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Models, Processes, and Roles of Universities in Technology Transfer Management: A Systematic Review

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Abstract: Universities play pivotal roles when research findings are to be adopted commercially. Although these roles vary from one country to another, effective patenting and licensing procedures, as well as eventual commercialisation of scholarly inventions, reflect hard work on the part of the University mediating between the researcher and the industry through technology transfer offices (TTOs) in order to ensure that knowledge-developers take motivational and monetary credit for their findings. This paper details some existing models, processes, and roles taken up in some countries where sharing of intellectual property exists, and links it up with aspects of university–industry technology transfer, such as policies surrounding patenting, government investment and marketing, and the process of academic entrepreneurship, among others. 22 articles were found via a systematic review of literature and analysed with respect to four identified areas of focus: internal strategy, investment and market, academic entrepreneurship and policy. Based on models, processes, and roles in reviewed studies, our results indicate that new models for technology transfer mainly stem from the fact that there is no universally accepted model in the literature. Furthermore, management of technology transfer is mostly the responsibility of TTOs in most countries. While university TTOs act as intermediaries to protect the interest of the author/inventor, issues such as poor relationships between universities and industry, as well as funding, remain major challenges in many emerging economies. In contrast, researchers in western economies are mainly challenged by financial motivation and recognition within the academic domains.

Keywords: technology transfer models; universities; systematic review; management; commercialisation

1. Introduction

Scholarly research efforts that lead to ground-breaking findings and inventions have significant impacts on technological innovation and continuous economic development globally (Ding et al. 2019). The Academia-Industry relationship has been widely described in literature (Munyoki et al. 2011; Alexander et al. 2018; Vick and Robertson 2018; Belitski et al. 2019), and dates back to many decades ago (Noh and Lee 2019). The enactment of the Bayh–Dole Act in 1980 proved to be a game-changer, further increasing the interest of universities in participating more in technology transfer (Bradley et al. 2013). Today, universities play pivotal roles when research findings are to be adopted commercially. Although these roles vary from one country to another, effective patenting and licensing procedures, as well as eventual commercialisation of scholarly inventions, reflect hard work on the part of the university, which mediates between the researcher and the industry through technology transfer offices

(TTOs) to ensure that knowledge-developers take motivational and monetary credit for their findings (Open University 2016).

As noted by Bradley et al. (2013), the literature on technology transfer (TT) in the past was seemingly focused on issues related to the functions of technology transfer offices (TTOs), as well as discussions on obtaining licenses and patents. There is very little documented literature with respect to the process flow until the last decade, during which ideas on technology transfer models started to emanate. Even so, different scholars have given contrasting ideas as to the model they feel would make the process easier. While some models have merely been proposed, others are actually in use in some countries. This divergence in technology transfer model implies that a true knowledge of a generalised technology transfer procedure that factors in the uniqueness of individual countries does not exist. As such, it may be safe to say that there is no model (at least in the body of literature as of now) that can be described as being ideal for carrying out knowledge transfer. This is mainly because most existing models follow traditional techniques, e.g., the so-called "*linear knowledge flow*" (Bradley et al. 2013), or country-specific techniques often based on the prevailing laws of the nation in which such research is carried out. It is on this premise that the current study looks at some of the technology transfer models in the body of literature with the goal of understanding how the process of TT progresses in different settings, bearing in mind the roles played by universities and other major actors.

The remainder of this paper is organised as follows: Section 2 details the past literature on the roles played by universities in ensuring smooth transactions between researchers and industry as well as some existing processes and models. It looks at prevailing models in some countries and links these to the technology transfer offices. Section 3 explains the method adopted in this study, focusing on the issue of quality, among other things. Section 4 looks at data analysis and results, while Section 5 draws relevant conclusions from the study.

2. Theoretical Background

There are different, but related, streams of research addressing technology transfer at universities. Considering research focus as registered in scientific databases, key words point to technology and knowledge transfer models, research and development in context of university industry collaborations and academic entrepreneurship (Figure 1), while other studies analyse TT as a part of the university ecosystem.

2.1. University–Industry Collaborations and Academic Entrepreneurship

One major role universities play in innovation transfer is to enter into joint ventures with industrial organisations without R&D departments or affiliates (Bucsai 2013). Although most large corporations in western countries have R&D units, adopting university research can proffer rapid solution to technical problems since universities often possess several ongoing researches through different clusters/units. Additionally, joint venture agreements can foster better results, since their common energy is focused on a common goal. Martino (1996) explained that the bulk of developmental research in the U.S. is carried out by universities through their research institutes, using monies mostly provided by government. U.S. universities create these institutes for several reasons: some research units do not fit into any of the usual university departments, and even more commonly, the usual university departments often impose commitments on employees on a long term basis, particularly if the need for a research project arises. This situation is, however, different for institutes, which may hire researchers on a short-term basis (Martino 1996).

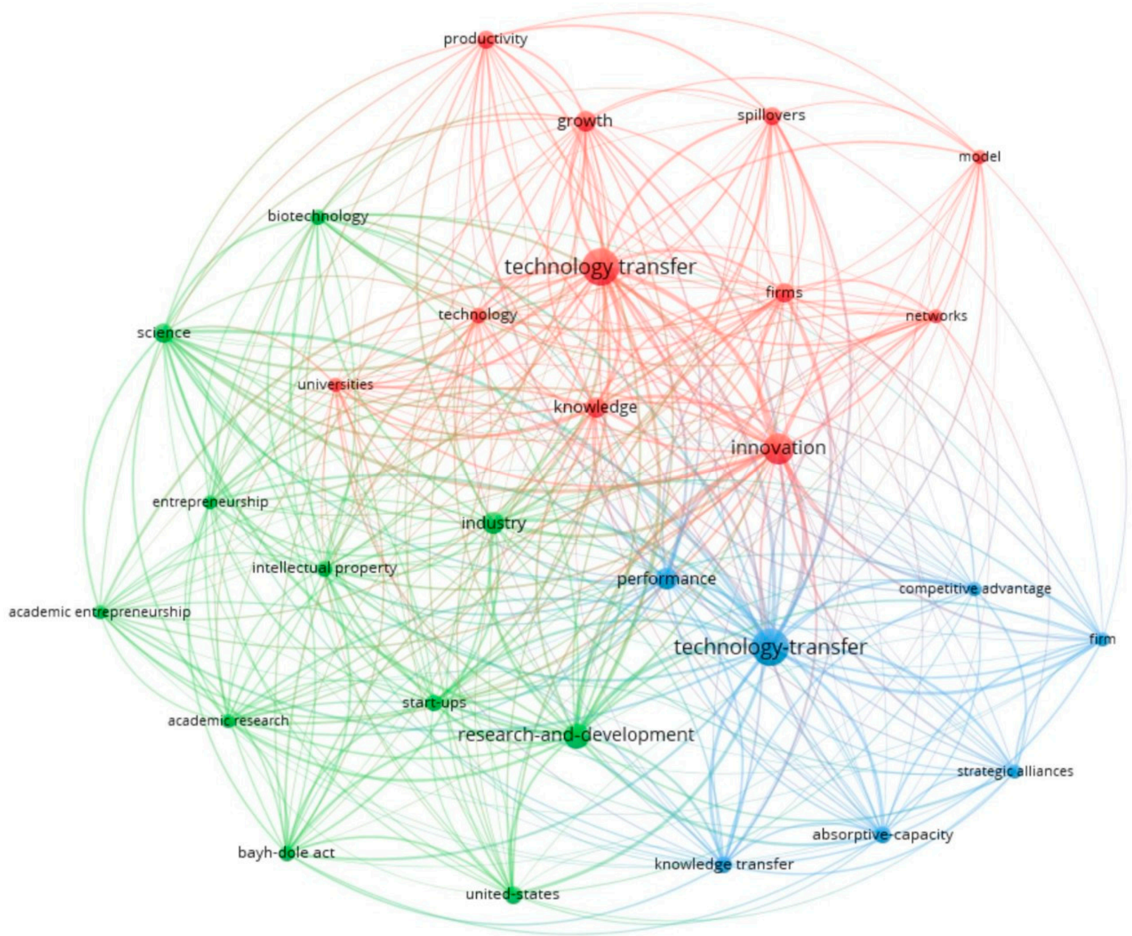

Figure 1. Main streams of research regarding technology transfer at universities.

Furthermore, Inzelt (2004) noted that the roles played by major actors within the TT processes can be divided into three unique co-operation types: institution–institution-based, individual-based and individual–institution-based. By relying on these cooperation types, the industry reaps benefits over both short- and long-term periods (Bucsai 2013). In the short run, real-time knowledge can be made available, as well as obtaining immediate solutions to technical challenges. In the long run, the industry can align strategically to research outputs from the universities by offering partnerships to the universities in the form of internships (for students) and research exchanges for faculty (Grimaldi et al. 2011). On the 30th anniversary of the enactment of the Bayh–Dole Act in the U.S., they confirmed the rationale for academic entrepreneurship and described the evolving role of universities in the commercialisation of research. According to Perkmann et al. (2013), research on university–industry interaction has strongly emphasised the role of TTOs, so some policy-makers have consequently resorted to subsidising technology transfer operations at universities. This led to an organisational focus at universities on formal mechanisms of commercialisation. These technology transfer structures are less adept at fostering academic engagement. As individual discretion seems to be the main determinant of academic engagement with industry, policy measures should address individuals, in addition to influencing university practices and structures. For instance, fostering individual-level engagement skills would appear to be a potentially powerful lever.

Lacetera (2009) distinguished between academic and non-academic researchers when deciding whether to engage in knowledge commercialisation, as well as on the time taken for the process to reach full maturity. The author proposed an academic entrepreneurship model referred to as the "two period model". Within this model, an academic researcher is seen to undertake commercially relevant research if the benefits (economic and otherwise) seem juicier than other academic engagements. As a result, Fini and Lacetera (2010) noted that university researchers derive satisfaction in terms of getting the opportunity to publish completed research items, as well as financial gains from knowledge commercialisation, with the latter also applying to industry scientists.

Central support by the TTO should spread its interventions across the university through the implementation of a transversal structure. However, in practice, there are cases where some researchers enter into contracts with entrepreneurs without the comprehensive service support of the technology transfer office. This can be the case if such a centre is not established or is not known internally at the institution. Furthermore, when the transfer centre is known, but individual workers have a long-term contractual relationship with a commercial entity, they have long been contracted, their common trust has already been built, and they do not need any support from a technology transfer office. A similar situation may occur in an extreme case, namely where the technology transfer centre is viewed negatively. An example of such a successful transfer in the Czech environment in 2017 was a project growing tumourous thigh bone prostheses developed by researchers at Masaryk University and sold to Beznoska. The main aim of the project was the launching of a clinical use program. Of the total number of patients operated on for limb cancer, 30% were indicated for amputation and 70% for limb conservation. Through the operation, the functional limb is able to be maintained, and a bone cell graft or one of the individual tumour endoprostheses types can be used to replace the bone defect (after removal of the bone tumour (TAČR n.d.)).

