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RESEARCH

(Re)envisioning the role of technology transfer intermediaries in socio-technical transition

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Abstract
Recent year has seen a rise scholarly interest in examining the functions and value of technology transfer intermediaries (TTIs) in spurring and commercializing sustainable innovations. In this paper, we embark on a conceptual endeavor that explores existing research on TTIs to identify their various roles, structure, networks and practices that define their organizing patterns and schemas. We adopt an envisioning approach to reconceptualize the role of TTIs in sustainable transition and go on to reconceive the core insights from the extant literature to inform ways to facilitating a global socio-technical transition agenda. This attempt thus set forth a system that captures a global TTI market for the exchange of technological capabilities across regions. Our study contributes to discourses at the intersection of international technology transfer intermediaries and sustainability transition.

Keywords Technology transfer intermediaries · Innovation ecosystem · Sustainability · Sociotechnical transition

1 Introduction

The increasingly globalized efforts to stimulate widespread economic growth through innovation, which has seeded several innovation models including a quadruple/quintuple helix innovation model underpinned by a multilateral flow of scientific output, expertise, and financial resources between industries, research institutions, government and the broader society, has come to inform contemporary innovation management policies (Carayannis,

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2018; Chang et al., 2022; Sarpong et al., 2023). Within this eclectic system, universities offer fertile knowledge-intensive environments to stimulate the scientific exploration and innovation, government policies and expenditures also provide the necessary enabling environment to expedite the transfer and application of research, while industry assumes an indispensable role in assimilating technological research and bringing into fruition (Bi et al., 2017; Rothaermel et al., 2007; Perkmann et al., 2021).

The contemporary practice of this helix of innovation model has however seen a rising trend of Technology Transfer Intermediaries (TTIs) who ensure and expedite the transfer and application of basic innovation research for widespread economic growth (Noviaristanti et al., 2023). Being ascribed different forms of labelling, TTIs are typically identified as Technology or Knowledge Transfer Office (TTO/ KTO), Incubator Intermediaries (II), Collaborative Research Centers (CRC), and competence centers (Fasi, 2022; Hayter et al., 2018; Wonglimpiyarat, 2016). These intermediaries engage in various functions such as brokerage, legal advisory, boundary-spanning, and commodification and commercialization of scientific research (Cunningham & O'Reilly, 2018; Gubitta et al., 2016). TTIs are thus entities that are established to facilitating collaboration between actors within the innovation ecosystem through their complementary activities that help realize the impact of research and technological development programs. They establish a network of interdependencies, define suitable organizational structures, and adopt specific practices (Massa et al., 2022; Sarpong et al., 2017) to stimulate knowledge commodification while simultaneously addressing impediments in the knowledge transfer process (Link & van Hasselt, 2019; Nugent & Chan, 2023).

Despite the compounding evidence of TTIs driving cutting edge innovation and facilitating the commercialization of innovation outputs, the presence of formal TTIs sometimes offer only marginal or even negative impact on the creation of technology and spin-offs (Meoli & Vismara, 2016). Furthermore, given the limited investment in high-end technological development in contexts marked by immature TTI market and resource constraints (Henry et al., 2009; Takata et al., 2022), the instrumental role of TTIs in the innovation process has yet to be fully yield widespread impact, thereby reinforcing geographical dominance in the design and organizing of the innovation ecosystems (Sarpong et al., 2024). In addition, extant emphasis on TTIs promoting cutting edge technologies, such as artificial intelligence, big data, and the metaverse, has continued to render innovation capabilities the preserve of few economic high powers (De Noni et al., 2018)—hence, we continue to battle with limited widespread socio-economic benefit from innovations. As Henry et al. (2009, p. 237) argue "by focusing primarily on technology transfer, it is likely that this literature provides only a partial explanation of cross-country productivity differences". This concern is very much existential, particularly given the global efforts required to realize the transitioning of current socio-technical system to a more sustainable frontier (Civera et al., 2024). Yet, how can we construct a shared global vision of the role of TTIs in the call for sustainability transition?

