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The evolution of university technology transfer research: a text mining approach

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Abstract
Over the last few decades, a substantive body of research has been created that focuses on university technology transfer (UTT), resulting in a rich and complex literature. The purpose of this paper, using a text mining approach, is to identify underlying key topics that have shaped this field of research and to determine key emerging themes. Using computational linguistic techniques, we systematically examine 1,944 papers published between 1981 and 2022. Based on the identification of 20 distinct topics, we analyze the popularity of these topics over time. Our findings reveal that UTT capacities are widely discussed, especially themes related to processes, enablers, and the third mission. Moreover, topics such as spin-offs and metrics are gaining ground in the UTT literature. However, topics related to the UTT context, including the role of institutions and transfer units, are losing research momentum, as do themes around legislation and commercialization. Our paper defines thematic clusters, posits a framework to consolidate UTT research, and suggests promising future avenues of research.

Keywords Technology transfer · Entrepreneurial university · Third mission · Commercialization · Academic entrepreneurship · Text mining

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1 Introduction

The commercialization of newly created knowledge originating from universities and research institutions has attracted increasing attention within the scientific community but also beyond (Cunningham et al., 2017). Since the 1980s, university technology transfer (UTT) has expanded fast as an original research field. UTT thereby persists as a key topic of relevance for scientists, industry professionals, and public administrators (Noh & Lee, 2019). With the passage of the Bayh–Dole Act in the United States in 1980, universities and research institutions expanded their focus in addition to teaching and research to include transfer activities as the third mission of universities (Link & van Hasselt, 2019). Various transfer activities, including strategic licensing and university patenting, have been implemented by universities to promote the exploitation of their research results and to secure (public) funding. This has also been driven by the need to increase the visibility and impact of their research (Gulbrandsen & Slipersæter, 2007).

As UTT becomes more widely recognized as being a part of a knowledge ecosystem, there has been a steady increase in the number of studies addressing this topic (Audretsch et al., 2024; Bozeman et al., 2015; Landström, 2020). Besides the promise of this research field, it has become very fragmented and diverse and has been studied in different areas at the macro-, meso-, and microlevels (Cunningham & O'Reilly, 2018; O'Kane et al., 2021). As a result, the literature on UTT has become complex. Several studies have been carried out to identify research trends and patterns in UTT (see Abdul Wahab et al., 2012; Audretsch et al., 2014; Belitski & Sikorski, 2024; Bozeman, 2000; Cunningham et al., 2017). According to Noh and Lee (2019), these approaches have two inherent limitations. First, there is no consensus on past research streams in UTT. Second, further research topics are still to be discovered for the future. Given the increasing importance of UTT research, it is important to overcome these limitations in order to seize valuable research opportunities in this field.

Against this background and in contrast to recent bibliometric studies focusing on UTT (see Borges et al., 2022; Craiut et al., 2022; Olvera et al., 2021), we employ a text mining approach in our study. In using text mining, our focus is not on keywords or co-authorship and co-citation networks, but on the knowledge content of the articles, which we investigated by analyzing the titles and abstracts (Arroyabe et al., 2022). Specifically, our paper aims to address the following two research questions: What thematic patterns can be identified in the UTT literature? Which areas in the UTT literature are gaining attention and offer significant potential for further research?

By applying topic modeling, i.e., a text mining approach, we are able to uncover the semantic structure of the diverse research streams and provide a detailed overview of the literature by extracting different topics and their evolution by analyzing citations over time (Blei, 2012). Topic modeling has been used to review topics and identify salient themes, for example in the field of entrepreneurship (Arroyabe et al., 2022), economics (Ambrosino et al., 2018), innovation management (Lee & Kang, 2018), or finance (Soltani et al., 2023). In addition, other disciplines have chosen this approach, such as healthcare (Ali & Kannan, 2022), medicine (Porturas & Taylor, 2020), social science (Lindstedt, 2019), or environmental science and engineering research (Palanichamy et al., 2021) to uncover underlying themes and trends. Our paper provides a comprehensive overview of all the topics covered in the literature on UTT over the last 40 years. The aim of our study is to bring more clarity and coherence to this complex area of research, and to enable a deeper understanding and reflection.

Our empirical findings reveal 20 different thematic areas, which, taken together, provide comprehensive insights into the underlying themes that are prevalent in the literature on UTT. Whereas UTT topics such as processes, enablers, missions, spin-offs, and metrics have emerged as prominent themes in the current research landscape, other topics such as institutions, commercialization, and units (e.g., technology transfer offices) appear to be losing momentum. Our study thus makes several important contributions to the literature on UTT, as we provide new insights into the evolution of UTT research. First, we bring conceptual clarity to the UTT literature by organizing the large number of studies into themes that have never before been structured using a text mining approach. Second, we provide a holistic perspective of the literature on UTT, which will help scholars and practitioners to navigate the growing literature and identify the relevant topics of UTT. Third, we identify increasingly relevant and already explored topics, which helps us to determine potential emerging research areas and to examine the development and focus of topics in the field of UTT over time. This will allow future researchers to focus on relevant topics, as we outline promising future avenues of research that will move the research field of UTT forward.

The remainder of this paper is organized as follows. Section 2 provides an overview of the literature, focusing on the definition and scope of UTT. In Sect. 3, we present our methodological approach. The results are presented in Sect. 4 and discussed in Sect. 5. A final section concludes and offers fruitful avenues for future research.

2 University technology transfer: a background

2.1 Definitions and mechanisms

Defining UTT is a challenging task, as it is characterized by a variety of definitions that vary according to research disciplines and objectives. In the literature, a multitude of concepts and definitions of UTT can be found (see Hayter et al., 2023). Apart from finding the true and universally accepted definition, a lot can be learned about the different research traditions by studying the distinct definitions (Bozeman, 2000). Through a comprehensive discussion of its concepts, an approximation of the essence of technology and its components can be achieved (Abdul Wahab et al., 2012). While there are different definitions of UTT (see Table 1), the literature on academic entrepreneurship reflects that knowledge development, scientific output, and intellectual property are immovable components of UTT, which is reflected in the definitions (Bozeman, 2000; Hayter et al., 2023; Tuma, 1987). Interestingly, not all of the definitions listed in Table 1 describe technology transfer as a core activity of universities and research institutions. One could infer from the definitions in the table that technology transfer encompasses elements such as knowledge development, property rights, and academic outcomes (Hayter et al., 2023). These elements are also important in the context of UTT research (Hayter et al., 2023).

UTT can be implemented via various mechanisms and channels, depending on the specific objectives of the transfer (Alexander et al., 2020; Radko et al., 2023). Possible avenues include the dissemination of information of a technical or scientific nature, the exchange of personnel, especially scientists and students, active participation in collaborative research and development partnerships, and the drafting and marketing of patents and other forms of intellectual

Table 1 List of selected definitions of technology transfer

Das (1987, p. 171)	"Technology transfers can be of two types basically: first, production of new products (product or embodied technology transfer) and second, more efficient production of existing products (process or disembodied technology transfer)"
Tuma (1987, p. 404)	"Technology transfer means acquisition and adaptation of a technique from one country or industry to another and its application in the production process. The transfer becomes complete when the technique has been domesticated and utilized as an integral part of the domestic production economy. Therefore, it is necessary to differentiate between inventing a technique, or becoming aware of it, and applying it"
Levin (1993, p. 499)	"Technology transfer is […] a socio-technical process implying the transfer of cultural skills accompanying the movement of machinery, equipment and tools. Transfer of technology is both the physical movement of artefacts and also, at the same time, transfer of the embedded cultural skills"
Carlsson & Fridh (2002, p. 200)	"Technology dissemination or transfer can occur in many different forms. The publication of research results in scientific journals and books is the most common form of dissemination. In some cases, the transfer may occur only if the intellectual property is protected and then commercialized"
Siegel et al. (2003a, p. 113)	"Technology transfer is usually thought of as occurring within or across firms, such as the dissemination of information through transfers of employees from one division or country to another (intra-firm transfers of technology)"
Gopalakrishnan & Santoro (2004, p. 57)	"Technology transfer is a narrower and more targeted construct that usually embodies certain tools for changing the environment"
Maskus (2004, p. 9)	"Technology transfer refers to any process by which one party gains access to a second party's information and successfully learns and absorbs it into his production function. Clearly, much technology transfer occurs between willing partners in voluntary transactions"
Audretsch et al. (2012, p. 9)	"Technology transfer is defined […] as the exchange of ideas, findings, and methods of production and management among research institutions, industry, and the public with the purpose of making scientific and technological advances accessible and appealing"
Hsu et al. (2015, p. 25)	"The transfer of university technology to industry involves a multitude of mechanisms which can be broken down into an even larger number of activities. These mechanisms and activities include launching technology-oriented start-ups, and providing the following: collaborative research, contract research, consulting services, technology licensing, graduate education, advanced training for enterprise staff, exchange of research staff, and other forms of formal or informal information transfer"
Association of University Technology Managers	"Technology transfer, and the professionals who work in the field, change the world one discovery at a time. They're responsible for successful innovation management, corporate engagement, protecting and licensing inventions to companies, new venture creation and incubation, and economic development"
European Commission	"Technology transfer […] refers to the process of conveying results stemming from scientific and technological research to the market place and to wider society, along with associated skills and procedures, and is as such an intrinsic part of the technological innovation process"
Federal Laboratory Consortium for Technology Transfer	"Technology transfer is the process by which existing knowledge, facilities, or capabilities developed under federal R&D funding are utilized to fulfill public and private needs"
World Intellectual Property Organization	"Technology transfer […] is a collaborative process that allows scientific findings, knowledge and intellectual property to flow from creators, such as universities and research institutions, to public and private users. Its goal is to transform inventions and scientific outcomes into new products and services that benefit society. Technology transfer is closely related to knowledge transfer"

property rights (Kratzer et al., 2010). Moreover, Gallagher (1986) provides a broad definition that UTT is simply the use of organized knowledge for practical applications. This broad definition includes both physical objects and processes within its scope (Bozeman, 2000). The transfer is complete when the technology in question has been fully implemented and is used as an integral part of the entity's own production process (Tuma, 1987).