The relationships and linkages of technology transfer, industry and commercialisation activities as a whole are described by studies that consider this area as an ecosystem. They describe existing frameworks, their weaknesses, and their possibilities for development. By studying the University of Chicago's entrepreneurial ecosystem, Miller and Acs (2017) explained that Turner's frontier had already changed the face of things, as the modern day campus had a more commercialised ecosystem. Fiaz and Rizran (2011) also noted that the right ecosystem is crucial in developing the strengths of a University in its quest to become fully entrepreneurial. Hayter et al. (2018) describes how academic entrepreneurship is conceptualised and the extent to which it adopts an ecosystem approach. Good et al. (2019) provide an understanding of the organisational design of the TT ecosystem and show that research considering this ecosystem as a whole is largely lacking. Acs et al. (2017) outline contributions to the entrepreneurial ecosystem approach and conclude with a promising new line of research into the emergence, growth, and context of start-ups that have achieved great impact by developing new platforms. Brown and Mason (2017) provide a critical review and conceptualisation of the ecosystems concept, which unpacks the dynamics of the concept, and outlines its theoretical limitations, measurement approaches and use in policy-making. It sets out a preliminary taxonomy of different archetypal ecosystems. The paper concludes that entrepreneurial ecosystems are a highly variegated, multi-actor and multi-scalar phenomenon, requiring bespoke policy interventions.

2.2. Technology Transfer Models

Several technology transfer models exist in the literature, as discussed by (Bradley et al. 2013; Arenas and González 2018). The foundational traditional model (Figure 2) is used by Vac and Fitiu (2017), in which the acceptance of the technological knowledge is a function of the kind of protection and marketing activities carried out (Malik 2002). Waroonkun and Stewart (2008) also presented a model that suits international technology transfer in which patenting and licensing must follow socio-political norms. By taking a step further from the work of Malik (2002), Khabiri et al. (2012) also presented a model that explains the ideas of Malik (2002) as being dependent on certain guidelines within an organisation. In the realm of models that focus on university–industry collaborations, Mayer and Blaas (2002) stressed several useful methods that are more or less functions of the features of the all the parties involved in TT, as well as the kind of technology to be transferred. Within this model, the authors explained that there is always a need to introduce a third party who helps to break the barrier of language challenges between technology transmitter and receiver. In a conceptual work, Rubiralta (2004) presented a triple helix-based model in which the technology transfer office mediates between the university and industry. Gorschek et al. (2006) and Hoffman et al. (2009) both presented practical cases of technology transfer models. While Gorschek et al. (2006) explained a stepwise approach (a series of steps to follow) to actualise effective knowledge transfer, Hoffman et al. (2009) explained that universities can transfer knowledge through science, technology, and through usage. Kalnins and Jarohnovich (2015) described formal and informal approaches to technology transfer. Munari (Munari et al. 2016) analysed the determinants of the university technology transfer policy-mix. This model stresses the fact that universities are responsible to industry for new knowledge. In Latvia, there have been many complaints about research results not reaching the market. As a result, of this, the InnoSPICE model (Novickis et al. 2017) was developed, which is a step beyond the traditional method (Figure 2). According to Novickis et al. (2017), the model provides an all-new approach to innovation by creating room for funding assessment. Another pair of Latvian researchers, Kalnins and Jarohnovich (2015), also proposed the so-called "*system thinking model*" from TT, mainly because industries do not think universities can offer them any research outputs. Furthermore, the many inadequacies of Latvian laws in boosting traditional technology also contribute to the search for newer ways of getting research to industry. Nevertheless, the model is flawed on the grounds that the conventional basic research interconnectivity is lacking in the commercialisation process it proposes. Wood (2011) proposed a process model within which the roles of the university, the researcher and the industry are well spelled out. Role separation makes it easier for every actor to know when to act in accordance with one another in order to lay down guidelines within the TT process.

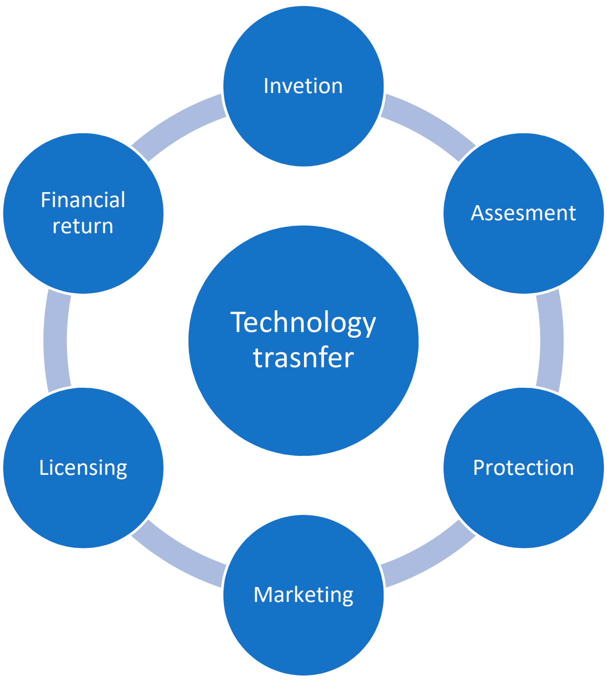

Figure 2. Technology transfer process, source: based on (Vac and Fitiu 2017).

2.3. *International Comparison of Academic Entrepreneurship and Technology Transfer*

According to Chapple et al. (2005), a large number of TTO affiliates of Universities in the UK are not very efficient with respect to linking scientific findings to industry, thus reducing the number of possible spin-offs that ought to be created. The study that was found to be most in line with similar research from the United States recommended further training on related business skills for managers of TTOs across British Universities so that better negotiation and increased marketing of Universities' results could be utilised by the public. Suggesting a reshuffling of the TT process among British Universities, Chapple et al. (2005) also noted that due to inefficiency on the part of most managers, larger Universities are able to concentrate on sectors in which there are high technological demands, while others can look into smaller TT projects. Clarysse et al. (2005) studied the techniques adopted by several European Universities in creating new ventures. Three distinct models—*Low Selective*, *Supportive*, and *Incubator*—were identified. It was observed that the process of managing the creation of spinoffs was unique for each of these models in terms of the resources needed in the areas of employee recruitment and monetary basis among others. Furthermore, the study also classified "Resource-Deficient" and "Competence-Deficient" units on the basis of the models. While the concept of the entrepreneurial University is stressed in the low selective and supportive models, it is quite scarce within the incubator model. Within the low selective model, the ideas of individuals with ties to the university (researchers and graduates) are broadened on an entrepreneurial basis. The case is, however, different in the supportive model, where business plans are used rather than ideas. The incubator model is not limited in scope, as it seeks effective worldwide collaboration in its entrepreneurial duties. While the models face different challenges due to their individual scope, Clarysse et al. (2005) noted orthogonality in objectives, causing the functions to intersect in complimentary terms.

In line with the ideas discussed by (Clarysse et al. 2005), Mustar et al. (2008) utilised a multi-level technique to analytically study how new ventures emanate from Universities in Europe. As a major observation, the authors found that University across Europe (even those within the same nation) approached their third missions uniquely. Universities now adopted specialist systems, causing a shift from the usual "jack of all disciplines" system (Larédo 2003). While most European governments continue to stress the need for universities to continually focus on TT to industry, Universities on their own explain that public finance of processes that support creation of spin-offs has still not been fully developed (Mustar et al. 2008). In a comparative study to understand University third mission processes in the United States and some of the strongest economies in Asia, Singh et al. (2015), similar to the findings of Wong et al. (2011), explained that a common reason for continuous work towards TT is the emphasis placed on the process by the government of each of the Asian economies. While different laws are in place between nations, each has so far recorded a certain level of success (Singh et al. 2015). In the midst of their successes, however, the number of intellectual properties so far created by China, Korea, Hong Kong, Singapore, and Taiwan remains generally low. The few existing patents were also found to be poorly organised and of extremely low quality when compared to European and U.S. patents (Singh et al. 2015). Analysis for the study was carried out using the triple helix model.

Wright et al. (2006) explained that governments in Europe mostly prefer spin-offs that add value to the economy through the wealth they are able to create. Nevertheless, investments are still low, given the paradox whereby most investors prefer to invest in spin-offs that have grown past the infant stages, while these finances are needed most at the beginning of the lives of the spin-offs.

Young (2007) discussed several models used in some countries of the world. Although these models are not generalised, they enjoy wide usage in these countries. As a core example, Japan—one of the most technologically inclined countries in Asia—established a law twenty years ago on which technology transfer contracts, patenting and licensing agreements depend. Within the framework of this legislation, universities are able to finance about 65% of their TT activities within the first 1825 days of existence of the TTOs. Public research organisations have the responsibility of creating technology transfer offices in Australia through a model known as a "fully owned subsidiary". It is through these platforms that the activities of the transfer offices are monitored and funded without the need for external funding. Furthermore, Young (2007) explained that individual countries rely on nationally developed laws to run TT in Europe, with Germany having developed its own version of the Bayh–Dole act in 2002 (Grimpe and Fier 2010). Technology transfer in the United Kingdom has, over the years, progressed away from being state funded via an established scheme which came into force roughly a hundred years ago. It is through this scheme that British Universities have started to put their own TT structures in place. Oxford University Innovation (formerly known as Oxford University Research and Development, Ltd., in 1987, and Isis Innovation in 1988), one of the most important technology arms of any British University, was established in 1987 to serve as the TTO section of Oxford University (Young 2007).

In comparing university TT between Germany and the U.S., Grimpe and Fier (2010) noted that researchers' motivations were a function of recognition for good research outputs, as well as the receipt of monetary rewards, which could be in form of grants to carry out further research (Link et al. 2007). The implication of this is that without the desired kind of motivation, faculty may begin to engage in some form of informal TT through the backdoor (Grimpe and Fier 2010; Link et al. 2007) Until the dissolution of the so called 'Professor's privilege' (*Hochschullehrer-Privileg*) in 2002, German researchers were at liberty to carry out private negotiations with industry regardless of the source of research finance. This was the result of "Article 5 of the German constitution" (Kilger and Bartenbach 2002), which brought about very few patents emanating from German universities before that time (Czarnitzki et al. 2007). Nowadays, poor rewards systems, as perceived by researchers, are making room for informal collaborations between academia and industry (Link et al. 2007). This is because the researchers are now so used to the professors' privilege that they find the state rewards to be small. In addition, most German universities are yet to have fully functional working TT structures, meaning that backdoor technology transfer may still have its way.