We argue that addressing this question relies on an effort to conceive, at the nascent stage at least, a shared vision that embeds diverse contextual configurations that allow TTIs to flourish in their role to trigger sustainable innovation at scale, and yield far-reaching socio-economic benefit. Within this agenda also lies an important need to attend to and re-envision the existing organizing networks, structures, and practices of TTIs as central to stimulating efforts that can lead to the realization of growth-driven sustainable innovation system

(Bishop et al., 2011; Carlsson et al., 2008; Chang et al., 2022; Sarpong et al., 2023). In this regard, we invoke lessons from the potentialities and limits of existing means of organizing TTIs to argue that securing a sustainable future require developing a globalized innovation system that integrate the varying configurations within which TTIs are structured and organized. We explore existing stock of knowledge on TTIs to tease out and reconfigure the organizing networks, structures, and practices for the purpose of re-envisioning their role in tackling societal challenges.

To the extent that our conceptual endeavor seeks to provide immersive understanding of the important literature on TTIs, we embark on process of discovery to envision the existing knowledge in ways that lead to our reconceptualization of the role of TTIs in accelerating sustainable innovations and securing widespread economic benefit. By delving into the organizing networks, structures, and practices of TTIs, our envisioning approach (Van der Helm, 2009) allows us to explicate common approaches for re-defining the innovation ecosystem to place TTIs at the center-stage of securing a sustainable future. Hence, we define strategic new pathways that can be conceived of TTIs in our existing socio-technical and make important claims about their efforts in spurring innovation. In this vein, we offer a theoretical framework that captures the centrality of TTIs in strengthening the interconnectedness and multilateral flow of knowledge, competencies, innovations and resources among complementary actors in the innovation ecosystems (de Falani & Torkomian, 2023; Good et al., 2019) in ways that could define common approached to addressing societal challenge.

The remainder of the paper is structured as follows. In the next section, we define our conceptual design and highlight our approach to searching, selecting, and analyzing the relevant literature sample for our study. Next, we provide a detailed discussion on TTIs based on emergent themes in the extant studies. Following this, we unpack some potential strategic new pathways, including a conceptual model, to envision and reposition TTIs within contemporary socio-technical transition efforts. We finish by discussing our main contributions and present new opportunities for future research.

2 Research procedure

In pursuant of our aim to re-envision the role of TTIs within a global effort to achieving sustainable transition, we sought to build insights from extant studies on TTIs a serve as a conceptual basis for our proposed global TTI model. Therefore, given that literature on TTIs is extensive and encompasses multiple disciplines (Good et al., 2019), we adhered to systematic literature review approach (Abid et al., 2024; Barros et al., 2020) to embark on a keyword search on academic database including Web of science, Scopus, JSTOR, Science Direct and Business Source Complete. We utilized keywords such as ["technology + transfer"] or ["university + industry"] along with different combinations of the terms "offices", "units", "intermediaries", "liaisons", "roles", "structures", "networks" "model" "collaboration", "innovation", and "triple helix". This initial search yielded a total of 342 peer-reviewed publications.

We then progressed to scan and select most pertinent articles. The first step entailed eliminating duplicated articles within the databases, leading to a sample size of 241 articles. Subsequently, a thorough examination was conducted of the abstracts of the remaining articles to ascertain their relevance to the research objective. We eliminate articles that did

not examine the role, practices, structures, and organizing networks of TTIs. The literature sample was subsequently restricted to articles published in peer-reviewed journals in the top quartile on the Scimago Journal and Country Rank system. A sample of 83 articles were retained and further categorized using identifiers such as the journal name, author(s), title, year of publication, research question, methodology, and key findings. In addition, we engaged in snowballing through cross-reference of the literature sample (Boakye et al., 2022) where additional 23 publications were identified and added. The final sample was hence 106 articles.