There are two main categories of UTT components: *transfer agents* and *technological knowledge* (see Noh & Lee, 2019). Transfer agents, i.e. donors, recipients, and intermediaries, facilitate the transfer of knowledge, which is crucial for UTT (Noh & Lee, 2019). Technological knowledge is viewed as a valuable asset that can be transmitted in both embodied and disembodied forms. Transfer agents and technological knowledge are crucial components of UTT and highly important for the dynamics within the process (Noh & Lee, 2019). Within universities, technology and knowledge transfer promote collaboration between research institutions, but also with industry. This collaboration is not just about generating and publishing research data (Bozeman, 2000). This process of collaboration can be very dynamic and agents play a vital role in the relation of value (Abreu & Grinevich, 2024; Noh & Lee, 2019). However, the process also varies due to the relationships among the agents. Ongoing and committed interaction is necessary to keep the complex multistage process running (Gorschek et al., 2006).

In order for scientific findings to be applicable to commercial use, UTT normally encompasses a diverse, wide range of different activities in this context (Kratzer et al., 2010). Consequently, UTT refers to the complex process of transferring knowledge, expertise, and technological innovation from one entity or organization to another. The transfer can thereby take place in various sectors, including academia, industry, and government (Kim et al., 2012), with the ultimate objective of creating value (Cunningham et al., 2018).

2.2 Technology and knowledge transfer

Technology and knowledge transfer have a lot to do with each other, or more precisely, they complement one another (Ashari et al., 2023). Knowledge transfer is the process through which knowledge is communicated or shared from one entity to another (Kratzer et al., 2010). This can be a person, a place, or an object (Bozeman, 2000). For knowledge transfer to be successful in organizations, knowledge must first be created and applied. However, UTT is not only characterized by the transfer of technological know-how, but also the knowledge required for its successful use and implementation. This shows how important the dovetailing of technology and knowledge transfer is in promoting learning and innovation in organizations (Woltmann & Alkærsig, 2018).

UTT enables innovation and applies the resulting new technologies to differing circumstances (Abdul Wahab et al., 2012). According to Gibson and Smilor (1991), UTT is often a disorganized process, involving different actors with different motivations and goals and individuals with different perspectives on the value and future use of the technology. Through this approach, UTT makes a significant contribution not only to economic but also to social development (Menter, 2024). Collaborations between academia and industry are essential to advance and commercialize research and technological development and stimulate regional wealth (Lehmann & Menter, 2016; Mascarenhas et al., 2024). The procedure or context of a transfer process can vary depending on the type of transfer and the purpose it serves (Lavoie & Daim, 2019). This corresponds to the collaborative nature of UTT, which, among other things, should also make it easier for new scientific findings, knowledge, and intellectual property originating from the creators to be disseminated in society (Menter,

2024). This dissemination serves the dual purpose of meeting public and private needs while generating social or commercial value.

2.3 Some barriers and enablers

Some universities have struggled to convert and transfer their highly concentrated research capabilities supported with public funding for research into locally based economic activity (Noh & Lee, 2019). For example, Johnson and Lybecker (2009) examine the mechanisms of diffusion, market variables, social attributes, and political components that both simplify and complicate the process of dissemination. Their findings indicate that UTT has a number of challenges in the industrial sector. In this instance, asymmetric information, market power, and externalities are the three primary issues. Particularly when it comes to research findings, technology adaptation to particular production demands and market requirements is challenging. Additionally, there are issues and challenges in choosing appropriate technology transfer mechanisms (Greiner & Franza, 2003). Insufficient funding and support structures, along with a deficiency in infrastructure and incentive systems, are the main issues concerning scientific personnel (Alexander et al., 2020; Bruneel et al., 2010; Mazurkiewicz & Poteralska, 2017). Technical, regulatory, and human barriers that affect UTT processes and activities are also taken into account (Greiner & Franza, 2003).

Elements such as culture, time horizon management, allocation of faculty time to devote to technology transfer activities, and theory-to-practice adaptation are viewed as effective ways to enhance transfer (Van Horne & Dutot, 2017; Grzegorczyk, 2019; Link et al., 2008). The effective management of universities' dynamic capabilities can promote knowledge transfer and technology commercialization and facilitate the configuration of the third mission, balancing arising tensions and goal conflicts (Guerrero & Menter, 2024). UTT is a complex process influenced by a variety of factors ranging from individual attitudes and skills to organizational structures and external conditions. For this reason, there are several factors that emphasize the importance of full cooperation and commitment of all parties involved in the process. Communication, innovation, knowledge, product quality, and motivation are identified as the five most important factors that enable UTT processes (Singhai et al., 2021).

2.4 University technology transfer outcomes and measurable impacts

Previous studies of UTT highlight the potential to make a substantial impact on both economic growth and revenue generation (Guerrero et al., 2015; Hayter, 2013). The impact of UTT has been assessed using adaptive econometric studies, focused and well-designed surveys conducted simultaneously across multiple organizations, and input–output analysis of the interindustry effects of university spending (Drucker & Goldstein, 2007). The measurable effect of UTT is thereby closely linked to the evaluation and assessment of scientific and technological endeavors as a whole (Autio & Laamanen, 2014). Similar to the life cycle of a company, universities also go through several stages of entrepreneurial development (Guerrero & Urbano, 2012). As a result, their economic impact has attracted the interest of academics, governments, and policy makers around the world, leading them to actively promote these institutions (Guerrero et al., 2015; Leyden & Link, 2015; Link, 2024). Numerous viable new businesses have been established using technologies devel-

oped through university research (see Corsten, 1987; Gorschek et al., 2006; Meoli & Vismara, 2016). Consequently, there has been a growing trend toward higher education impact studies. These studies have used a variety of data collection and analysis methods to assess a broader range of economic impacts beyond mere expenditure and employment (Guerrero et al., 2015). The primary objective of these researchers has been to quantify outputs rather than to translate them into economic variables. Examples include quantifying spin-offs (see Fini et al., 2011; Hayter, 2013; Lockett et al., 2005), assessing the quantity and quality of university–industry collaboration (see Cunningham et al., 2020), quantifying technology transfer outcomes such as patents, licensing agreements, and revenues (see Azoulay et al., 2009; Kratzer et al., 2010), and assessing the impact of higher education policies (Civera et al., 2020; Menter et al., 2018).

There is also a need for changes that are an expression of a reorientation of the third mission of universities, which was originally focused on the commercialization of research results and scientific knowledge (Menter, 2024). Due to its interaction with the socioeconomic environment, the transfer mission of universities has great potential for achieving social impact and actively addressing societal challenges (Lehmann et al., 2024). With this reorientation, there has been an emphasis and research focus on the social impact of UTT (Carl & Menter, 2021; Parrish, 2023). Conceptually, an innovative approach to considering and implementing social innovations is sought. This is in response to society's demand for a more sustainable and integrative growth strategy in order to address challenges of environmental protection and social development (Fini et al., 2018; Menter, 2024; Parrish, 2023). The important role of academic entrepreneurship, especially UTT, raises the hope of utilizing the knowledge available in universities to promote local and national economic development and ensure competitiveness of a nation. UTT is thought to be the engine that propels the country's innovation system, making it vital to the system's overall quality (Mowery & Sampat, 2006; York & Ahn, 2012). Overall, the research topic of UTT is an interdisciplinary field that has become increasingly important for academia, policy, and practice communities.

3 Methodology

3.1 Text mining and topic modeling

To address our research questions, we employ a computational technique to extract the relevant information, enabling us to manage, search through, and organize a large collection of documents automatically (Ranganathan & Tsahai, 2021). Text mining allows valuable insights to be extracted from large text datasets without any underlying structure, making it a powerful approach to enable scientific discovery by taking retrieval and usability to a new level (Noh & Lee, 2019; Woltmann & Alkærsig, 2018). A particular form of text mining is topic modeling, which enables the autonomous identification of subjects within extensive document sets (Porturas & Taylor, 2020). In addition to other interdisciplinary studies, text mining, especially topic modeling, was used to systematically identify and analyze patterns and trends in large datasets of texts (Arroyabe et al., 2022; Noh & Lee, 2019; Woltmann & Alkærsig, 2018). In different fields, text mining has been used to analyze and further consider the underlying structure and evo-

lution of a research stream (Ali & Kannan, 2022; Barua et al., 2014; Lindstedt, 2019; Palanichamy et al., 2021; Porturas & Taylor, 2020). These studies have also employed topic modeling to identify various topics within the text of papers and determine the key terms associated with each topic. By conducting this type of analysis, these studies enable scholars to obtain a comprehensive overview of the existing literature and assist scientists and practitioners in navigating the growing body of literature on a specific topic (Arroyabe et al., 2022). With the advent of increasing computing capacity, improved processing power and the growing volume of digital data, the social sciences can apply more and more text mining methods, greatly expanding their potential for empirical research (Arroyabe et al., 2022; Noh & Lee, 2019; Schmiedel et al., 2019; Woltmann & Alkærsig, 2018).