The idea of technology transfer in China can be can be grouped into two categories: "intra-China" technology transfer, which looks at the process flow from R&D institutes/universities to industry within China; and "China–foreign nation" or "foreign nation–China" (export and import) technology transfer, which mainly involves technology transfer from China to a foreign nation and vice versa. Nevertheless, it can be argued that technology export and import models differ significantly. In the case of China as a "*technology transferee*", having a large market is often a source of advantage for the country, even when it is expected that the "*technology transferor*" should have more say. As reported by Holmes et al. (2013), for a new technology to gain entry into the Chinese market, the owner(s) must be willing to form some kind of alliance with China, which may come in the form of sharing technological ideas with China and/or training Chinese citizens in the same. This is also known as a "*Quid pro quo*" policy (Holmes et al. 2013). For instance, fifteen years ago, Kawasaki shared its expertise with a state-owned Chinese firm for the design and development of a speed train network, and also trained several engineers in order to gain access to showcase its product in China. Similarly, Siemens, a German-based train manufacturer, partnered with CNR Chinese Corporation Limited to manufacture high-speed trains and to train over 500 engineers. Many years later, the German outfit is having to buy from her former trainees (Nowak 2012). While *Quid pro quo* takes effect in China, Siemens will exercise its patenting rights should CNR decide to sell abroad, particularly if the same technology has been used in production (Holmes et al. 2013). In their eighteen year-old study, Zhao and Grier (1991) explained that China established R&D institutes that worked independent of industry and were owned by a few industry giants. The authors argued that this was different from the norm in industrialised nations, where industrial giants also handled R&D tasks. This independent work slowed down China's development technology-wise, as smaller industries had no access to the latest technology. It was only in the 2000s that China married its R&D to industry under the administration of the country's science and technology department, with support offered by national and regional technology transfer centres (Miesing and Tang 2018). Prior to this time, Zhao and Grier (1991), after studying 60 Chinese R&D institutes, concluded that, even though there seemed to be a tremendous increase in R&D towards knowledge transfer, funding remained a serious issue. This is due partly to the fact that Chinese R&D institutes look to the government for research funds, and partly to the large number of technology transfer institutes and technology demonstration centres, which has increased over the years (Miesing and Tang 2018). While some researchers believe that the opening of the Chinese economy to foreign technology is not yielding the expected results (Oktay 2018), others ascribe the poor "new-technology" absorption and assimilation to excessive preferences given to state-owned organisations (Fuller 2019). Another group criticised China's knowledge transfer policies, claiming that the country uses its laws to favour itself in its technology transfer processes (Office of the U.S. Trade Representative 2018). Similarly, Pinkert (2019) reports that several Chinese technology transfer partners have made known their reservations with respect to knowledge transfer in China, leading to additional efforts in protecting intellectual property rights when heading to China (China IPR SME Helpdesk 2018).

While positive scientific results may lead to rapid development in all areas of human endeavour, Fini and Lacetera (2010) expressed concerns with regard to the proclamation of fabricated scientific findings for popularity and monetary gains. Citing the case of the discovery of falsified results and discoveries by Jan Hendrik Schon, Diedrick Stapel, and Yoshika Fuji, among others (Mungeon and Larivière 2019; Katavić 2014; Bhatt 2019). These kinds of research then have negative socio-economic impacts on society, given that government invests so much money in it.

Nowadays, university–industry relations have grown so much that each party is willing to do more in terms of time and monetary inputs. A few such instances, as listed by Fini and Lacetera (2010), include:

- Washington University (St. Louis) entering into a two-decade partnership agreement with Monsanto, a chemical manufacturer, in a deal not less than $5 million, and Massachusetts Institute of Technology (MIT) and Exxon striking a decade-long research deal worth $8 million, for the former to carry out studies in combustion engineering (Kenney 1986)
- MIT and DuPont also agreed in 2000 to jointly engage in bio- and nanotechnology research, with the deal estimated at around $60 million. Furthermore, Novartis reached an agreement with a department of the University of California, Berkeley for plant and microbe research, with the deal estimated at $25 million (Lawler 2003).

3. Methods

3.1. Design of Study

Given the many dimensions of university–industry technology transfer (Zhang et al. 2018), and the continuous development of models aimed at detailing the best way for the process to progress (Rybnicek and Königsgruber 2019), it is becoming imperative to understand how these models relate to the aspects of university–industry TT. Researchers and scholars alike continue to develop models for university–industry technology transfer, with the mindset that these models, and the processes they are comprised of, will help TT attain the desired success. Nevertheless, we argue that for the university–industry technology transfer process to be successful, models must be tied to key aspects of TT (internal strategy, investment and market, academic entrepreneurship, as well as patenting policies.

From the foregoing review of the university–industry TT literature, it is clear that models offer routes to success for the TT process, whether locally or internationally. However, there are tendencies for models to exhibit flaws when slight system changes occur. For instance, when government (who are the major investors in university–industry TT) policies on education change. As a result, this study seeks to address the following research questions:

Q1: What are the make-ups of some existing university–industry TT models?
Q2: How are the models useful to the development of the university–industry technology transfer process?
Q3: What is the relationship between TT models and the aspects of university–industry TT?

To address the questions raised by this research, this study utilises a systematic review of the literature within the broad context of university–industry technology transfer. First, we group the literature on the basis of the "type of proposed model(s)", and then on the basis of the "topic segment" addressed. Next, we link the models to the topic segment in order to create a balance for the success of the TT process.

A scoping review of the literature and a search of articles related to the ongoing study was carried out. This details articles' central focus as they relate to the overall ideas of the study (Jesson et al. 2011). A database search was carried out on three websites using the advanced keyword search method and thesaurus style. This gave rise to several articles that were further examined with respect to technology transfer models, roles, and processes. For accuracy in terms of the selection of specific articles, a hand search was also conducted. Inclusion and exclusion criteria were subsequently applied, followed by a quality assessment check of selected studies.

3.2. Inclusion and Exclusion Criteria

A set of inclusion and exclusion criteria were developed to guide article selection. These criteria were in line with the goals of the study and were developed prior to the article search. Hence, peer-reviewed studies that examined technology transfer in relation to management and administration of the process, and roles played by major actors, written in English language and published from 2012 onward were included. Articles with characteristics different from those that adhere to the inclusion criteria were, however, excluded. Furthermore, articles selected for the study were articles that the authors had direct access to through their affiliations. This implies that there were no financial obligations on the part of the authors to assess the articles. Abstract-only papers, study protocols, books, book chapters, conference-only papers, bachelor and master thesis, doctoral dissertations and all other articles, asides journal articles were excluded. However, conference papers that were forwarded for further consideration by journal bodies were included. Only empirical studies that adopted qualitative, quantitative or mixed methods were found to be useful. The choice of timespan (2012–2019) was selected based on the large volume of literature published within this time. Table 1 summarises the criteria for selecting or dropping articles.

Table 1. Inclusion and exclusion criteria.

	Inclusion Criteria	**Exclusion Criteria**
Availability	Available full text	Not in full text
Language	English	Not in English
Publication type	Research articles published in peer-reviewed journals	Abstracts, study protocols, books, book chapter, conference-only papers, thesis, and other literature
Age range	1 to 7 years	Above 7 years
Setting	Related to university–industry collaborations, academic entrepreneurship, university ecosystem, TT models	Setting not related to university–industry collaborations, academic entrepreneurship, university ecosystem, TT models
Year	2012 to 2019	Older research
Articles' area of interest	Articles/research related university technology transfer practices and commercialisation models, roles, processes and strategies, and activities of university transfer offices	Not related to university technology transfer and commercialisation practices and models, roles, processes and strategies, and activities of university transfer offices

3.3. Search Strategies and Sources

A database search was carried out in April 2019. Relevant studies were derived from searching Web of Science (WoS), Scopus and ERIC databases. The search within WoS and ERIC databases adopted a Thesaurus search style, in addition to the common advanced free search. Within the Scopus database, only advanced free search was possible. Furthermore, search terms were largely similar across the databases. Database selection is the result of the volume of articles and details contained on each of the databases on technology transfer. Key terms that relate to the ongoing topic and its central focus and point to the goal of the study were used to locate useful studies on technology transfer models and process around the world. They include: technology transfer, model, process, country, and management, as well as all possible combinations of these terms. Searching commenced within the ERIC database using advanced search terms, as well as search terms found through Thesaurus. The following arrangement was adopted: ("Technology transfer" OR "Transfer of technology" OR "Knowledge transfer" AND "Model" OR "Design" AND "Process" OR "Procedure" AND "Country"

OR "Nation" AND "Management" OR Administration"). Table 2 summarizes the number of articles derived from each database between 2012–2019.

Table 2. Number of results in years and databases.

Database/Year		2019	2018	2017	2016	2015	2014	2013	2012
ERIC	1100	69	190	200	173	117	130	125	96
WoS	1168	75	185	180	194	152	149	120	113
Scopus	952	43	111	171	151	101	158	112	105
Total	3220								

The ERIC database search yielded 1100 relevant articles. It is noteworthy to mention that the "OR" and "AND" operators generally combine clusters/key terms during the search. WoS database search followed using similar key terms, with the search returning a total of 1168 articles. Only advanced search was possible within the Scopus database, and similar search terms were used as for the other databases; 952 relevant articles were derived from this search. All 3220 articles gathered from the databases were compared, and the duplicates (1916 articles) were removed, leaving 1304 articles for further screening and analysis. Figure 3 shows a flowchart of article screening procedure.