We analyzed the final article sample by re-reading their key findings and contributions and the future research suggested. In doing this, the central study details, themes, subthemes and quotes verbatim from the selected sample were extracted utilizing the JBI Qualitative Assessment and Review Instrument data extraction tool (Lockwood et al., 2020). The derived themes and quote verbatim were combined in Microsoft Excel and later analyzed with the meta-aggregation approach (Abid et al., 2024; Lockwood et al., 2020). Additionally, to strengthen the reliability of the derived themes, the data synthesis was done by two authors and subsequently controlled and verified by the third author. The themes extracted from the selected studies were done through recurrent reading of the complete manuscript of the studies that passed the abstract screening. The derived themes and concepts were clustered into categories based on connected concepts. The categories were then grouped into themes with a general statement representing all the synthesized themes, including roles, organizing networks, structures and practices. Table 1 provides a summary of some salient articles in our final sample.

3 Labelled roles of TTIs

The fundamental role of TTIs has been to bridge the gap between academia and industry, as well as aid the commercialization of innovation output. In this vein, TTIs ensure that basic research match with industry needs and serve as a channel to escape the "valley of death" in innovation (Son et al., 2022; Takata et al., 2022). A noteworthy aspect this role emerges from the literature as a leap stemming from commodification and commercialization functions of TTIs. The commodification and commercialization of science-based research is the center-stage of TTI functions of transforming scientific knowledge, physical products, working procedures, and concepts into marketable outputs to extract value (Brock et al., 2020). This involves identifying, protecting, negotiating, licensing technologies, negotiating agreements, and managing the associated intellectual property rights (Battistella et al., 2016; Gonçalves et al., 2023). Furthermore, it includes multifaceted functions such as marketing, intellectual property safeguarding, and administrative overseer of licensing agreements (Chang et al., 2022). Furthermore, an important extension of the role of TTIs that has emerged in the extant literature is the legal advisory role (Brantnell & Baraldi, 2022; Fini et al., 2011). The significance of this role hinges on the legal complexities encircling IP management which, as Fitiu (2017) observed, TTIs employ a staffing composition consisting of a combination of scientists and legal experts to ease such challenges. TTIs thus provide competent workforce adept at effectively managing innovation and legal affairs, including resolving intellectual property rights disputes, negotiating licensing agreements, and providing legal counsel to innovating firms and scientists. This role is further rooted

Table 1 Summary of some key insights from the literature sample

Roles	Organizing network	Organizing structure	Practices
· TTIs engage in the systematic up-skilling and reskilling of university personnel (Compagnucci & Spigarelli, 2024). · TTIs effectively serve as boundary spanners by facilitating knowledge flows and fostering the development of structured, motivating collaborative networks (Ferrer-Serrano et al., 2022). · TTIs ensure that academic research matches with industry needs and serve as a channel to escape the "valley of death" in innovation (Takata et al., 2022). · TTIs implement effective governance and coordination mechanisms that operate in synergy with the governing bodies of the university (Villani et al., 2017). · TTIs enhance an arms-length transaction between complementary actors by ensuring that IP rights and commercial interests are clearly defined and protected (Huyghe et al., 2014). · TTIs identify, assess, protect, promote, apportion profit from technologies and provide post-deal support (Gumbi, 2010). · TTIs expedite the transfer of scientific knowledge, products, procedures, and concepts into marketable outputs (Hertzfeld et al., 2006).	· Constructing and strengthening internal and external collaborations with key stakeholders in the ecosystem is crucial for enhancing cooperative efforts (Compagnucci & Spigarelli, 2024). · Gatekeepers are crucial in R&D projects with high technological intensity and tacit knowledge, as these factors increase the likelihood of communication barriers among individuals (Gonçalves, 2023) · Formal networks have been associated with a heightened degree of rigidity (Ferrer-Serrano et al., 2022). · Social connections within the technology transfer ecosystem are facilitated by mutual trust, familial ties, and shared experiences (Quiñones et al., 2019). · Relationships among university TTIs are maintained through national associations (Battaglia et al., 2017). · Intermediary organizations address proximity dimensions based on the experience of academic and industrial actors and the nature of knowledge transferred (Villani et al., 2017). · TTIs assume the role of a system integrator with the technology transfer network, partaking in cooperative endeavors, consolidating resources, and establishing a strategic alliance (Huyghe et al., 2014). · Occupying structural positions within TTIs facilitate networking with industry players (Stovel & Shaw, 2012). · A proficient technology transfer network comprises actors who are skilled at networking and act with integrity (Bercovitz & Feldman, 2006). · Practitioners with prior experience with the specific research partners expedites the formation of a new collaborative R&D agreement (Hertzfeld et al., 2006).	· Organizational structures significantly affect various TTI characteristics, including resource flow, relationships, and commercialization strategies, which can subsequently influence TTI performance (Compagnucci & Spigarelli, 2024). · Internal organizational structures of TTIs are commonly categorized as the trichotomy of centralized, decentralized, and hybrid structures (Ozman & Parker, 2023). · The adoption of suitable structures serves as the basis sharing and absorbing of best practices among TTIs (Battaglia et al., 2017). · The concept of control is a determining factor in the ownership and governance of TTIs which exhibit high conformity with their generic organizational practices (Villani et al., 2017). · TTIs, particularly within universities, operate under a centralized administrative structure (Arqué-Castells et al., 2016). · Research organizations have two distinct structures to managing commercialization: the separation model and the integration model (Derrick, 2015). · Hybrid structures enable research groups to actively engage in the commercialization of their findings (Brescia et al., 2016). · University policies significantly influence the organizational structure of knowledge transfer (Bercovitz & Feldman, 2006). · Extremal Intermediaries are known to have more expertise and understand the business process better than the universities themselves (Hertzfeld et al., 2006).	· Promoting an entrepreneurial mindset among academic and non-academic staff and students enhance innovation and commercialization efforts (Takata et al., 2022). · The practice of benchmarking may produce harmful results due to substantial variations in national and institutional context (Gumbi, 2010). · Studies suggest that the complete reproducibility of practices may not guarantee successful commercialization in different settings (Walter et al., 2018). · The practice of informal commercialization is a valuable alternative, specifically in the transfer of tacit knowledge (Audretsch et al., 2006). · Research institutions in emerging economies prefer a unified IP management approach, unlike developed economies that maintain separate policies for IP rights (Jefferson et al., 2017).