Using topic modeling, large amounts of text data are analyzed using certain algorithms and recurring topics are identified in order to obtain a representation of the topics discussed (Blei & Lafferty, 2007; Schmiedel et al., 2019). This technique is used to examine a group of documents, identify words and patterns, and automatically group words to categorize the documents (Ranganathan & Tsahai, 2021). Topic modeling treats documents as collections of words, where each word is assigned to a topic with a certain probability, and the frequency of occurrence of words associated with key topics is greater than that of other words (Blei et al., 2003). The approach relies on the premise that texts are composed of a variety of topics, each characterized by a distinct set of words. The application of topic modeling enables the utilization of quantitative techniques to identify and analyze specific themes within individual texts, thereby facilitating the analysis of the evolution over time (Blei et al., 2003; Blei & Lafferty, 2007). In this context, the latent Dirichlet allocation (LDA) algorithm provides a powerful topic modeling approach that enables the analysis of large volumes of documents, with the great advantage of mitigating the biases inherently introduced by manual coding (Arroyabe et al., 2022; Mardones-Segovia et al., 2022). The LDA algorithm is a probabilistic model for which texts are a composition of topics, with a unique distribution of topics in each text of the collection (Blei et al., 2003).[1] Topic modeling, particularly LDA, is capable of functioning without the necessity of text classification or labelling (Blei & Lafferty, 2007). In doing so, existing dictionaries or interpretation resources are not required (Blei et al., 2003).

3.2 Data scoping and collection

To address our key research questions, we used text mining as a method to uncover key topics and themes. Our approach is distinctly different from recent bibliometric studies analyzing the UTT literature (see Borges et al., 2022; Craiut et al., 2022; Olvera et al., 2021). Computational linguistics, the scientific basis of text mining, has become increasingly relevant to empirical studies and plays a central role in scientific research (Arroyabe et al.,

[1] By analyzing the frequency of words in text corpora, LDA calculates the probability distributions of words for each topic and the distributions of topics within each document. LDA assumes that each document is a mixture of topics and that each topic is represented by a specific distribution of words (Blei et al., 2003; Chen et al., 2023). Based on these probability distributions, it is possible to categorize texts in text corpora or to identify latent topics present in the texts (Arroyabe et al., 2022; Blei et al., 2003; Mardones-Segovia et al., 2022; Syed and Spruit, 2017).

2022; Rzhetsky et al., 2009; Yau et al., 2014). The key steps in our methodological approach are outlined in Fig. 1.

To conduct our analysis, we used data from the Web of Science (WoS) Core Collection, provided by Clarivate Analytics. The WoS Core Collection contains more than 85.9 million records from scholarly journals, conference proceedings, and other resources spanning more than 250 disciplines and subject areas. Due to its reliability and comprehensive coverage, the WoS Core Collection has become one of the most widely used databases for bibliometric analysis in the social sciences (Arroyabe et al., 2022; Bengoa et al., 2021). WoS maintains a comprehensive repository of essential publication details, including title, author information, abstract, and keywords. Our data was collected from WoS through a query that retrieved all documents containing terms related to UTT in the title, abstract, or keywords.

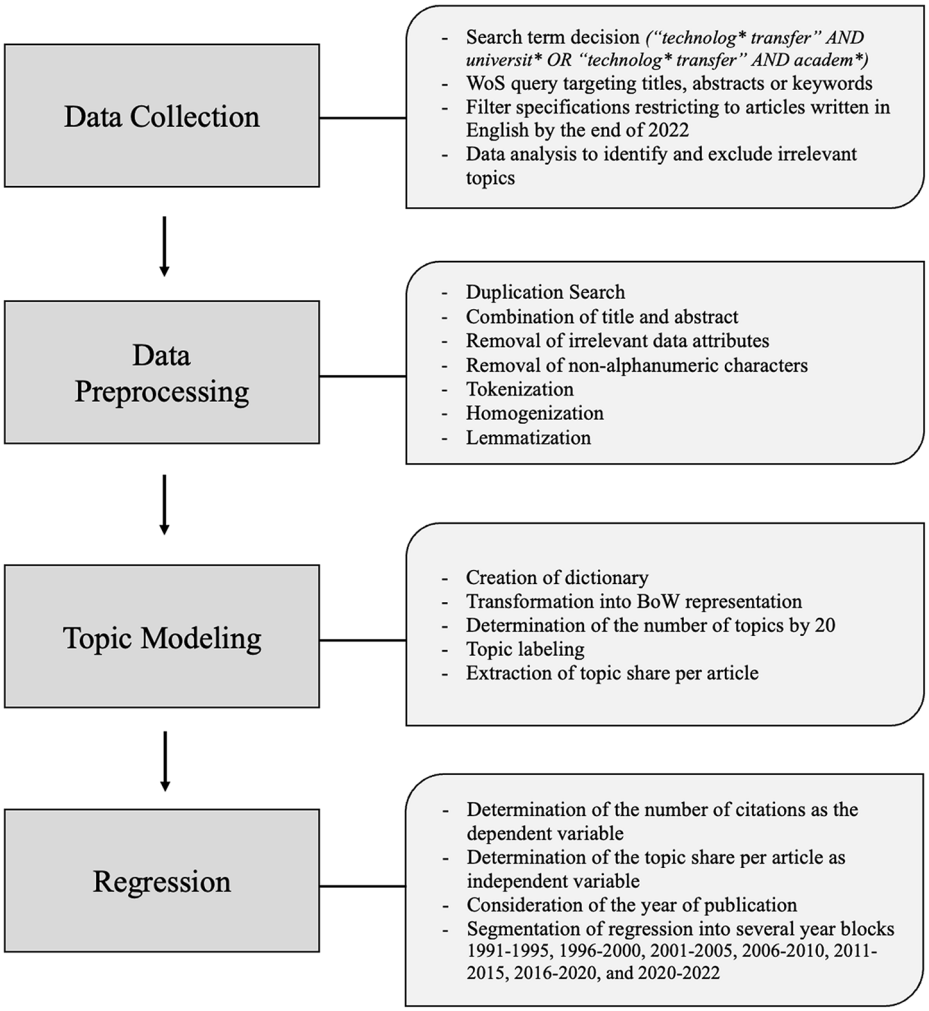

Fig. 1 Key steps of methodological approach

Being interested in the university context of technology transfer, we used the following topic search (*TS*) to gather the necessary data in our research area:[2]

(1) *TS = ("technolog* transfer" AND universit* OR "technolog* transfer" AND academ*)*

We limited our search to articles written in English through the end of 2022. We found 2,228 articles for this search. We conducted a thorough analysis of the dataset to identify any missing information or topics that were not relevant to our research area, specifically focused on UTT. During this process, we identified a total of eight articles that were missing an abstract and 276 articles that were not relevant to our research area. Following the data cleaning process, we identified a total of 1,944 articles over the period from 1981 to 2022 that were relevant and suitable for our research.

For the successful implementation of text mining techniques, data preprocessing plays a crucial role, involving data cleaning and the transformation of unstructured raw text into statistically and computationally meaningful entities, as the effectiveness of text mining results depends heavily on the thoroughness of the preprocessing phase (Chen et al., 2023). By performing these procedures, we obtained a more refined dataset consisting of words, which led to a better interpretability of the topics and reduced the computational cost (Arroyabe et al., 2022; Blei et al., 2003; Blei & Lafferty, 2007). We analyzed the titles and abstracts of all 1,944 downloaded documents.

In our first step, we searched for duplicate entries and found no instances of duplication. Second, we combined the article title and abstract into one column called "text". Third, the dataset was thoroughly inspected for null values and irrelevant data attributes. As a fourth step, we removed all nonalphanumeric characters, including punctuation, numeric values, special characters, and tokens less than three characters in length, while making sure to remove multiple extra spaces. Fifth, we removed stop words as these words do not provide any specific information. Furthermore, we tokenized the documents into unigrams (single words). Sixth, we homogenized all the words by converting them to lower case. In the last step, we defined the lemmatization function, a process that converts words to their base or root form. This process helps to reduce the dimensionality of the data and consolidate different forms of a word into a single entity for better text analysis.

To find the desired number of topics to be generated from the corpus, the LDA algorithm relies on human user input. This leaves the determination of the number of topics to be extracted by the LDA algorithm in the hands of the researchers (Blei et al., 2003; Mardones-Segovia et al., 2022). A lower value indicates a more general topic coverage and a coarser resulting analysis. Conversely, a higher value indicates a more specific topic coverage and a more detailed resulting analysis. In the present study, the objective was to achieve a medium resolution, thereby enabling the capture of general patterns in the data set that can still be clearly distinguished from one another. It is not the case that a single value is equally suitable for all data sets and situations. After several iterations in which different values were evaluated, it was determined that 20 topics represented a reasonable resolution (Barua et al., 2014; Blei, 2012).

[2] The arguments in Eq. (1) are search terms as defined in Fig. 1.

Each word is contained in each topic distribution, but with different probabilities assigned to it. Words that occur together more frequently have a higher probability within a topic (Syed & Spruit, 2017). In order to facilitate interpretation and labelling, the 10 words for each topic with the highest probabilities were selected (Syed & Spruit, 2017). The algorithm calculates the distribution of topics from the optimal list of terms associated with each topic that it has previously determined. We interpreted the most frequent words for each topic and were able to manually label the different topics (Blei, 2012). The reliability of a topic model is contingent upon the accuracy of the human judgement that informs its construction. It is therefore essential to ensure that the model captures established general trends and factual knowledge within the domain (Ramage et al., 2009).

3.3 Regression analysis

As part of our data analysis, we analyzed the proportion of topics per article and citations captured by WoS using linear regression analysis, with the aim of determining the popularity of the identified topics over time. In the regression analysis, the number of citations provided by WoS is treated as the dependent variable, while the topic share per article serves as the independent variable. We determined the proportion of topics for each article in our analysis, with each article having a different distribution of topics.