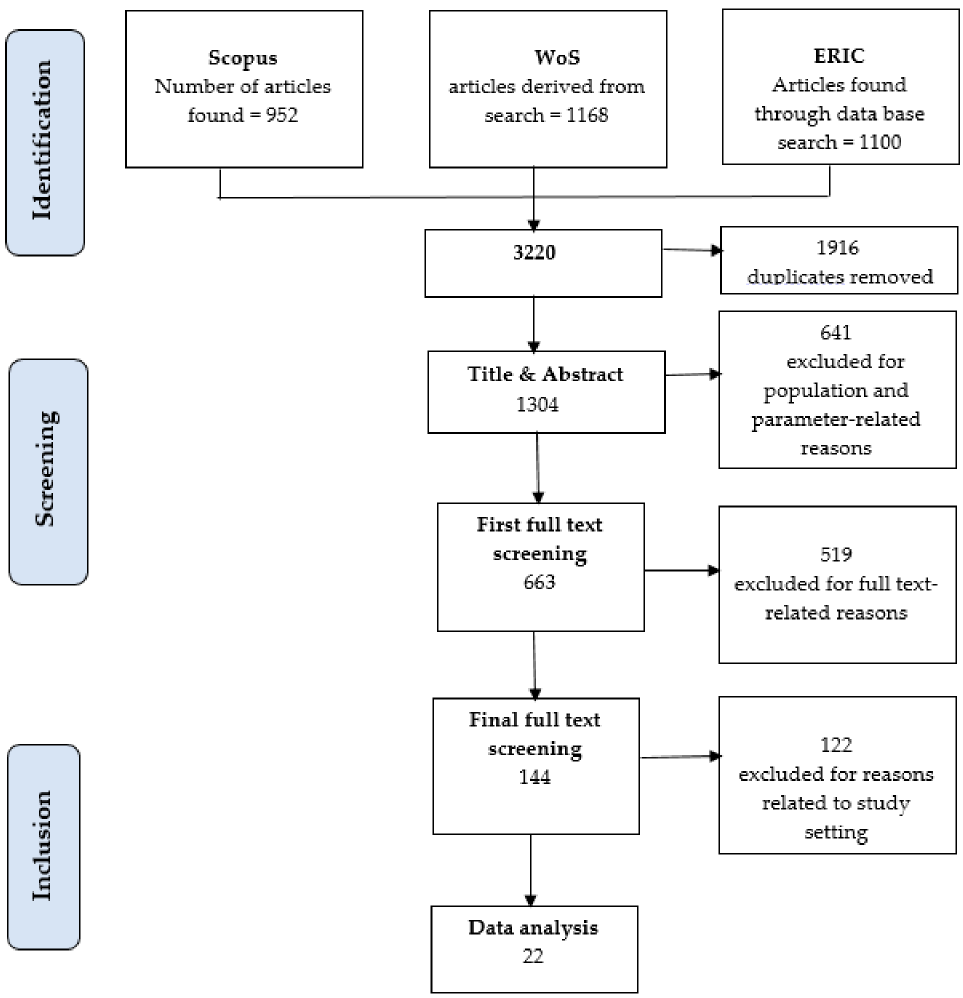

Figure 3. Article selection flowchart.

3.4. Quality Assessment

Systematically selected articles were assessed for quality by combining the rubrics provided by "Critical Appraisal Skills Program" (CASP) (Critical Appraisal Skills Programme CASP), and the "Critical Review Form" (CRF)" (Letts et al. 2007). Adapting these tools provided the study with the option of crosschecking each article against a set of well-defined outlines in a systematic review process. Key points of the outline include: peer review process, aim and research questions, information about the technology transfer model, study design, control group, and follow up. In addition, scale measure was adopted in line with the current study to follow the quality range; high, medium high, medium low, and low (see Appendix B).

CASP helps to gather and summarise crucial information related to the different areas of a research. To put this article appraisal tool to best use, it is important to ascertain the validity of the results of each study, and the implications of such results to the local settings (Critical Appraisal Skills Programme CASP). CRF, on the other hand involves very simple procedures adaptable to conducting critical reviews of literature (Letts et al. 2007). The method was put forward by the "McMaster University Occupational Therapy Evidence-Based Practice Research Group", and it has undergone technical review by Letts and his team (Letts et al. 2007).

To carry out quality assessment, we selected 3 unique scales—2, 1, and 0 points, which was adapted from the original scale of 1, 0, and −1 points, and a "Not Applicable" (NA) option. The adapted quality assessment tool for this study was comprised of 4 themes derived from 18 unique item categories. The four themes include: article publication and background, method, measurement, and analysis (see Appendix A). Each of the articles was critically checked against the questions within the themes. The check was followed by a grading (see Appendix B). The goal of the quality assessment in this case was to drop any study with a low grade after being subjected to the rubrics. 8 of the selected articles had high quality (based on grade), 10 were medium-high quality, while 4 were of medium quality. Articles with medium quality were classified as such mainly because the articles provided: very little information in some key areas of the study, inadequate design adopted to study the roles, models and processes of transfer of technology among others. Since no article was of low quality after the quality assessment procedure, none was dropped for reasons associated with poor quality.

4. Results

University TT models refer to a group of inter-connected steps through which scholarly inventions are made to serve public needs. These models are made up of a series of processes within which actors such as university leaders, inventors (researchers), TTO managers, industry representatives, and government representatives all play unique roles. Table 3 shows the countries in which certain new models and/or process are being used, while Table 4 describes some current studies in TT model research. For each article, the study goals, shortcomings, model and processes, and results are explained. Technology transfer researchers are gradually shifting away from a conventional linear model towards TT as the entire commercialisation process grows increasingly complex. This shift is birthing newer models for looking into the newer challenges posed by the changing university TT climate (Bradley et al. 2013). Traditional TT practices are flawed on the grounds of their over-simplicity (Bradley et al. 2013), and they rarely factor in informal TT (Link et al. 2007). Newer models generally allow for ideas to be theorised and practically implemented only in a specific country (setting), especially given that "one method truly does not suit all regions" (Baglieri et al. 2018).

Table 3. Article identification.

Place	Reviewed Article	AIN
Azerbaijan, Belarus and Kazakhstan	Belitski et al. (2019)	I
UK	Horner et al. (2019)	II
Korea	Min et al. (2019)	III
Brazil	Fischer et al. (2019)	IV
New Zealand	O'Kane (2018)	V
Brazil	Dalmarco et al. (2018)	VI
Canada & U.S.	Tahmooresnejad and Beaudry (2019)	VII
Portugal	Rocha et al. (2017)	VIII
Latvia	Novickis et al. (2017)	IX
Thailand	Wonglimpiyarat (2016)	X
Taiwan	Hsu et al. (2015)	XI
Netherland, Belgium, Slovenia, UK	Kalar and Antoncic (2015)	XII
Latvia	Kalnins and Jarohnovich (2015)	XIII
21 European countries	Munari et al. (2016)	XIV
Italy	Frondizi et al. (2019)	XV
Not country-specific	Yun and Liu (2019)	XVI
Austria	Backs et al. (2019)	XVII
Portugal and 15 innovation-driven EU economies	Sá and de Pinho (2019)	XVIII
Not country-specific	Bozeman et al. (2015)	XIX
U.S.	Hayter (2016)	XX
Italy	Meoli and Vismara (2016)	XXI
U.S.	Leih and Teece (2016)	XXII

AIN = Article identification number.

In reviewing the articles for current models, processes and roles, the following groupings are recognised;

- Newly proposed models were mentioned in 9 articles (I, IX, XIII, XIV, XV, XVII, XVIII, XX, XXI)
- New processes following existing models were mentioned in 5 articles (II, III, IV, VI, XI)
- Existing models were mentioned in 3 articles (X, XVI, XIX)
- Improvements in role playing were mentioned in 5 articles (V, VI, VIII, XII, XX, XXI, XXII)

Our observations also show that all of the articles followed some form of pattern (*topic segment*) with respect to what seems to be the main focus of each of the studies (Figure 4). Topic segments were determined based on research outputs between 2015and 2019, which pointed to 786 records. The first 500 records were exported with a minimum of 7 keywords. Finally, 104 records were visualised. These form four thematic segments.

Table 4. Summary of selected studies.

AIN	Topic	Goal	Sample	Model/Process	Result	Shortcomings	Comment
I	Commercialising university research in transition economies: Technology transfer offices or direct industrial funding?	Understand the role-playing activities by TTOs and funding agents in university-based research commercialisation in emerging economies	20 universities; 272 Scientists	Multi-level	There is no relationship between TTO establishment, contract generation and university research commercialisation	There is a possibility for falsification of commercialisation income provided by interviewed researchers	Opinions of TTO executives were not sought, this may be termed incomplete, especially given that some of the Universities have TTOs
II	Strategic choice in universities: Managerial agency and effective technology Transfer	Examine the importance of the choices made by university leaders with respect to improving the TT process	115 Universities	Strategic management	Research incentives, although good, may not be the only factor needed to improve TT	Researchers' incentives as well as the choices by university leaders for TT improvement may not be as useful as combining these choices to supports from TTOs	Ideas may not completely generalise to other countries
III	Commercialisation of transferred public technologies	Explore the activities that aid smooth university/public research institute-industry TT	43 universities and public research institutes	Technology-readiness levels of collaborators, strength of competition in markets as well as absorptive capacity	Strength of competition within the market is crucial to the effectiveness of collaboration of technology-ready partners and absorptive capacity to achieve effective commercialisation	Due to specific complexities emanating from absorptive capacity issues and partnership in most industries, the technology transfer procedure is highly complex in Korea.	In highly technical situations, especially in the sciences, building adaptive capacities for transferable knowledge takes a lot of time
IV	Evolution of university–industry collaboration in Brazil from a technology upgrading perspective	Assess how universities has in developing countries are adapting to TT via patent and relationship with industry	807 patent applications from 12 Universities	Social Network Analysis (SNA); co-patenting	To better improve university–industry collaboration to drive country's value chain	A more extended data series may present a robust result	The case is country-specific and may not generalise effectively to other developing economies

Table 4. *Cont.*

AIN	Topic	Goal	Sample	Model/Process	Result	Shortcomings	Comment
V	Technology transfer executives' backwards integration: An examination of interactions between university technology transfer executives and principal investigators	Assessing the relationship between government-funded researchers and the managers of university TTOs	42 TTO manager and researchers	Qualitative methods (interviews)	The role of TTO managers is becoming more valuable to university researchers towards creating avenues for research funds than merely linking researchers to industry	TTOs in New Zealand universities are mostly in their grooming stages and not as developed as those in the United States or Europe	The ideas presented in this article may need further investigation especially in other countries with similar developing TTOs
VI	Creating entrepreneurial universities in an emerging economy: Evidence from Brazil	Identification of policies, programs and activities that will foster development of TT In Brazil	4 business incubator managers & 14 entrepreneurs	Qualitative content analysis	Start-ups in Brazil rarely depend on university technology for patents, rather, they make use of self-developed technology	There is little or no link at all between university and industry in Brazil	There is more to be done to completely infuse the knowledge adopted in the U.S. and Europe to achieve improved entrepreneurial universities in Brazil
VII	Collaboration or funding: lessons from a study of nanotechnology patenting in Canada and the United States	To observe the influence of funding obtained from government and partnership between researchers on academic output	Not specified	Network of co-inventors and co-authors	Canada and U.S. differ in terms of the influence of states funds on technology production output	Number of nanotechnology patents and publications have grown rapidly due to increase in funding into the research area	Comparison is only based on nanotechnology and may be flawed when applied to other industries
VIII	Payment types included on technology licensing agreements and earnings distribution among Portuguese universities	Provision of evidence to support the many types of compensation to technology transfer outputs in Portuguese universities	8 heads of TTOs across eight universities	Semi structured survey	Monies accrued from licensing are used to compensate researchers/inventors	Payment and revenues accrued are functions of how important an invention is	Compensation methods may not be accepted if technology is to be transferred from a foreign institution.

