology transfer. Given the importance of TTOs to research-intensive universities, the lack of a comprehensive study with conclusive results has scarcely contributed to an understanding of the central TTO-performance relationships. This work used insights from extant research that were combined via a systematic literature review and corresponding meta-analysis to provide a more complete and rigorous view of this matter. Here, the Knowledge-Based View of strategy was applied to tech transfer to establish the finding that the relationship between TTO knowledge management and knowledge deployment and startup business performance is where TTOs secure the strongest returns.

Knowledge management was operationalized by features of TTO research administration and related legal staffing. Knowledge deployment was operationalized as the deployment of resources, including faculty invention disclosures, patent applications and patents owned by universities. Knowledge infrastructure was operationalized as the presence of incubators and medical schools. It was discovered that knowledge deployment is significant relative to startup business formations. The Knowledge Based View (KBV) indicates that knowledge becomes internalized, shared, accumulated, and used in the process of knowledge integration. Once these processes are established, an organization can achieve competitive advantages. Consequently, we can consider that where universities are able to bolster the TTO capability (e.g., in terms of tech transfer and legal staffing levels) and when combined with a dynamic academic environment with inventions and science and technology breakthroughs by teams of researchers, this has the potential to lead to a higher level of tech transfer performance (i.e., in terms of patent licensing and generating startups). Also, it is important to note instances where small effects are observed (i.e., when the correlation r is significantly less than 0.5). There was practically no relationship between knowledge infrastructure (i.e., the presence of medical schools and incubators) and licensing performance; nor with overall TTO performance; or startup formations.

The KBV paradigm continues to be applied to a range of diverse enterprise and technology management applications that require further analysis, such as recent work on the relationship between social networks among academic entrepreneurs and entrepreneurial development (Hayter 2016), corporate governance and IPO underpricing (Judge et al. 2015), and the implementation of corporate sustainability strategies in regard to company size (Horisch 2015). Therefore, and from an epistemological perspective, this study of tech transfer based on the KBV combined with a meta-analysis enabled by a systematic literature review extends the literature on the KBV and the range of applications that have been investigated using the construct.

The findings from this research are useful because they can steer TTO managers and leaders in the direction of bolstering their knowledge deployment with their limited financial investments, rather than focusing on knowledge infrastructure using physical infrastructure, such as incubators and medical schools, in order to improve performance success. Doing so will not only reconcile conflicting findings in extant research but will also enable university leaders to optimize the use of their scarce resources. The findings from this research are also useful to scientists, engineers and managers from industry who are looking to commercialize university research as an enhanced awareness of the characteristics of the tech transfer process is likely to support an improved likelihood that the technology commercialization process will ultimately be successful. Future work is suggested in the following areas: (1) study effects other than correlations using meta-analyses; and (2) conduct an international comparative study between countries (e.g., China and the European Union in comparison with the United States of America). Further research is also suggested on developing an improved understanding of the broader benefits of tech transfer; not only the financial aspects, but also the industrial, societal and knowledge impacts generated through transferring technology and the corresponding knowledge from academic institutions to industrial companies.

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Conflicts of Interest: The authors declare no conflict of interest.

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