Based on the quantity of citations, we were able to evaluate a topic's popularity. As a result, our regression analysis indicates that more popular subjects are linked to more scholarly citations. However, we took the year of publication into account, as older papers are likely to have a higher number of citations. Previous studies have mostly looked at decadal intervals to identify and analyze changes in UTT in the context of scientific trends (Abdul Wahab et al., 2012; Audretsch et al., 2014; Bozeman, 2000). To look more closely at the development of the literature on UTT topics, the present study uses a five-year interval approach while examining the development of UTT research over time. Therefore, we further split the investigation into seven separate year blocks reflecting the following periods:[3] 1991–1995, 1996–2000, 2001–2005, 2006–2010, 2011–2015, 2016–2020, and 2020–2022. This analytical approach enables careful trend analysis, which allows us to recognize persistent patterns in the popularity of topics and make predictions about future trends. The identified topics can also be benchmarked and evaluated comparatively in order to assess their relative importance and their development over time. The use of a linear regression is particularly advantageous, as it supports a granular examination of long-term developments in the popularity of themes in UTT research. By extrapolating validated findings, this method enables data-driven decision-making in the field of UTT. Through this analytical lens, we gained a nuanced understanding of how different topics evolved, helping researchers to make informed decisions based on empirical evidence. This method further allows the extrapolation of validated facts based on data-based decision-making in the field of UTT. In this way, we were able to gain a nuanced understanding of the evolution of specific topics and could help researchers make well-reasoned decisions based on empirical data.

[3] Due to an insufficient number of publications in the previous years, the analyzed periods only start in 1991.

4 Findings

4.1 Descriptive analysis

In this section, we present a descriptive overview of the results of our extracted dataset. This descriptive analysis provides crucial insights regarding our complex dataset's distribution, dominant pattern, and disperse. Figure 2 shows the distribution of articles by the year of publication. The first two articles were published in 1981. As can be seen from the literature, there has been a steady increase in research over time. Furthermore, there has been a notable increase in research on the topic since 2018, with the majority of papers being published in the following years, with the highest peak in 2022. This result provides a brief insight into the importance around the UTT research field and how the scientific community is currently focusing on topics related to UTT.

Figure 3 displays the citations documented by WoS per year. As with the distribution of papers, citations took off in 2018. Since the 2000s, there has been a steady increase in the number of cited articles on UTT. In 2021, a record high of 8,767 citations was reached, highlighting the growing relevance and demand for topics related to UTT. This is a clear indication of the level of interest and importance that the subject has had in recent years.

The scientific community considers it important to identify the most frequently cited works in a particular field in order to obtain an overview of the scientific literature. In terms

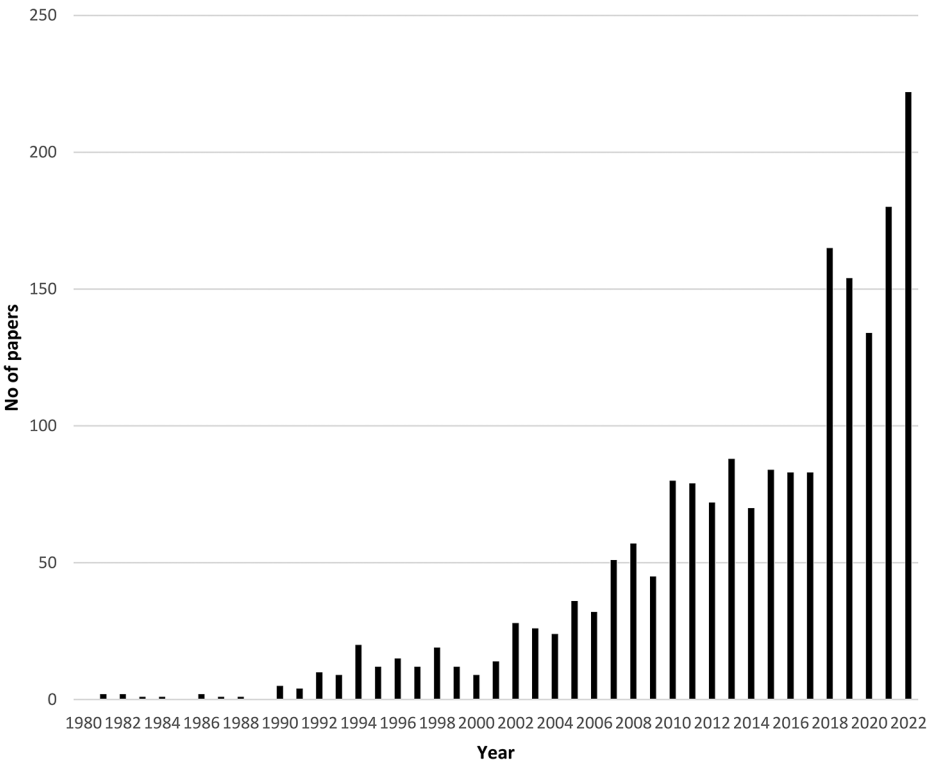

Fig. 2 Distribution of papers by year of publication

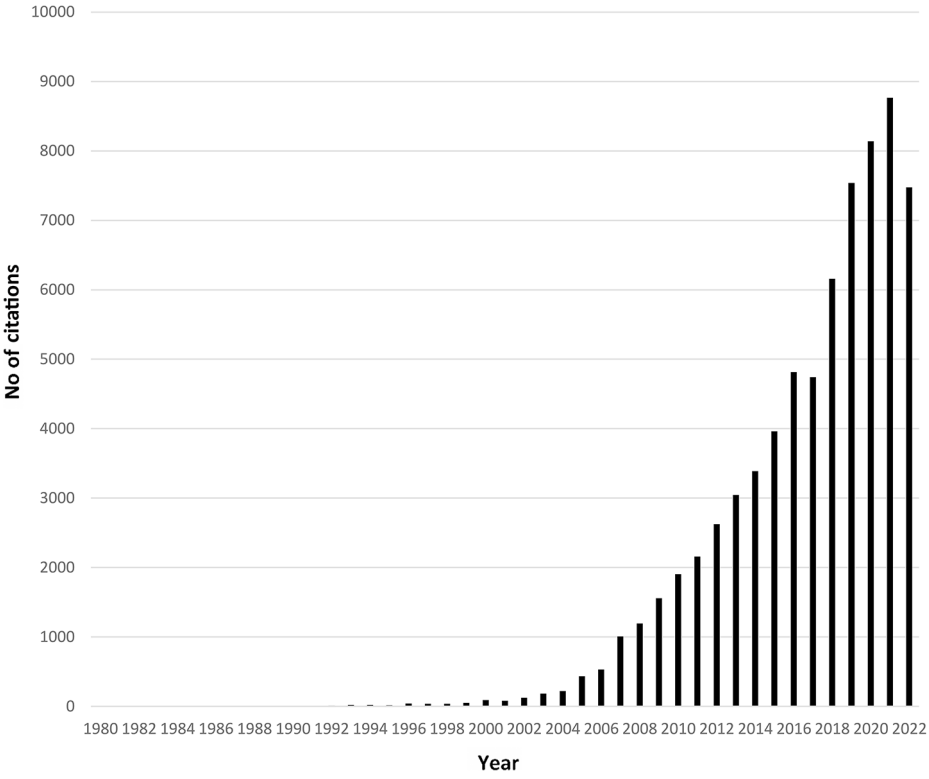

Fig. 3 Distribution of citations documented by WoS per year

of the most prominent articles published, Table 2 shows the top 20 most influential articles in the UTT literature, as measured by the number of citations documented by WoS. With 991 citations, the most cited paper is "The knowledge spillover theory of entrepreneurship" by Acs et al. (2013). According to the knowledge spillover theory of entrepreneurship, the environment in which decisions are made may influence an individual's propensity to become an entrepreneur, especially in knowledge-rich environments. Entrepreneurs serve as conduits for the transmission of information and stimulate inventive activity by commercializing ideas from established firms and research institutions, leading to improved economic performance through the efficient allocation of resources (Acs et al., 2013).

Table 3 illustrates the distribution of articles on UTT across different academic journals. *The Journal of Technology Transfer* is premier with 260 identified articles, followed by *Research Policy* with 156 articles, *Technovation* with 86 articles, and *Technological Forecasting and Social Change* with 65 articles, making this group of four the primary journals in the field as defined by publishing the largest number of articles about UTT during the period 1981 through 2022.

Table 2 List of journal articles with the most citations until 2022

Authors	Year	Article Title	Journal	Citations
Acs, Audretsch and Lehmann	2013	The knowledge spillover theory of entrepreneurship	*Small Business Economics*	991
Siegel, Waldman and Link	2003	Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study	*Research Policy*	882
D'Este and Patel	2007	University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry?	*Research Policy*	823
Rothaermel, Agung and Jiang	2007	University entrepreneurship: a taxonomy of the literature	*Industrial and Corporate Change*	820
Etzkowitz	2003	Research groups as 'quasi-firms': the invention of the entrepreneurial university	*Research Policy*	778
Mowery, Nelson, Sampat and Ziedonis	2001	The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh-Dole act of 1980	*Research Policy*	719
Di Gregorio and Shane	2003	Why do some universities generate more start-ups than others?	*Research Policy*	696
Bruneel, D'Este and Salter	2010	Investigating the factors that diminish the barriers to university-industry collaboration	*Research Policy*	651
Etzkowitz	1998	The norms of entrepreneurial science: cognitive effects of the new university-industry linkages	*Research Policy*	649
Vohora, Wright and Lockett	2004	Critical junctures in the development of university high-tech spinout companies	*Research Policy*	579
Agrawal and Henderson	2002	Putting patents in context: Exploring knowledge transfer from MIT	*Management Science*	568
O'Shea, Allen, Chevalier and Roche	2005	Entrepreneurial orientation, technology transfer and spinoff performance of US universities	*Research Policy*	544
D'Este and Perkmann	2011	Why do academics engage with industry? The entrepreneurial university and individual motivations	*The Journal of Technology Transfer*	519
Bercovitz and Feldman	2008	Academic entrepreneurs: Organizational change at the individual level	*Organization Science*	480
Thursby and Thursby	2002	Who is selling the Ivory Tower? Sources of growth in university licensing	*Management Science*	461