Table 4. *Cont.*

AIN	Topic	Goal	Sample	Model/Process	Result	Shortcomings	Comment
IX	Information Technology Transfer Model as a Bridge between Science and Business Sector	To be part of the solution of problems in Latvian innovation system by linking research organisations to industry and then market	Unspecified number of questionnaire participants of Riga University, Latvia	InnoSPICE model	Model helps to create a link between innovators and the market where the innovations are needed	Markets may differ from country to country. In a place like China where innovation market is large, InnoSPICE may not solve technology transfer challenges	Model may require further investigation on a wider scale.
X	The innovation incubator, university business incubator and technology transfer strategy: The case of Thailand	Assessing how university incubators influenced entrepreneurial development in Thailand	3 universities and several incubator centres	Triple helix model	The process of technology transfer from university to the industrial sector is not effective but can be improved using the model suggested	Triple helix model may be slow-paced especially when the government feels that the University is not doing enough in terms of output	Some countries still make use of the traditional linear knowledge flow to TT
XI	Toward successful commercialisation of university technology: Performance drivers of university technology transfer in Taiwan	Identifying factors crucial to the development of TT	Selected literature	Performance drivers (University's internal resources)	Human capital, institutional culture, financial and commercial resources are crucial for effective technology transfer	There is a possibility for variation in the relation among drivers, given a change in expert panel	The barriers to the process of university technology transfer are not linked to performance drivers.
XII	The entrepreneurial university, academic activities and technology and knowledge transfer in four European countries	To provide an insight into researchers' perception of entrepreneurial university	1266 respondents	ENTRE-U scale (Todorovic et al. 2011)	The university environment has an influence on the researchers input to TT activities	Responses gathered may not be exact as researchers who do not participate well in TT processes may have been indisposed	-

Table 4. *Cont.*

AIN	Topic	Goal	Sample	Model/Process	Result	Shortcomings	Comment
XIII	System Thinking Approach in Solving Problems of Technology Transfer Process	Study tries to systemise linkages of TT process in less developed country into proper system model scheme.	-	System Thinking Model	System thinking describes that there is not only formal technological transfer, but also informal TT	Model is based on the fact that the university currently has the mission of helping the industry generate innovation	Model considers operations only within the Latvian economy
XIV	Determinants of the university technology transfer policy-mix: a cross-national analysis of gap-funding instruments	This study examines a policy differences across Europe nations by evaluating whether or not policy instruments are centralised (or decentralised)	21 European countries; 125 TTO managers (For data verification 42 experts; 20 European countries); 117 gap-funding avenues	Gap-funding analysis	Gap-funding policy instruments vary across countries, and are functions of level of TT development in any given European country	It is important for future research directions to consider how TT is influenced by existing instruments.	Study is quite robust. Nevertheless, Selected countries are at different levels in terms of TT development, this in itself is a weakness of the analysis
XV	The Evaluation of Universities' Third Mission and Intellectual Capital: Theoretical Analysis and Application to Italy	To examine whether intellectual capital can be useful for evaluating universities' new role of knowledge creation	Unspecified number of officers of the Italian National Agency for the Evaluation of the University and Research Systems (ANVUR)	Intellectual capital model (ICMM)	Human, structural and relational capitals can be used to maximise TT process	The method needs further investigation in other countries in order to be sure of its potentials as discussed in the current study	Intellectual capital approach could make up part of a generalised and universally accepted TT model. However, literature is yet to go in this direction
XVI	Micro- and Macro-Dynamics of Open Innovation with a Quadruple-Helix Model	To develop a model for sustainable socio-economic and environmental aspects for the fourth industrial revolution	Review of 38 articles of a special issue	Quadruple-helix model	Model is only conceptual and its practicality in impeding the advancement of capitalism remains to be seen	-	As a concluding remark by the authors, there is need for further research on the concepts discussed within the paper

Table 4. *Cont.*

AIN	Topic	Goal	Sample	Model/Process	Result	Shortcomings	Comment
XVII	Stimulating academic patenting in a university ecosystem: an agent-based simulation approach	To analyse how the proposed agent-based approach can be useful for academic patenting	16 public (research) universities; 558 researchers (157 of this figure responded to questionnaire on type of invention incentive)	Agent-based model	The nature of incentive is a crucial factor when the TTO is planning researcher's reward	The agent-based approach introduced in this context is simulation-base, and may have more underlying weaknesses than strengths; monetary incentives have only considered paid bonuses	The approach is backed up by several state-of-the-art literature, making it a one of the most viable future techniques.
XVIII	Effect of entrepreneurial framework conditions on R&D transfer to new and growing firms: The case of European Union innovation-driven countries	To examine the workability of a model that brings together conditions of R&D in different countries, in order to verify how the model influences TT and aid spin offs.	683 experts across 15 selected European countries, under the auspices of National Expert Survey (NES) of Global Entrepreneurship Monitor (GEM)	Measurement model	Countries are able to reap the benefits of their TT investments through the creation of spin offs.	The study largely focuses on Portugal; since expert opinions have been sought, there is a chance for personal interpretation of specific terms, thus introducing some error margins	Further research on multi-country approaches to university–industry technology transfer could be the turning point to future development of TT processes
XIX	The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model	Carry out a review of state-of-the art TT literature in order to update and scale up the "Contingent Effectiveness Model" using a set of effectiveness criteria	15-year span of literature review	A revised form of "Contingent Effectiveness Model" (Bozeman 2000)	The study elaborates some effectiveness criteria for TT. For instance, out-of-the-door success is attributed to a TT agent, so long TT has taken place	Public value perspective to technology transfer will take some time to be fully appreciated	Some of these criteria might be developed in future into full TT models.
XX	Constraining entrepreneurial development: A knowledge-based view of social networks among academic entrepreneurs	To examine the importance of social networks to the initiation of university spin offs	79 academic entrepreneurs from 9 university in New York State	Knowledge Spillover Approach (Mixed methods; Social Networks Analysis & Interviews)	Academic entrepreneurship cannot grow if networking is isolated from its core processes	Studies based on networks analysis often require continued follow-up of spin offs in order to monitor their progress. As such, research may be flawed on this basis	The spill over approach needs to be validated in the context of spin off development. This is achievable through further research

Table 4. *Cont.*

AIN	Topic	Goal	Sample	Model/Process	Result	Shortcomings	Comment
XXI	University support and the creation of technology and non-technology academic spin-offs	To understand why academics choose to establish independent spin offs based on administrative inadequacies by university	559 spin-offs affiliated to 85 universities	-	University bureaucratic bottlenecks to TT often results in non-technology spin offs	Administrative issues and slow progress in the process of spinoff creation may as well bring about backdoor processes to TT in future	Too slow or highly bureaucratic university process may be unhealthy for university entrepreneurship systems
XXII	Campus leadership and the entrepreneurial University: a dynamic capabilities perspective	This study explores how university leadership can utilise dynamic capabilities to grow crucial university system areas	Interview with university leaders and researchers in Stanford and Berkeley universities	Dynamic capabilities	Associating strategic thinking and to universities' dynamic capabilities breeds development and influences universities' research onus.	Dynamic capability is not a TT model per say. Nonetheless, it is useful for understanding the role of university leadership in the process.	-

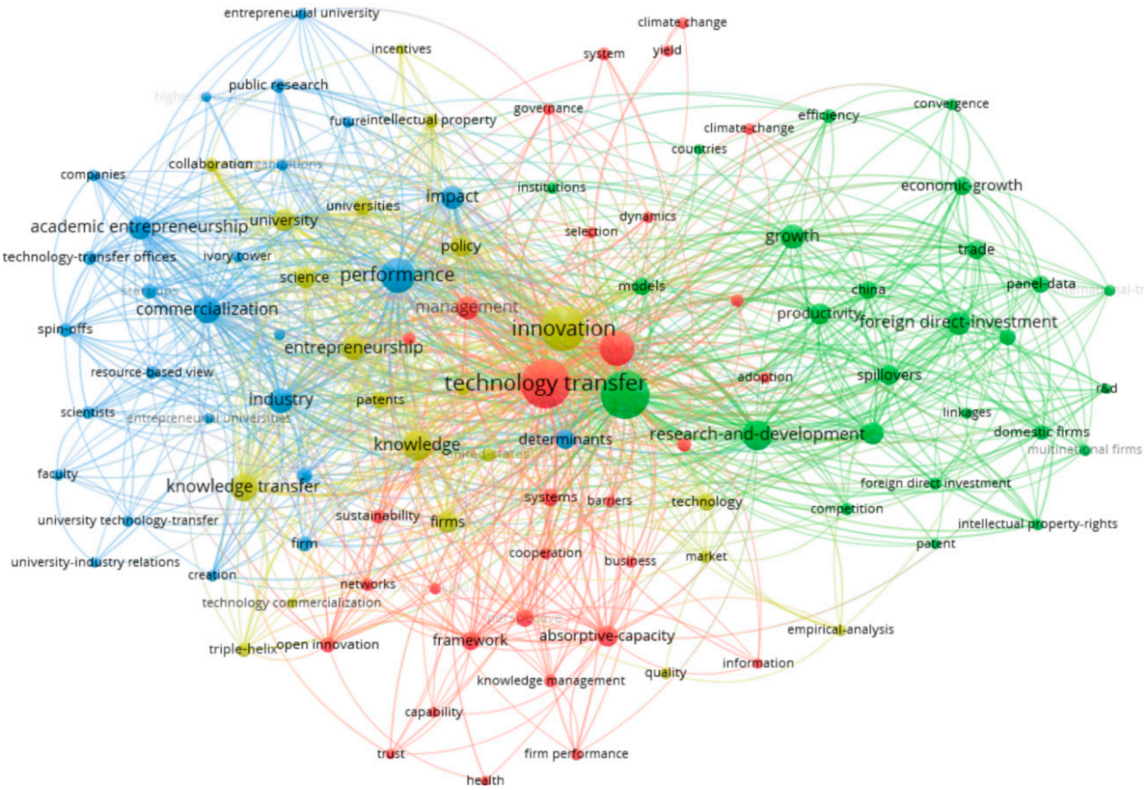

Figure 4. Topic areas in technology transfer models in 2015–2019 according to Web of Science.

For this, the following groupings were identified

- Internal strategy (all articles except IX, XV, XVII–XXII)
- Investment and the market (I, III, VI, VII, IX, XI, XIV, XVI, XVIII, XIX)
- Academic entrepreneurship (all articles except III XIX, XXI, XXII)
- Policy (intellectual property/patenting) (III to VII, XIV, XV, XVIII, XIX, XX)

There is a prevalence of new models in developing economies such as Azerbaijan, Belarus, Kazakhstan (Belitski et al. 2019), and Latvia (Kalnins and Jarohnovich 2015; Novickis et al. 2017). Several new models can also be seen in Austria (Backs et al. 2019), U.S. (Hayter 2016) and in other parts of Europe (Frondizi et al. 2019; Sá and de Pinho 2019; Munari et al. 2016).

Studies in countries where TT is more advanced mainly focus on new processes for smoothening existing models (Horner et al. 2019; Tahmooresnejad and Beaudry 2019), while improvements in role playing seems a common activity, covering studies from Oceania, Europe and South America (Dalmarco et al. 2018; Rocha et al. 2017; Kalar and Antoncic 2015; O'Kane 2018; Leih and Teece 2016). All 23 articles pointed to either a new model, an existing one, a process or technique that will improve role playing activities in university–industry TT.

In terms of topic segment, academic entrepreneurship remains a dominant topic in many of the reviewed articles, closely followed by discussions aimed at improving country-specific or regional strategies of improving the process. Studies that have discussed investment in University research and spin-off funding continue to grow in number, while patenting and policy discussions remain relegated. A positive observation is the fact that studies are complementary, with ideas being replicated across literature fronts.

4.1. References to an Existing Model

While very few reviewed articles point to existing models of triple helix (Wonglimpiyarat 2016), quadruple helix (Yun and Liu 2019) and contingent effectiveness (Bozeman et al. 2015), the triple helix model is indirectly referenced in almost all articles with emphasis on university, government and industry relationship. Furthermore, studies I, IX and XIII, XIV, XV, XVII, XVIII and XX, which propose new models such as multi-level, innoSPICE, system thinking, gap funding, intellectual capital, agent-based, measurement and knowledge spillover, are steps forward in the already-existing triple helix model, quadruple helix, and contingent effectiveness. This follows the idea that research commercialisation systems differ from one country to another (Clarysse et al. 2005; Mustar et al. 2008; Wong et al. 2011; Singh et al. 2015). Novickis et al. (2017), Kalnins and Jarohnovich (2015), as well as Frondizi et al. (2019), came up with the ideas for their respective models as a way of providing country-specific solutions.

The traditional linear model of technology transfer looks very simple to understand and implement. This is, however, deceptive, especially given several complex processes involved nowadays with the commercialisation of technologies. The triple helix model, which brings together university, industry and government, is nevertheless a step forward. Etzkowitz (2003) described two forms of TT process: endogenous and exogenous. Endogenous procedures takes the shape of university entrepreneurship, where the university carries out the entire development, from invention to patenting and licensing, while exogenous processes involve external actors like the government. Nowadays, the literature is developing towards newer models for TT commercialisation. Baglieri et al. (2018) noted a business model approach in which transfer of technology could progress in four unique ways: the catalyst form, where innovation is mainly used as a source of income generation through TTOs; the smart bazaar form, where inventions are mainly used as gifts to humanity to solve problems, and in which little or no income is generated; the traditional shop form, where the university produces innovation mainly for patenting; the local buzzers, where innovation is mainly for the pursuit of a so-called "third mission". As explained by Cesaroni and Piccaluga (2015), university–industry TT business models are crucial for providing a system to be followed by the processes, and for better understanding the roles assumed by university for regional and societal development. In addition, Miller et al. (2014) noted that the extent of negotiation between TT actors may be time consuming, hence the development of a business model. In the work of Schrankler (2018), a "cradle-to-grave model" in which an individual starts and completes the entire commercialisation procedure to market level was described. This process is applicable to very small universities in which TT processes are relatively weak, so that a so-called licensing manager assumes the role of all "should-be" actors in the process. While some authors favour the triple helix model, others are of the opinion that all scientific activities within the confines of university–industry collaboration that are managed and funded by government (in most cases) end up being useful for societal development. Hence, the development of the quadruple-helix model (Galvão et al. 2017; McAdam et al. 2018). In specific terms, it is important to stress how models have developed so far from the linear to the triple helix, and then the quadruple helix. Nevertheless, there are other complex models, such as the *contingent effectiveness* model (Bozeman 2000), which introduces the relationships between some dimensions of TT. It is noteworthy to state that the overall expression within the current study is closely related to the contingent effectiveness model; nevertheless, a distinguishing factor is the way we have curled out the "topic segment" to relate the models, with both effecting the positivity in the university–industry TT process.

4.2. References to a New Model

As discussed earlier, eight new university–industry technology transfer models were discovered from the articles reviewed in the current study: the innoSPICE model (Novickis et al. 2017), the multi-level approach (Belitski et al. 2019), the system thinking approach (Kalnins and Jarohnovich 2015), gap funding (Munari et al. 2016), intellectual capital (Frondizi et al. 2019), the agent-based approach (Backs et al. 2019), the measurement model (Sá and de Pinho 2019), and knowledge spillover (Hayter 2016). The new models are mostly the results of a desire for effective technology transfer results. For instance, studies by Kalnins and Jarohnovich (2015), as well as by Novickis et al. (2017), have both stressed that TT process in Latvia needs to be improved, given that industries have lost faith in the universities, and do not expect any research results with impacts from them. Furthermore, research results when produced rarely reach the markets, leaving entrepreneurs to look for alternatives rather than waiting on the universities.

New models for technology transfer continue to spring up frequently, given the perception that no single model can effectively cater for every society's needs, hence the saying "one size does not fit all" (Baglieri et al. 2018). A highly comprehensive modern approach was presented by Bradley et al. (2013). One key input of the model was the inclusion of informal technology transfer (Link et al. 2007) within the overall TT framework. With this development, Bradley et al. (2013) described a situation in which a researcher may decide not to make an invention known to the university TTO if he/she perceives there to be excessive barriers to the process. In this case, the researcher may link up with an industry contact to commercialise the invention, thereby bypassing the TTO. This is, however, not a completely new observation It is noteworthy to explain that there are possibilities for even more new models in the future like those proposed by Novickis et al. (2017) and Kalnins and Jarohnovich (2015). This is so because some economies, like those of the U.S., UK, Australia and Canada, may have attained maturity in their university TT processes, and since these countries are within the network of developed countries, applying their TT systems may be problematic for emerging economies, especially given the level of funding enjoyed by faculty in those countries.

4.3. References to Processes for Improving Existing Models

Strategic management was one of the most common TT process-enhancers found by De Moortel and Crispeels (2018) to show up within the reviewed articles. Strategic choices (Horner et al. 2019), absorptive capacities (Hsu et al. 2015) and dynamic capabilities (Leih and Teece 2016), all of which are subsets of strategic management and have been used in analysis within the articles, confirming that effective strategic management tends to contribute to university–industry collaboration, if rightly implemented. Performance drivers (Hsu et al. 2015) (such as quality of faculty and level of available funding) were also used within the reviewed articles. The strength of the market into which technology is to be transferred could also be a very important process-enhancing pathway. After licenses, another issue is the market penetration sought by a new technology. Technological innovations will thrive more within competitive markets in which technology subscribers are open to new products.

Given the prevailing technological development in many spheres of life, of the performance of existing university–industry collaboration models, most of which are aimed at attaining a balanced system, continues to be evaluated. Beyond the walls of the university, technology transfer from research institutes and other laboratories with government funding continues to take on new dimensions of improvement as time goes by. As noted by Choudhry and Ponzio (2019), technology metrics that have existed since the enactment of the Bayh–Dole Act are no longer effective, nowadays. Most of these foundations require inputs that upgrade them and prepare them to meet the current technological needs of society. The author concluded that major actors must begin to look at ongoing research by funded units (such as laboratories within the U.S. Navy) to improve the system. Waroonkun and Stewart (2008) disclosed that merely adopting TT does not turn out to be an instant success, emphasising that certain underlying processes must be worked upon for TT success to be achieved. Among these TT process-boosters, Waroonkun and Stewart (2008) described: enhancement of the features of technology 'transferor' and 'transferee' to make the process work, positive governmental impacts, and effective relationship building. Leydesdorff and Porto-Gomez (2019) stressed the need for effective networking of organisations across technological and geographical domains. This result came after observing that decentralised innovation systems were dominant in Spain's technological environment and were largely concentrated in big cities (Leydesdorff and Porto-Gomez 2019).

4.4. Mixed Methods for Analyzing Role Playing in Technology Transfer

Quantitative and qualitative methods have been used widely in the technology transfer literature to analyse the roles and impacts of the roles played by the different actors in the process. Statistical techniques have also been adopted to check the significance of several variables on the entire university–industry collaborative processes. Noh and Lee (2019) carried out a comprehensive quantitative assessment of literature within a 40-year period, analysing the strengths and weaknesses of each published work within the large body of extant literature. Content analysis has also played a part in helping to understand the role playing by researchers in the context of the of technology transfer topic (Belitski et al. 2019). Kalar and Antoncic (2015) also used the ENTRE-U scale proposed by (Todorovic et al. 2011), which was used to gather information from heads of department, seeking to know their opinions and roles within the university–industry technology transfer process. Other role playing pointers within the surveyed articles include co-authorship and co-invention (Tahmooresnejad and Beaudry 2019), and interaction survey of universities and business communities (Horner et al. 2019).

4.5. Topic Segment

In the course of this systematic review, we have identified and classified the authors' area of focus on the basis of the different dimensions of the university–industry TT literature. We earlier argued that models should be linked to key TT aspects (internal strategy, investment and market, academic entrepreneurship, and policies guiding intellectual property ownership and usage) for effective university–industry TT processes. By internal strategies, we refer to ideas and methods within the reviewed articles that are geared towards further building technology transfer. The investiment and market literature is that in which issues relating to funding and researchers' reward for scientific outputs are discussed. Academic entrepreneurship and patenting topics are integral parts of university industry technology transfer. As shown in Table 5, policies that govern ownership and usage of intellectual properties are the least discussed topic segment within the reviewed articles, while academic entrepreneurship is the most discussed. The turn taken by the results is not surprising, given that academic entrepreneurship is one of the major reasons for the establishment of the university–industry technology transfer scheme.

Table 5. Data synthesis.

AIN	Type of Model					Topic Segment			
	Reference to an Existing Model	Reference to a New Model	Reference to a Process for Improving an Existing Model	Quantitative Method to Describe/ Analyse Role Playing Activities	Qualitative Techniques Describing/ Analyzing Role Playing Activities	Internal Strategy	Investment and Market	Academic Entrepreneurship	Policy (Intellectual Property/Patenting)
I	√	√	√	√		√	√	√	
II	√		√			√		√	
III	√		√	√	√	√	√		√
IV	√		√	√		√		√	√
V	√		√		√	√		√	√
VI	√		√		√	√	√	√	√
VII	√		√	√		√	√	√	√
VIII	√		√		√	√		√	
IX	√	√	√	√			√	√	
X	√		√		√	√		√	
XI	√		√	√		√	√	√	
XII	√		√	√		√		√	
XIII	√	√	√			√		√	
XIV		√				√	√	√	√
XV		√			√			√	√
XVI	√				√	√	√	√	
XVII		√						√	√
XVIII		√					√	√	
XIX	√		√				√		√
XX		√		√	√			√	√
XXI		√		√		√		√	
XXII			√		√	√		√	

5. Discussion

In this paper, we tried to group models, processes and roles in the existing literature through a systematic review of the process. First, we observed that some country-specific models had been developed in order to replace older ones, and to further help increase the success rate of university–industry technology transfer in some countries, i.e., areas in which the traditional linear model, as well some existing models (e.g., the triple helix model), had not been completely effective. We stressed that new models are developed in emerging economies to suit existing situations, such as there being very little funding and a lack of trust in the university system. Although it is yet to be confirmed in the literature that any country has fully adopted the use of any of the newly proposed models, it is important to note that researchers have only developed models after careful observation that the use of existing models do not seem to yield the desired results.