Table 2 (continued)

Authors	Year	Article Title	Journal	Citations
Grimaldi, Kenney, Siegel and Wright	2011	30 years after Bayh-Dole: Reassessing academic entrepreneurship	*Research Policy*	457
Lockett and Wright	2005	Resources, capabilities, risk capital and the creation of university spin-out companies	*Research Policy*	451
Bekkers and Freitas	2008	Analysing knowledge transfer channels between universities and industry: To what degree do sectors also matter?	*Research Policy*	433
Siegel, Waldman, Atwater and Link	2004	Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: qualitative evidence from the commercialization of university technologies	*Journal of Engineering and Technology Management*	431
Kostoff and Scaller	2001	Science and technology roadmaps	*IEEE Transaction on Engineering Management*	408

Table 3 List of journals with the most articles published

Journals	Number of papers	Share
The Journal of Technology Transfer	260	13.37%
Research Policy	156	8.02%
Technovation	86	4.42%
Technological Forecasting and Social Change	65	3.34%
Science and Public Policy	46	2.37%
International Journal of Technology Management	42	2.16%
Sustainability	38	1.95%
Technology Analysis Strategic Management	34	1.75%
Scientometrics	27	1.39%
IEEE Transactions on Engineering Management	27	1.39%
R&D Management	24	1.23%
Small Business Economics	22	1.13%
Higher Education	20	1.03%
Industry and Innovation	20	1.03%
Studies in Higher Education	20	1.03%

Note: The table shows only journals with at least 20 articles published on the topic of university technology transfer. The share refers to the percentage of total paper identified (1,944)

4.2 Topic modeling and cluster building

In this section, we present a comprehensive overview of our analysis, addressing our first research question: What thematic patterns can be identified in the UTT literature? Our analysis identified 20 different topics that gave us a broad overview of the underlying themes in the UTT literature. In reviewing the literature, we found that the themes we uncovered address four distinct areas, namely, UTT contexts (Gerbin & Drnovsek, 2020; Lehmann et al., 2021), UTT capacities (Bercovitz & Feldman, 2008; Siegel et al., 2003a), UTT mechanisms (Chen et al., 2022; O'Kane et al., 2020), and UTT policy (Cunningham et al., 2019, 2021; Jaffe & Lerner, 2001; Lockett et al., 2005). We categorized these areas into clusters and assigned our identified 20 issues to these four clusters. The formation of these four clusters provides an organized, effective method of grouping our identified issues into understandable and useful categories. This leads to an easier understanding and organized structure of our identified issues. Table 4 lists the clusters and the corresponding themes that were extracted, along with the ten most common words. All abbreviations that appeared in the most frequent words have been written out in full so as not to hinder the flow of reading.

4.2.1 UTT context

The UTT context cluster, characterized by *institutions*, *units*, and *stakeholders*, refers to a framework covering several structural and organizational issues. The themes in this cluster concern the interactions and processes required for the successful transfer of research results and scientific knowledge between academic research and the private sector. The focus is on the relationships between research institutions and enterprises, as well as on the environments and conditions in which UTT takes place (Gerbin & Drnovsek, 2020; Lehmann et al., 2021).

Table 4 List of clusters with topic labels and of the most frequent words per topic

Cluster	Topic label	Most frequent words
UTT context	UTT institutions	institutional, context, role, environment, actor, support, focus, dynamic, condition, structural
	UTT unit	office, practice, strategy, technology transfer offices, resource, process, decision, manager, structure, effectiveness
	UTT stakeholder	organizational, stakeholder, service, community, interaction, formal, mechanism, exchange, informal, agency
UTT capacity	UTT infrastructure	company, institute, system, technical, enterprise, laboratory, conduct, establish, make, access
	UTT process	develop, stage, market, barrier, critical, concept, potential, identify, tool, skill
	UTT enablers	entrepreneurial, entrepreneurship, design, purpose, methodology, theory, social, practical, orientation, contribution
	UTT mission	science, scientific, scientist, mission, field, social, society, teach, life, change
	UTT activities	academic, activity, researcher, engagement, engage, experience, involvement, intention, motivation, behavior
UTT mechanism	UTT legislation	program, intellectual, property, issue, interest, work, article, engineering, federal, create
	Spin-off	spin, offs, creation, venture, resource, growth, create, support, incubator, university spin-offs
	Patenting and licensing	patent, license, invention, faculty, inventor, licensing, incentive, ownership, dole, bayh
	UTT commercialization	commercialization, project, process, product, commercial, effort, capability, experience, commercialize, gap
	University-industry collaboration	industry, firm, collaboration, industrial, cooperation, relationship, partner, collaborative, interaction, partnership
	UTT outcome	innovation, system, technological, innovative, emerge, investment, drive, low, sustainable, promote
UTT policy	UTT support	policy, public, sector, fund, government, funding, initiative, higher education institutions, programme, financial
	UTT impact	impact, economic, time, generate, increase, output, benefit, long, growth, direct
	UTT metrics	result, analysis, paper, data, country, international, survey, empirical, determinant, evidence
	UTT performance	performance, factor, effect, influence, affect, measure, significant, efficiency, productivity, outcome
	UTT output	knowledge, network, region, capacity, production, source, cluster, spillover, absorptive, diffusion
	UTT evaluation	model, framework, present, method, future, evaluate, evaluation, objective, element, conceptual

The theme of *UTT institutions* examines all factors at the institutional level. Effective use of the scientific capacity of the scientific academies and other specialised entities (such as higher education institutions and research centres) is essential for the protection of intellectual property (Vityaz and Shcherbin, 2022). This theme explores the benefits that institutions can derive from researchers' discoveries. Literature in this area explores issues such as the politics of intellectual property, cultural tensions, boundary work, and the public good (Fisher & Atkinson-Grosjean, 2002). For example, participants involved in knowledge transfer processes share a common knowledge base and adhere to common norms and spe-

cific frameworks despite operating in potentially different institutional settings, which also applies to cultural barriers (Kalantaridis et al., 2017).

UTT units serve as a link between universities and the private sector and encompass all forms of transfer of scientific knowledge and research results in an economically viable form (Kratzer et al., 2010; O'Kane et al., 2021). This includes the provision of scientific or technical information, the exchange of personnel, the networking of scientists and private entrepreneurs, and the licensing or sale of patents and other industrial property rights (Dolan et al., 2019; Kratzer et al., 2010). Furthermore, technology transfer offices have played a crucial and increasingly important role in the UTT literature due to their role as intermediaries between universities and industry. The conversion of inventions into marketable innovations is based on network effects between science and the private sector, with transfer units acting as boundary spanners between universities and companies (Hülsbeck et al., 2013).

UTT stakeholders represent the various actors that enable the successful transfer of innovations as part of the collaboration. These include university scientists, who discover new technologies, technology managers, and administrators who facilitate the interaction between scientists and industry (Cunningham & Menter, 2020). Furthermore, investors and venture capitalists play a crucial role by providing the necessary capital and business expertise to navigate the commercialization pathway, effectively bridging the gap between innovation and market success (Clauss et al., 2018). According to Siegel et al. (2003a), companies or entrepreneurs who take on the commercialization of technologies and the state, which often provides financial support for research projects, are also considered important actors in UTT processes.

4.2.2 UTT capacity

The UTT capacity cluster includes *infrastructure*, *process*, *enablers*, *mission*, and *activities* and is concerned with the aggregated capabilities and resources of an entity or organization to effectively assimilate, understand, exploit, and subsequently disseminate scientific knowledge and research results. It encompasses a set of capabilities, structures, and processes that enable an organization to actively engage in UTT activities (Bengoa et al., 2021). It emphasizes the importance of internal expertise, resource management, and the ability to adapt to new technological developments (Bercovitz & Feldman, 2008; Siegel et al., 2003a) to make UTT processes smoother in order to maximize the potential for innovation and entrepreneurship and to improve the efficiency and success of UTT activities.

UTT infrastructure focuses on the role of research universities and possible interactions with key players and organizations in innovation ecosystems. This topic explores how collaborations between universities and companies and the diffusion of innovation among companies can be improved. Infrastructures facilitate these interactions, as they often rely heavily on permanent resources such as human and material assets. The rapid development of technological possibilities and the constant need for new information require the provision of resources to maintain highly specialized infrastructures. Moreover, the need for adaptable infrastructure frameworks that can meet the changing demands of different technological capabilities and the rapidly growing innovation scene is recognized (Brodhag, 2013). It is thereby important to have lean infrastructures, characterized by a lower distribution of fixed resources and thus a better ability to adapt quickly to unforeseen changes in the context of the UTT environment (Azzone & Maccarone, 1997).

The *UTT process*, spanning the development of new scientific knowledge to its market implementation, is highly complex and involves numerous actions and stages. Within these activities, the outcomes are difficult to predict. This is further affirmed by Karanikic et al. (2021), who emphasize that there is no single model within the UTT process. The study describes different phases within this process, including the initial discovery by a university scientist, the disclosure of the discovery, the evaluation of the invention with a decision to patent, the patent application, the commercialization of the technology to companies or society, the negotiation of an equity investment, and finally technology licensing.

UTT enablers support the cooperation between academia and industry, which is crucial for economic growth, in steps of UTT development (Jamison & Jansen, 2001). The key requirements vary from phase to phase. Enablers provide support in overcoming trust barriers and concluding agreements on intellectual property by utilizing the experience and knowledge complementarity of the partners (Cunningham et al., 2022). In terms of UTT enablers, public funding and strategic investment are contributors to competitiveness and development. In addition, research-based knowledge and technology are enabled by potential synergies, credible alternatives, and the reduction of uncertainty, which are essential for the successful commercialization of academic research and provide strategic insights.