The multi-level knowledge commercialisation approach, as explained by Belitski et al. (2019), is similar in scope to the triple helix model. Although Belitski et al. (2019) explained that the external ecosystem (referring to the government and industry) may be a second link if researchers choose not to go through the university for the patenting and commercialisation process. The innoSPICE model is based on the ideas of how new software technology thrives in the market. Using this idea, Novickis et al. (2017) developed the idea for use in other industries. Nevertheless, the model may be useful, especially in emerging economies in which a lot of tech applications are being developed on a daily basis. According to Kalnins and Jarohnovich (2015), the system thinking model brings together several aspects of probable TT systems, including aspects such as decision making and government funding, among others. The model factors in delay periods between TT stakeholders, which sometimes bring about a lack of motivation on the part of government to continue to provide funding. For instance, if the university does not provide any innovation over a long period of time, the government may decide to withhold funding for a time. This multilevel approach has been confirmed by successful commercialisation at Oxford University. The unique project BioEscalator, involving a consortium of stakeholders, catalyses the translation and commercialisation of the university's fundamental and clinical research for the benefit of patients and society. The BioEscalator, by bringing university and hospital scientists, drug development companies, funding organisations, investment communities, patient groups and entrepreneurs together in a new building, will accelerate the creation of many new companies. The public space within the BioEscalator will encourage interactions and networking opportunities for emerging businesses, established enterprises, researchers, entrepreneurs, and investors that will foster entrepreneurship and commercial developments and help business ideas in this sector to emerge, start-up, grow and move onto larger science parks in the region. £11m of Government money was recently awarded for the Oxford BioEscalator, to be matched by £10m of University funding (towards a total proposed cost of £21m). Through ISIS were developed spin-off companies like Syncona partners' development of NightStaRx for the commercial development of a novel gene therapy treatment for choroideremia. Another spin-off company was created for the treatment of Duchenne Muscular Dystrophy.

Furthermore, we found that some literature mainly described TT process-enhancers, capable of improving the success of university–industry TT. These process-enhancers are crucial, but are not among the basic requirements for effecting TT. Among the TT process-enhancers can be found elements of strategic management and university performance drivers, to mention a few. Strategic management pointers, such as absorptive capacity, dynamic capabilities, and strategic choices, as well as performance drivers, are important parts of the foundation of TT within the reviewed articles. Within the realm of strategic management processes, university managers' abilities to make informed choices on technology transfer in response to dynamic organisational configurations were found to have an influence on TT (Horner et al. 2019). This influence is, however, a function of how well the university makes strategic plans. When a university effectively plans the process with which TT should flow, they are strategically positioned to benefit more from TT (Horner et al. 2019). Hsu et al. (2015) explained university–industry TT using the resource-based view developed by Wernerfelt (1984). The author noted that drivers such as the existing culture in the university and partner organisation, the financial-base of the partner organisation, the university's human capital, and its ability to provide marketable inventions (commercial resource) are some of the most important internal factors that can enhance TT (Siegel et al. 2007). Additionally, absorptive capacity by a "technology receiver" is important in the sense that, regardless of how good an invention is, if there is no market available for the invention, the revenue for the invention will be low, and little or nothing will go to the inventor. Therefore, there is a need for competitive markets that tends to absorb inventions, making them instant market hits. As such, Min et al. (2019) noted that there has to be some form of strategic management of the firm licensing an invention, and that this is important for the TT process. Another important aspect that could better enhance TT process as seen in the reviewed articles is for the university to adopt an entrepreneurial mindset and be ready to influence spin-offs. Dalmarco et al. (2018) explained that continuous innovations from universities will bring about economic development, as newer start-ups are simultaneously created and given the license to use and market such innovation.

In terms of the roles played by different actors making up part of the grouping in this systematic review, Dalmarco et al. (2018) explained that universities have the role of ensuring that start-ups are created. This is often the result of research outputs. This can be confirmed by one example of a very successful technology transfer into practice, such as the history of Google. Google began in 1998 as a research project by Larry Page and Sergey Brin, both PhD students at Stanford University. As their dissertation theme, they considered, among other things, exploring the mathematical properties of the World Wide Web, understanding its link structure as a huge graph. Page's web crawler began exploring the web in March 1996, with Page's own Stanford home page serving as the only starting point. To convert the backlink data that it gathered for a given web page into a measure of importance, Brin and Page developed the PageRank algorithm. The Google company was officially launched in 1998 by Larry Page and Sergey Brin to market Google Search, which has become the most used web-based search engine.

The greater the number of start-ups created, the better the economy of the nation. For technology innovations to reach the hands of entrepreneurs, university transfer offices (TTOs) play roles through their executives (O'Kane 2018). These executives ensure that agencies ready to fund research are linked with researchers. The findings from the reviewed articles grouped herein show that TTO executives need to gain the trust of researchers in terms of funding provisions from government and other funding bodies. Rocha et al. (2017) also discussed how TT systems rewardd researchers (inventors) monetarily for their outputs. In terms of revenues accrued from signed agreements for licensing a patent, running royalties are paid as long as the invented item is in use. The cost of patent re-imbursement, as well as payments for milestones, are also in use in Portugal, for instance (Rocha et al. 2017). In many cases, inventors rely solely on the activities of their TTOs for inventions to access markets. This makes university TTO executives very important agents of the TT process. Other than cases in which the inventor chooses informal technology transfer routes, TTOs are also able to negotiate what goes to the university as a whole and what goes to the researcher in particular. The general impression as to whether TTOs act as bottlenecks to the technology transfer process is yet to receive major attention in the literature.

Several scientific studies have tried to explore the most effective methods for commercialising scientific knowledge. Most of these studies have focused excessively on collaboration between industry and universities, and on academic entrepreneurship (Fini et al. 2018) through the building of models. While most part of this paper has been focused on the description of models and linking the models to some aspects as university–industry TT, it is also relevant to make reference to the field of management (as in the case of Fini et al. (2018)), where the foundation and usefulness of this study lies. So far, we have been able to characterise the importance of this study with respect to conceptual development in university–industry TT by systematically reviewing the commercialisation of scientific ideas.

Until now, academic collaboration has been completely based on theories (Wright and Phan 2018). Nevertheless, there is the possibility for future authors to start to link theoretical writings to the aspects of TT as discussed in this paper (Fini et al. 2018). Given the many papers reviewed in this study, it is very important to begin to seek answers as to how commercialisation of knowledge can be used to test models within the field of management. This will, however, be effective if such models are linked to the key aspects of management, similar to what is shown in Figure 5 for university–industry TT. Figure 5 is a schematic diagram for the findings within this study. In the middle, where technology transfer stands, the activities shown in Figure 2 are included, i.e., invention disclosure, assessment, protection, marketing, licensing and financial return. The figure shows in which context and with which subject these processes should be solved. These tasks are also related to the choice of a given model, according to which the processes will be set up. This model is again presented in general, because it can be created by self-illumination of the university in the context of current support of government and national strategies. Generally, Figure 4 explains the most important ways of achieving success in university–industry technology transfer by opining that future models must have strong foundations in process.

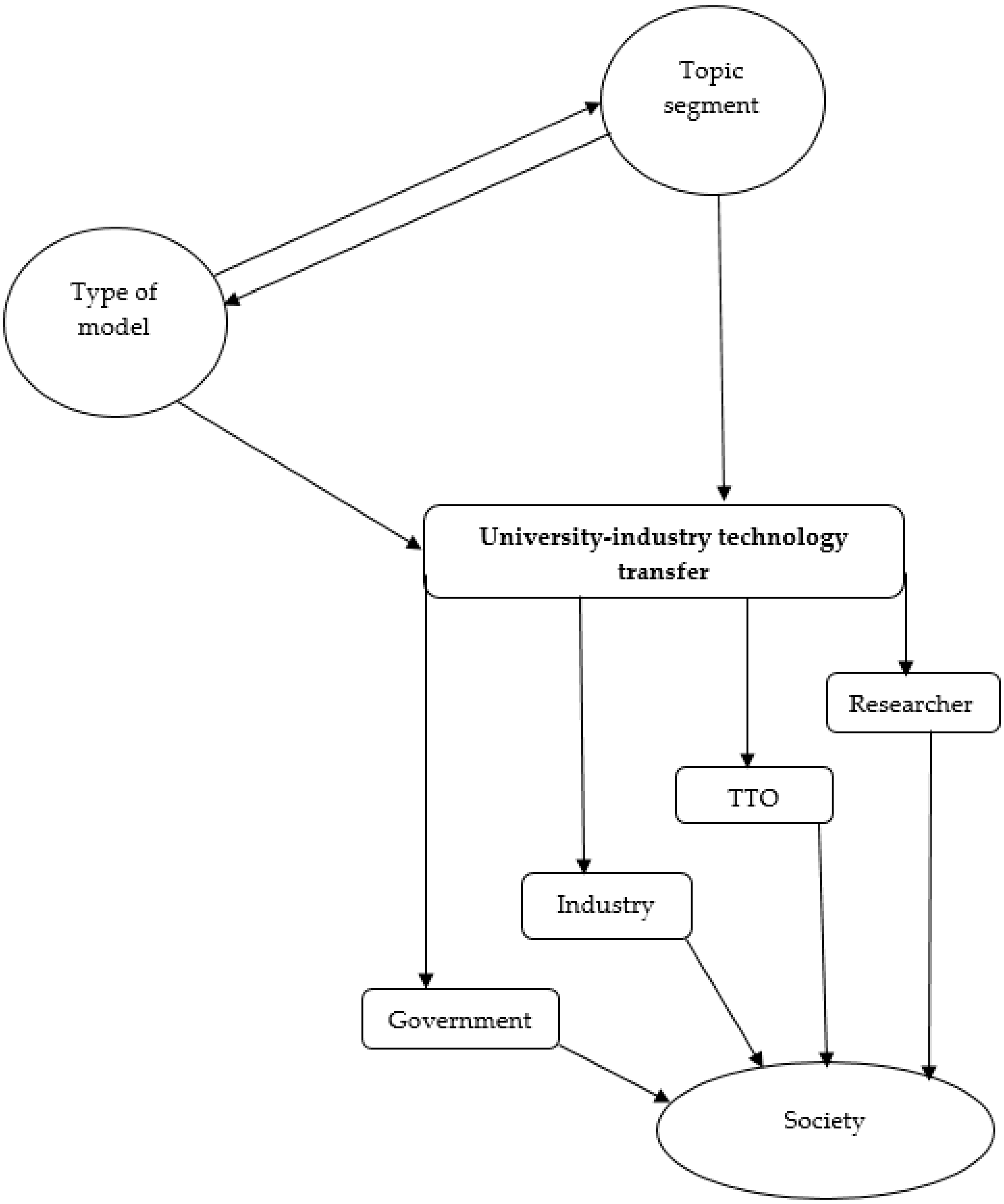

Figure 5. Schematic representation of how models should drive effectiveness of TT.