UTT mission refers to the extension of traditional university functions to the so-called third mission: the generation, utilization, and exploitation of knowledge in collaboration with external stakeholders and society as a whole (Gulbrandsen & Slipersæter, 2007). It complements teaching and research with entrepreneurial elements and the promotion of social commitment. This orientation influences the entrepreneurial intentions of academics and is crucial to global development. As a result, universities are becoming entrepreneurial institutions that cater to the needs of a wide range of stakeholders and reveal their competitive advantage in the global marketplace (Kratzer et al., 2010; Trencher et al., 2014). There has also been an evolution in the role of research institutions, from being the initiator of UTT and founder of knowledge-based start-ups to a stronger focus on entrepreneurship in general and a permeation of society with entrepreneurial culture (Audretsch, 2014). Knowledge-based entrepreneurship has been found to be a strong driver of economic growth (Guerrero et al., 2015).

Within the topic of *UTT activities*, the scope extends to active collaborations with different stakeholders, the impact of commercialization on scientific research, the role of inventors in the transfer process, and the adoption of a central role in the knowledge-based society (Berbegal-Mirabent & Martin-Sanchez, 2024). In particular, the key factors contributing to the microeconomic level of academic entrepreneurship are analyzed. The importance of scientists' perspectives in the context of their participation in technology transfer and the influence of institutional and organizational resources, especially ethics and research quality, on universities' approach to technology and knowledge transfer are highlighted (Hewitt-Dundas, 2012; Jain et al., 2009; Zhou & Baines, 2023). The strategic focus areas for knowledge transfer are evident in various activities, such as the diverse knowledge transfer channels, the partners universities collaborate with, and the geographic focus of their organizational engagement (Fitzgerald et al., 2021; Mascarenhas et al., 2024). Several studies focused on personal intentions and competencies related to their activities. The motives, incentives, motivations, and social factors for scientists to collaborate with industry or become entrepreneurs have been explored (Acs et al., 2013; Clarysse et al., 2011; Cunningham et al., 2020; D'Este & Perkmann, 2011; Philpott et al., 2011). The individual characteristics of

researchers thereby have a stronger influence than characteristics of their departments or universities (D'Este & Patel, 2007).

4.2.3 UTT mechanisms

The discussions within the UTT mechanisms cluster cover various topics, such as *legislation*, *spin-offs*, *patenting and licensing*, *commercialization*, *university–industry collaboration*, and *outcomes*. This cluster therefore includes organized procedures, processes, or strategies used by research and scientific actors to facilitate the exchange of knowledge and technology. According to O'Kane et al. (2020), the mechanisms include topics dealing with the transfer of research results and emphasizes the importance of established procedures and processes to ensure an optimal transfer to the free economy.

UTT legislation refers to the regulations governing the UTT of research institutions—in particular, laws and regulations. Several studies in the field have examined the effects of barriers and challenges as well as the impact of legislation promoting UTT (Cunningham et al., 2019; Siegel et al., 2007). The topic deals with intellectual property rights, the establishment of regulations, or the legal aspects of agreements during a cooperation. The research examines how these legal structures may facilitate or hinder UTT (Goldfarb & Henrekson, 2003).

Spin-offs are companies founded by members of universities or research institutions with the aim of commercializing university research results. University spin-offs play a crucial role in the dissemination of knowledge and have the capacity to create employment opportunities and stimulate economic development (see Fini et al., 2011; Hahn et al., 2024; Hayter, 2013; Lockett et al., 2005). There is less research on the performance and impact of spin-offs, particularly from the perspective of academic entrepreneurs (Hayter, 2013). The research by Lockett et al. (2005) and Pirnay et al. (2003) explores the formation of spin-offs, including the processes, barriers, and obstacles faced by scientists, and their subsequent position in the innovation ecosystem.

The topic *patent and licensing* explores various forms of knowledge commercialization and promotes innovation to establish itself in the ecosystem of the free economy (Keestra et al., 2022; Mowery et al., 2001). In addition, by defining clear ownership and use rights, this topic serves as an important mechanism for mitigating conflicts over intellectual property rights, ensuring that all participants are fairly compensated for their contributions to the UTT process (Mowery et al., 2001). According to Walter et al. (2016), patenting and licensing have a high impact on the successful integration of scientific discoveries into the market.

In a broader context, *UTT commercialization* explores how research results can be transformed into products or services, how economic value can be created, how sustainable ways of commercialization can be identified, how market potential can be assessed, and how strategies can be developed for the introduction and dissemination of the technologies concerned. The process of transforming and transferring research results and scientific knowledge into marketable products and services is subject to numerous obstacles that must be overcome (see Jaffe & Lerner, 2001; Kalantaridis et al., 2017). According to Audretsch et al. (2014), the dispersion of production processes across different geographical locations in the 1990s influenced the shift in academic research interests from a national-level focus to a focus on interactions at the organizational level.

University–industry collaborations support common objectives in the commercialization of innovations and deal with partnerships between academic institutions and industry

(Albats et al., 2018). They replaced state organizations as UTT's main intermediaries. UTT research has increasingly addressed the transfer from universities to the private sector and its importance for the growth of existing and the creation of new firms, with a focus on the creation of new jobs (Harmon et al., 1997; Jones-Evans et al., 1999). According to El-Ferik and Al-Naser (2021), studies in this context focus on the analysis of moderators and barriers, the management of joint projects, and the exchange of knowledge and technology. Studies on UTT with a focus on relationships between academia and industrial enterprises have focused on how the development of new products can be leveraged through the use of scientific work from universities (Boyle, 1986; Corsten, 1987). The focus of interest was the motivation for collaboration, what obstacles arose, and what alternative ways there could be to ensure an efficient exchange of knowledge (Boyle, 1986; Rahm, 1988).

UTT outcomes include the measurable and intangible benefits of UTT, including new products, services, business models, improved industrial processes, job creation, and contributions to economic development (Fini et al., 2018; Prokop, 2021; Sun et al., 2020). The evaluation of these outcomes focuses not only on results, but also on specific performance indicators that cover the entire life cycle of resource allocation, efficiency in collaborations, and the resulting innovations (El-Ferik & Al-Naser, 2021). UTT outcomes also address future challenges and seize new opportunities at the macro-, meso-, and microlevel, and foster a culture of continuous learning and adaptation.

4.2.4 UTT Policy

The UTT policy cluster consists of the topics *support*, *impact*, *metrics*, *performance*, *output*, and *evaluation*. This cluster focuses on strategies and measures to facilitate the transfer of knowledge and technology from academic institutions to the commercial sector. The cluster emphasizes the importance of policy frameworks and promotion strategies that support and facilitate UTT to effectively transform innovation into marketable products and services (Cunningham et al., 2019, 2021; Jaffe & Lerner, 2001; Lockett et al., 2005). At least in the United States, there were also significant changes in public policy perspectives regarding UTT during this period, due to the need to improve competitiveness in various industries (Bozeman, 2000; Link, 2024).

The topic of *UTT support* focuses on policies and laws that promote the commercialization and transfer of research results to the free economy. The aim is to provide relief to the parties involved in this process and it manifests itself in various forms. These range from supporting spin-offs in the founding phase (Fini et al., 2011; Meoli & Vismara, 2016) to government programs to support academic entrepreneurs (Song et al., 2020) and female entrepreneurship (Menter, 2022; Mercier et al., 2018).

The significance of scientific research in promoting innovation and economic success at the firm and regional level is included in the topic *UTT impact*. It highlights the internal and external factors that contribute to producing effects on regional economic development by looking at the spatial reach of these effects and separating the influences of various university roles (Fini et al., 2018). These effects are, nevertheless, placed within the framework of UTT. Several empirical studies in this area have examined the impact and effectiveness of legislation designed by governments to promote effective UTT (Cunningham & Menter, 2021; Guerrero & Urbano, 2019; Song et al., 2020). The idea of the entrepreneurial university draws attention to the importance of universities for society and the economy, including the creation of spin-offs (Guerrero & Urbano, 2012; Kirby, 2006; Cunningham et al., 2019; Yeo, 2018).

The topic *UTT metrics* deals with the quality, processing, and interpretation of research results and their application in empirical studies. It is about the importance of a solid data basis for obtaining reliable results and evidence in scientific research that is based on empirical evidence and careful analysis. The empirical measurement and validation of science and technology initiatives as a whole is closely linked to the quantifiable impact of UTT (Autio & Laamanen, 2014). Research in the field of UTT metrics intensively focuses on empirical data in order to understand the complex mechanisms, success factors, and challenges of UTT processes (see Gibson & Smilor, 1991; Sun et al., 2020).

The success rate of transferring knowledge and technologies from academic institutions to the industrial sector is examined in the topic *UTT performance*. The efficiency and efficacy of the transfer process are examined in this topic, with an emphasis on fostering academic entrepreneurship, including licensing, research partnerships, and university start-ups (Siegel et al., 2007). UTT units are often challenged to quantify and improve their performance into viable, marketable technologies and solutions. It is crucial to measure this performance, because it directly affects the success of converting scholarly research into workable, commercially viable technologies and solutions (Hülsbeck et al., 2013; Kratzer et al., 2010; Zhang & Zeng, 2024).

The topic *UTT output* refers to the impact and measurable outcomes of UTT, particularly in the context of research commercialization. This topic includes an analysis of the role of patents and their impact on the direction and output of academic research, focusing on the positive aspects and the challenges there (Siegel et al., 2004). For example, Azoulay et al. (2009) show that patenting activities can have a positive impact on publication rates and may lead to a reorientation of research focus toward commercially relevant issues. In order to explore measures, strategies, and ways to improve transfer points, the performance of cooperation between university and industry must be assessed (Pujotomo et al., 2020).