The efforts of researchers must go beyond monetary gains and link to the society, which derives the ultimate benefits from the results of scientific findings; TTOs must also ensure that researchers are supported to reach their full potentials in terms of provision of enabling environment, as well as the expected levels of motivation. On the part of industry and government, the bigger picture of societal and regional economic growth should be the objectives in the midst of the overall challenges.

As opined by Fini et al. (2018), it is of no use seeking more management models to further develop the process of TT. Rather, it is time to seek knowledge commercialisation models (linked with aspects of TT) that would resolve challenges posed by management processes. This would be an interesting research pathway within the management domain (Fini et al. 2018).

6. Conclusions

This systematic literature review shows that quite a number of studies exist explaining models, processes and roles by actor in TT. The reviewed articles also showed how models evolve in emerging economies, given the challenging environment, as well as the many processes available to boost the effectiveness of new and existing TT transfer models. This study adds to research on university–industry technology transfer in the following ways: first, it presents researchers and inventors with an overview of the entirety of TT procedure around the world, which may be useful for future transactions on patenting and licensing. Secondly, the expository nature of the research presents policy-makers in emerging economies with a wide variety of choices to select from and adopt in their country, bearing in mind the challenges posed by each model. In addition, this systematic review could also find practical application by managers of TTOs hoping to enter into contractual agreements with industry partners on behalf of researchers/inventors. It presents the roles played by different actors within the process, thereby stating the important and limitations of each. For instance, the literature stressed the roles of the TTO manager in ensuring that the best industry partner is recruited for a new technology, so that the inventor is able to earn better royalties in the long run. Furthermore, it also explains some reasons why inventors may decide to take solo steps of reaching out to industry as an individual, thus bypassing the TTOs.

With special reference to emerging economies, this literature review affirms that a growing interest in state-of-the-art models exists. This is because there are several challenges that do not favour effective TT procedures in many developing nations. Articles describing processes and steps to be taken to improve TT were also discovered. From the absorption capacity of markets to performance indicators, strategic management tools were found to be highly relevant if TT is to succeed in many areas. Thus, it was observed that TT as a process will continue to evolve, given organisational and market dynamics.

This paper is not without its limitations. There was no basis for the selection of databases from which the articles were retrieved. Since there is no rating for the available databases, there is the possibility that some databases may be better equipped than others in terms of available research items. As such, there is no guarantee that the articles selected for this study are the best-suited for a review of this nature. In terms of future work, given the many emphasis found in literature on the subject of informal transfer of technology, as well as TTOs possibly standing as bottlenecks (Meoli and Vismara 2016) to the TT process in some cases, it may be necessary for future researches to look into these study areas. Additionally, further studies can investigate the roles strategic management can play in the process of university–industry technology transfer. Furthermore, there is also a need for new investigations into some newly proposed technology transfer models as proposed by Novickis et al. (2017), Kalnins and Jarohnovich (2015), and many others. Finally, it is noteworthy to state that there is yet to be a model (at least not in the body of literature for now) that can be described as ideal for carrying out knowledge transfer. This is mainly because most existing models are either country-specific or specific to a given economic situation, often depending on the existing laws of the nation in which the research is carried out.

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Appendix A. Quality Assessment Tool (Combination of C.A.S.P and C.R.F)

Assessment tools for article quality rating
Publication and background
1. Peer review. Was the article published in a peer-reviewed journal? [1] Yes [0] No 2. Aim and research question(s). Did the study clearly state the aim and research question(s)? [2] Both the aim and research question(s) are clearly stated. [1] The aim is clearly stated but research question(s) are absent. [0] Both the aim or research question(s) were not stated.
Method
3. Information about university–industry technology transfer. Does the article cover sufficient and useful information on university–industry technology transfer? If yes, was the university–industry technology model stated clearly? Was it enough information to understand? The university–industry technology transfer? [2] The information about university–industry technology transfer was sufficient and clear. [1] The study covers some information on university–industry technology transfer but these were not sufficient enough. [0] The study did not include any information on university–industry technology transfer. 4. Did the article specifically mention a university–industry technology transfer approach? [1] Yes [0] No 5. Study design. Was the article based on quasi experimental design? Or was it randomised controlled trial (RCT) [2] The study was a quasi-experimental design. [1] The study was RCT. [0] There was no information given about study design. 6. Control group. Was the study based on a control group? [1] Yes [0] No 7. Follow-up. Was there a follow-up after the experimentation to see if there had been any changes since the initial study on university–industry technology transfer took place? [1] Yes [0] No 8. Population. Does the population for study selection cover the whole population of interest? Or, is the eligible population just a selected subgroup of the population of interest? [2] Eligible population covers the whole population of interest or a major part of it. [1] Population represents only a selected subgroup of the population of interest. [0] There are no details with respect to study population 9. Randomised selection of participants. Were participants selected randomly? Or, were participants volunteers who were not selected? Or, were they gotten via specified organisations or through individuals who have ties with the researcher? [2] Random selection. [1] Non-random selection. [0] There are no description as regards sample selection procedure. 10. Sample size. How many participants were selected for the study? Does the selected sample cover sufficient number of participants from major subgroups to accurately analyse subgroup differences? (when compared to other articles) [2] Sample size is greater than those in similar articles. [1] Sample size is the same as those in similar articles. [0] Sample size is less than those in similar articles or sample size details is not given 11. Response and attrition rate. What percentage of the selected sample did follow the study until completion? [2] High response rate (>60% response rate, >85% participated in follow-up studies). [1] Moderate to low response rate (response rates of less than 60%). [0] There are no information on the rate of response or participation.

Assessment tools for article quality rating
Publication and background
Measurement
12. Crucial concepts. Are each of crucial terms of interest fully explained? Can these terms be matched to the variables in the tables? [2] Accurately explained and can be matched. [1] Vague description or cannot be matched. [0] There are no definitions at all as regards the crucial concepts. 13. Operationalisation of concepts. Did the authors select terms that truly measure the concepts in the articles? Do these terms appear in previous studies or are they an improvement of the terms in previous articles? [2] Important concepts are measured with terms that truly measure concepts. Or, terms have either been previously used in similar studies or are improvements of previous measures. [1] Important concepts are measured with terms that do not exactly measure concepts, and terms have not been used in previous research studies. [0] There are no information on the operationalisation of variables
Analysis
14. Numeric tables. Are the descriptive statistics and error margins presented for all the numeric variables? [2] Descriptive statistics and error margins are presented. [1] Only means, but no standard deviations/error margins are presented. [0] Descriptive statistics and error margins are not presented. 15. Missing data. Is the number of cases with missing data given in details? Is the statistical procedure(s) for handling missing data explained? [2] Details on the number of cases with missing data are given and the strategy for handling missing data is explained. [1] Details on the number of cases with missing data are given, but these cases are not used in data analysis. [0] There are no information related to missing data issues. 16. Appropriateness of statistical techniques. Does the study describe the statistical technique utilised? Does the study describe the reason behind the selection of the statistical technique? Does the article cover caveats on conclusions based on statistical technique? [2] Statistical techniques, reasons behind technique choice and caveats are given in detail [1] Statistical technique is described, but reasons for choice of selection are not given [0] Statistical technique, reasons for choosing and caveats are not explained. 17. Bias based on variable omission. Could results of the study be a function of alternative explanations not addressed in the article? [2] All important explanations are factored into the analysis. [1] Important explanations are isolated from the analysis. [0] Variables and concepts factored into the analysis are not explained in detail to show that important alternative descriptions have been omitted. 18. Has the analysis of main effect variables been carried out. Are coefficients for the main effect variables in the statistical models shown? Are the standard errors of these coefficients shown? Are significance levels or the results of statistical tests shown? [2] Model coefficients and standard errors or hypothesis tests for the main effects variables are presented. [1] Either model coefficients or hypothesis tests for the main effects variables are presented. [0] Neither estimated coefficients or standard errors for the main effects variables are presented.
Note. Adapted from the Quantitative Research Assessment Tool (CCEERC 2013)

Appendix B. Article Scores

	Reviewed Study (AIN)																					
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**	**XV**	**XVI**	**XVII**	**XVIII**	**XIX**	**XX**	**XXI**	**XXII**
	Assessment of quality																					
High (25 to 32 points)	X	X	X									X		X				X		X	X	
Medium High (17 to 24 points)				X	X	X	X	X	X	X	X						X					X
Medium (9 to 16 points)													X		X	X			X			
Low (0 to 8 points)																						
Reasons																						
Article publication and background																						
1. Peer reviewed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2. Aim and research question	1	1	1	1	1	1	2	1	1	1	1	2	1	2	1	1	1	1	1	2	1	1
Method																						
3. Information on university–industry TT	2	2	2	2	2	2	2	2	2	2	2	22	2	2	2	2	2	2	2	2	2	2
4. Dimensions of university–industry TT	2	2	1	2	1	1	1	1	1	1	2	2	1	1	1	1	2	1	2	1	1	1
5. Study design	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2
6. Control group	1	1	1	1	2	1	1	1	1	1	0	2	0	1	1	0	1	1	0	1	1	1
7. Follow-up study	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
8. Population	2	2	1	1	1	2	1	1	1	2	0	1	0	0	1	0	1	2	0	1	2	2
9. Randomised selection of participants	2	1	0	1	2	1	1	1	1	1	0	2	1	2	1	0	2	1	0	1	1	1
10. Sample size	2	2	2	0	0	2	0	0	0	0	0	2	0	1	0	0	1	2	0	2	2	1
11. Response rate	1	0	2	0	2	0	0	0	2	0	0	0	0	2	0	0	2	2	0	0	2	2

	Reviewed Study (AIN)																					
Measurement																						
12. Explanation of concepts	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
13. Operationalisation of concepts	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2
Analysis																						
14. Numeric tables	2	2	2	2	0	0	2	2	0	0	2	2	0	2	0	0	0	2	0	2	2	0
15. Missing data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16. Appropriateness of statistical techniques	2	2	2	2	0	1	2	2	1	2	2	2	2	2	0	2	2	2	2	2	2	2
17. Omitted variable bias	2	2	2	2	2	2	1	2	2	2	2	2	0	2	2	2	0	2	2	2	2	0
18. Analysis of main effect variables	2	2	2	2	0	0	2	2	2	0	2	2	0	2	0	0	0	0	0	2	2	0
Total points	28	26	25	23	20	20	23	20	21	19	20	28	12	26	16	15	23	25	14	25	27	20

Note. AIN = Article Identification Number.

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