The topic *UTT evaluation* focuses on the process of measuring the effectiveness of UTT. The scale of academic entrepreneurship and the associated activities of the transfer units increase over time, but the missions, visions, and goals of the universities differ. That is why choosing suitable performance indicators is crucial (Sutopo et al., 2019). A comprehensive approach to performance assessment, combining quantitative measures and qualitative assessments, is needed to adequately reflect the different impacts of UTT efforts, taking into account the different objectives and scopes of universities (Noh & Lee, 2019; Olvera et al., 2021).

4.3 Popularity of university technology transfer research over time

As part of our analysis, we considered the popularity of UTT research over time, addressing our second research question: Which areas in the UTT literature are gaining attention and offer significant potential for further research? To discern how the salience of each cluster has evolved over the past decades, the cluster allocations have been aggregated for each article across the various publication years. Due to variations in the number of topics encompassed by each cluster, we have computed the average proportion for each year. The evolution of the 20 different topics is also analyzed, whereby all topics of each cluster are included as independent variables. We used linear regression analysis as a robust statistical tool to explore the dynamic trends among our clusters and to identify popular and unpopular themes within the UTT research domain (see Table 5). Our research shows a remarkable interest in topics related

Table 5 Popularity of clusters in the university technology transfer literature

Cluster/Year	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020	2020–2022
UTT context			unpopular***	unpopular***	unpopular***	unpopular***	unpopular***
UTT capacity					popular***	popular***	popular***
UTT mechanism			popular***	popular***	popular**		
UTT policy				unpopular*			
Observations	70	137	265	530	923	1542	1944

Note: In order to obtain a more comprehensive overview of the 20 topics that we have identified, we have undertaken the creation of four distinct clusters. The 20 individual topic allocations per article have been integrated into the four respective clusters to which each topic pertains. Consequently, each article is associated with four distinct cluster allocations. We control the number of topics for each cluster because they vary in the number of topics they contain. The extracted citation report facilitates the examination of citation patterns over time, enabling the observation of trends and fluctuations in citation frequencies. The regression coefficient (see Appendix III for details) represents the average increase in the dependent variable "citations recorded by WoS" when the independent variable "cluster share per article" is increased by one unit. A coefficient greater than zero indicates a positive relationship (which we have presented as a popular cluster), while a coefficient less than zero indicates a negative relationship (which we have presented as an unpopular cluster). The number of stars next to each regression coefficient indicates its level of significance: "* = significant at the 10% level", "** = significant at the 5% level", "*** = significant at the 1% level"

to the cluster UTT capacity. As the current topics and proposals for future studies show, the cluster UTT capacity seems to be a popular theme in UTT research. However, our analysis also shows that the emphasis on issues in the cluster UTT context is decreasing, especially with regard to *institutions* and *units*. Our analysis of the data shows that research interests in relation to different clusters in the field of UTT have changed over time. The evolution of the different clusters over time can be analyzed on the basis of the data provided.

Current topics in the cluster UTT capacity, such as *processes*, *enablers*, and *mission*, are evident and seem to attract significant research attention in the UTT research domain. However, there are also several topics from different clusters, such as *spin-offs* and *metrics*, in which the academic community is currently showing interest. This may indicate that these topics are considered particularly relevant or promising for future UTT research. Within the cluster UTT context, our analysis highlights that there seem to be limited prospects for future research efforts throughout the period from 2001 to the present, as evidenced by the low number of citations. The cluster UTT capacity has been recognized as a popular area of research since 2011, as evidenced by the increasing number of citations. It is worth noting that the cluster UTT mechanisms showed a significant increase between 2001 and 2015. During this period, research activity and academic interest in this field peaked, as evidenced by citation metrics. Between 2006 and 2010, the cluster UTT policy was losing momentum. An analysis of the individual topics is shown in Appendix I.

5 Discussion

In many ways, topic modeling is a useful method in social research. On the one hand, it allows researchers to quickly gain insights into the main content of large-scale text data. On the other hand, topic modeling transformations allow scholars to discover patterns in large quantities of text that would otherwise only be visible by manual coding. This method can thus be used as an inductive tool to find previously unexplored categories. Employing this method allowed us to obtain an overview of relevant topics in the UTT literature. Research has dealt with how UTT institutions and units successfully transfer knowledge and technology to the industrial sector, focusing on barriers (Siegel et al., 2004), productivity (Siegel et al., 2003a), commercialization (Gregorio & Shane, 2003; Siegel et al., 2007), and mechanisms (Debackere & Veugelers, 2005). Consequently, analyzing the efficiency of these actors has been a pertinent focus of the literature (Teixeira & Mota, 2012). Our research consolidates knowledge about UTT in order to highlight the themes and show the importance of UTT in science. The results of our investigation therefore provide further opportunities to broaden our understanding of the UTT literature.

Our study makes several contributions. First, in contrast to and to complement bibliometric studies of UTT, our study offers a differentiated understanding of the complex structure of UTT research and its evolution over time. Our findings contribute to the understanding that research topics have evolved differently over time. We show that earlier UTT research focused on fundamental aspects such as outcomes, legislation, or university–industry collaborations, while more recent research focuses on issues related to UTT capacity. This reflects the fact that successful UTT requires a variety of skills and knowledge across traditional disciplinary boundaries. We emphasize that the concentration of UTT research increasingly integrates interdisciplinary approaches, which is reflected in the evolution of our identified themes. Our study provides researchers with an

understanding of the evolution of the UTT research but also offers a guide for future researchers by enabling them to focus their efforts on areas that are of the utmost importance and relevance in the ever-changing landscape of UTT.

Second, by employing a text mining approach, our analysis of the development of UTT research goes beyond identifying new areas. It also provides valuable insights into important research trends over a longer period of time. We offer a historical context that highlights the development of research interests in the field by emphasizing the changing focus of UTT research. This contextual understanding is of great importance for researchers and practitioners who want to understand the broader pathways of UTT research. Understanding the evolution of themes and their dynamics provides important insights for researchers, practitioners, and policy makers, helping them to improve strategies to promote UTT by focusing on the clusters that are particularly relevant to the current and future UTT landscape. The increasing popularity of the themes we identified suggests a deeper engagement with the internal and external conditions affecting UTT for successful action.

Third, our quantitative analysis of the literature offers a systematic view of the emergence and development of various topics in UTT research. This approach adds to our understanding of how research themes have evolved over time and how important different topics are. Consequently, our study brings conceptual clarity, a holistic view of the literature, insights into new research areas, and a comprehensive analysis of research trends over time. These contributions not only expand our understanding of UTT, but also provide a useful foundation for future research endeavors that will ultimately advance the UTT field. By identifying and categorizing relevant UTT topics, we facilitate a clearer understanding of the current landscape of the field and enable researchers to identify areas of interest and relevance.

6 Conclusion

To interpret our findings in a meaningful way, some limitations of our empirical methods must be considered. The underlying assumptions that topic modeling makes about the nature of texts are an issue, potentially leading to data shortages and difficult word correlations (Chen et al., 2023). Furthermore, it is possible that the use and analysis of article titles and abstracts as part of our methodology is not sufficient to provide a comprehensive understanding of the topics discussed in the analyzed articles. Therefore, the inclusion of the entire content of the investigated papers could lead to additional insights. As authors, we have defined certain criteria by using our expertise and judgment to create a framework for our study. These criteria included selecting the number of topics published by the LDA, labelling the topics, determining the amount of self-created clusters, and allocating themes to these cluster groups. The selection of keywords in our study does not reflect all potential topics that are represented in the literature about UTT. Furthermore, the regression analysis approach to analyze research trends is subject to limitations. For example, certain topics with significant practical implications could be prioritized, especially if they have a direct impact on politics, industry, or society. Certain topics may have been selected because of their topicality or their particular interest in the research community. This indicates that they are new or that UTT research has changed due to new circumstances. We give relevance by considering the number of citations per article as a dependent variable in our regression analysis. However, there are also other factors that affect the popularity of articles.

Future research could explore the evolving landscape of UTT capacities and dive into the nuanced dynamics of emerging areas such as spin-offs and metrics. Further research could explore the factors contributing to the observed decline in academic interest with regard to the UTT context, with particular emphasis on institutions and units. Furthermore, scholars should study the themes around enablers and processes, which would improve our understanding of the various facets of UTT. Based on our study, Table 6 shows exemplary research questions that should be addressed in future research. We hope that future studies will further enhance our understanding of the field of UTT and that researchers make use of our identified pathways to guide their own research efforts.

Table 6 Future avenues of research

Cluster	Exemplary research questions
UTT context	♣ How have the framework conditions and the dynamics of UTT changed since the 1980s and what factors have influenced these changes?
	♣ What will be the future role of technology transfer offices in the context of changing UTT trends?
	♣ What are the key challenges and enabler for the UTT in less developed and emerging country context?
	♣ To what extent have the strategies and approaches of UTT units changed over time to respond to new challenges and opportunities in the field of UTT?
	♣ To what extent do global trends in UTT vary, and what cultural, economic, and political influences shape different practices and priorities in various regions and countries?
	♣ What barriers and challenges do technology transfer offices encounter in the context of digitalization?
UTT capacity	♣ What impact do changes in capacities have on the success of UTT initiatives at universities?
	♣ How are UTT processes being digitalized and what specific digital tools are these institutions using in their processes to make UTT more efficient and innovation more successful?
	♣ What role does UTT and entrepreneurial education play at universities?
	♣ To what extent are social innovations integrated into the third mission of universities?
	♣ What are the skills and role competencies need to support UTT?
UTT mechanism	♣ How can measurement and evaluation systems be introduced to identify the success of the transfer of social innovation to the private sector and/or society?
	♣ What insights can be gained from a comparative approach to various UTT mechanisms to better understand their effectiveness and sustainability?
	♣ How have the performance and effectiveness of UTT units evolved over time, and what specific measures or strategies have contributed to certain offices improving their performance?
	♣ To what extent has the adoption of digital tools contributed to enhancing the efficiency and capability of UTT units and their engagement with stakeholders?
UTT policy	♣ What adjustments in political frameworks could contribute to further fostering the dynamics of UTT and sustainably influencing the innovation landscape?
	♣ What impacts do political frameworks have on the broader innovation ecosystem, particularly concerning the growth of start-ups, industries, and regional economic development?
	♣ Which methods and metrics can be further developed for assessing the effectiveness and efficiency of UTT activities?
	♣ How have political frameworks for UTT evolved over time, and what factors contribute to the observed stability in the political landscape?

Appendix I: popularity of topics in the university technology transfer literature

Cluster	Topic	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020	2020–2022
UTT context	UTT institutions				unpopular*	unpopular*	unpopular***	unpopular***
	UTT unit			unpopular***	unpopular***	unpopular***	unpopular***	unpopular***
	UTT stakeholder			unpopular*	unpopular**			
	Observations	70	137	265	530	923	1542	1944
UTT capacity	UTT infrastructure							
	UTT process					popular***	popular***	popular***
	UTT enabler				popular*	popular***	popular***	popular***
	UTT mission		popular**				popular***	popular***
	UTT activities							
	Observations	70	137	265	530	923	1542	1944
UTT mechanism	UTT legislation		popular***			unpopular**	unpopular***	unpopular**
	Spin-off		popular*		popular***	popular***	popular***	popular***
	Patenting and licensing							
	UTT commercialization						unpopular**	unpopular**
	University-industry collaboration				popular**			
	UTT outcome			popular***	popular***	popular*		
	Observations	70	137	265	530	923	1542	1944
UTT policy	UTT support							
	UTT impact			unpopular*		unpopular**	unpopular*	
	UTT metrics			popular***	popular*	popular***	popular**	popular**
	UTT performance				unpopular**	unpopular**		
	UTT output			unpopular**	unpopular***	unpopular**	unpopular**	
	UTT evaluation							
	Observations	70	137	265	530	923	1542	1944

Note: The extracted citation report shows citation activity over time, making it possible to identify trends and changes in citation rates. The regression coefficient (see Appendix II for details) represents the average increase in the dependent variable "citations recorded by WoS" when the independent variable "topic share per article" is increased by one unit. A coefficient greater than zero indicates a positive relationship (which we have presented as a popular topic), while a coefficient less than zero indicates a negative relationship (which we have presented as an unpopular topic). The asterisks *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively

Appendix II: regression about relation between citations and topics

Cluster	Topic	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020	2020–2022
UTT context	UTT institutions	1.871	-1.513	-3.461	-12.047*	-13.974*	-23.923***	-20.049***
		(2.776)	(2.885)	(4.024)	(6.798)	(7.429)	(7.449)	(6.384)
	UTT unit	-1.704	-2.639	-8.807***	-22.038***	-26.152***	-32.832***	-33.182***
		(1.852)	(1.716)	(2.712)	(5.167)	(5.847)	(6.145)	(5.491)
	UTT stakeholder	3.602	-3.447	-12.263*	-16.098**	-8.467	-1.730	-4.929
		(2.954)	(2.615)	(4.712)	(7.736)	(7.959)	(7.045)	(5.864)
	Constant	0.140	0.790***	2.480***	5.442***	6.148***	7.382***	7.248***
		(0.281)	(0.205)	(0.395)	(0.638)	(0.639)	(0.599)	(0.508)
	Observations	70	137	265	530	923	1542	1944
UTT capacity	UTT infrastructure	-0.973	-3.753	0.538	-3.872	-8.788	-4.841	0.495
		(3.566)	(2.497)	(5.711)	(8.906)	(8.354)	(7.522)	(6.286)
	UTT process	0.517	-1.259	2.109	2.528	19.052***	30.898***	28.411***
		(3.647)	(1.660)	(6.209)	(6.616)	(6.043)	(5.952)	(5.295)
	UTT enabler	4.780	-2.426	8.856	14.666*	21.234***	26.623***	24.969***
		(3.986)	(2.988)	(6.385)	(8.150)	(6.308)	(5.215)	(4.425)
	UTT mission	1.078	3.017**	0.443	0.682	4.338	17.433***	21.744***
		(2.703)	(1.509)	(3.836)	(6.714)	(6.685)	(6.737)	(5.903)
	UTT activities	-5.195	3.242	-5.371	-4.630	-3.578	-10.228	-4.162
		(3.972)	(2.899)	(6.240)	(9.398)	(8.202)	(6.397)	(5.312)
	Constant	0.271	0.433*	0.746	2.145**	1.864**	1.316	0.744***
		(0.383)	(0.255)	(0.581)	(0.912)	(0.873)	(0.805)	(0.965)
	Observations	70	137	265	530	923	1542	1944

Table (continued)

Cluster	Topic	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020	2020–2022
UTT mechanism	UTT legislation	-3.651	10.711***	0.001	-9.007	-18.886**	-22.753***	-13.475**
		(4.249)	(2.545)	(4.898)	(8.249)	(7.906)	(6.818)	(5.694)
	Spin-off	-2.291	4.909*	3.439	18.860***	18.984***	18.887***	12.569***
		(5.217)	(2.575)	(3.262)	(4.898)	(5.052)	(4.768)	(4.206)
	Patenting and licensing	1.293	2.240	3.285	10.481	-4.199	4.749	4.643
		(4.719)	(1.759)	(6.059)	(9.807)	(8.233)	(7.157)	(6.026
	UTT commercialization	-1.015	-2.497	3.983	3.590	-4.345	-13.366**	-12.312**
		(2.251)	(3.263)	(3.530)	(5.968)	(6.014)	(5.819)	(5.232)
	University-industry collaboration	-5.532	-1.868	7.368	18.223**	4.863	-0.465	-6.274
		(6.222)	(2.159)	(5.250)	(8.090)	(7.657)	(6.992)	(5.936)
	UTT outcome	1.519	-1.134	15.467***	16.690***	7.230*	-1.985	-5.528
		(2.461)	(1.141)	(2.771)	(3.896)	(4.110)	(4.102)	(3.745)
	Constant	0.683*	-0.039	-0.644	-0.390	3.228***	5.167***	5.425***
		(0.408)	(0.308)	(0.550)	(0.938)	(0.946)	(0.884)	(0.768)
	Observations	70	137	265	530	923	1542	1944
UTT policy	UTT support	3.798	-2.072	1.273	4.030	7.204	2.248	2.177
		(4.279)	(2.082)	(5.169)	(7.645)	(7.562)	(7.326)	(5.287)
	UTT impact	-0.571	-0.749	-6.837*	-11.240	-16.977**	-11.119*	-4.337
		(2.949)	(1.462)	(4.075)	(7.175)	(6.717)	(6.232)	(5.536)
	UTT metrics	-5.009	1.909	17.853***	13.258*	19.170***	16.205**	13.853**
		(5.066)	(1.586)	(5.770)	(7.790)	(7.258)	(6.726)	(5.767)
	UTT performance	-3.262	0.580	-6.261	-13.931**	-15.505**	-8.280	-7.329
		(3.677)	(1.572)	(4.069)	(6.347)	(6.171)	(6.229)	(5.341)
	UTT output	0.837	4.029	-6.980**	-21.598***	-13.548**	-12.166**	-7.594
		(2.088)	(2.696)	(3.478)	(6.038)	(6.118)	(5.861)	(4.968)
	UTT evaluation	2.553	-3.384	-3.885	9.142	13.161	10.801	8.772
		(3.794)	(3.871)	(5.049)	(7.931)	(8.075)	(7.736)	(6.475)
	Constant	0.325	0.401	1.425**	3.654***	3.875***	4.513***	4.090***
		(0.443)	(0.293)	(0.647)	(0.981)	(0.988)	(0.954)	(0.820)
	Observations	70	137	265	530	923	1542	1944

Note: The asterisks *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Standard errors are in brackets

Appendix III: regression about relation between citations and clusters

Cluster/Year	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020	2020–2022
UTT context	1.423	-3.463	-23.670***	-53.382***	-55.078***	-64.013***	-61.613***
	(3.954)	(2.728)	(5.866)	(10.382)	(11.242)	(11.193)	(9.666)
UTT capacity	1.689	0.720	5.066	12.755	51.843***	77.492***	81.484***
	(7.984)	(5.202)	(11.988)	(18.070)	(16.906)	(15.117)	(12.955)
UTT mechanism	-4.714	3.546	45.544***	83.881***	35.677**	1.469	-13.774
	(7.450)	(4.801)	(10.132)	(16.297)	(16.745)	(16.038)	(14.054)
UTT policy	1.179	1.782	-19.165	-36.977*	-24.055	-11.676	-0.977
	(8.338)	(5.718)	(12.720)	(19.416)	(19.391)	(18.695)	(15.951)
Observations	70	137	265	530	923	1542	1944

Note: In order to obtain a more comprehensive overview of the 20 topics that we have identified, we have undertaken the creation of four distinct clusters. The 20 individual topic allocations per article have been integrated into the four respective clusters to which each topic pertains. Consequently, each article is associated with four distinct cluster allocations. We control the number of topics for each cluster because they vary in the number of topics they contain. The extracted citation report facilitates the examination of citation patterns over time, enabling the observation of trends and fluctuations in citation frequencies. The regression coefficient represents the average increase in the dependent variable "citations recorded by WoS" when the independent variable "cluster share per article" is increased by one unit. A coefficient greater than zero indicates a positive relationship, while a coefficient less than zero indicates a negative relationship. The asterisks *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively

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