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in objective is to enhance an arms-length transaction between complementary actors while simultaneously stimulating commercialization.

Furthermore, boundary-spanning role remains core to the TTIs. TTIs are widely known to facilitate meaningful engagement between complementary actors within innovation ecosystem (Bolzani et al., 2021; Huyghe et al., 2014). This significant responsibility involves the efforts of TTIs to cultivate and orchestrate a stakeholder network between complementary actors to expedite the bilateral exchange of knowledge and resources within the technology transfer market (Ozman & Parker, 2023; Villani et al., 2017). As Villani et al. (2017) highlights, the role of TTIs in establishing a symbiotic nexus between research institutions and financiers has been duly underscored to propel academic research. For example, in so far as we observe, the boundary-spanning role catalyzes the formation of more tightly knitted social networks among complementary actors, expediting the commodification and commercialization of science-based research to industry (Battistella et al., 2016). Furthermore, sourcing and harnessing external legal expertise via boundary spanning has demonstrated its profound ability to expedite licensing IP complex technological outcomes (Holgersson & Aaboen, 2019).

In recent years, however, there has been several contemplations over the evolving roles of TTIs. A notable surge in this scholarly pursuit points to the commodification and commercialization role of TTI, as they have been observed to introduce a significant temporal lag within the technology transfer ecosystem. Fasi (2022), for instance, argued that the process of transforming science-based research into a commercially viable product is a protracted endeavor as it includes complex intellectual property management functions. This significantly impedes their capacity to effectively carry out their commodification and commercialization functions (Jefferson et al., 2017; Sengupta & Ray, 2017). Yet, this challenge largely stems from existing frameworks not properly synchronized with the structures in diverse contexts, culminating in inertia in TTI operations and temporal lag (Collier, 2007; Cunningham & O'Reilly, 2018). Further, several scholars contend that TTIs have historically prioritized patent generation over other roles, thereby transitioning from being active entities to assuming a more passive role (Swamidass & Venubabu, 2009). Litan et al. (2007) had however hinted that focusing on the commodification roles has an unintended consequence of shifting focus away from other vital roles, like providing legal advisory and nurturing meaningful connections among various complementary actors.

On the boundary-spanning role, scholar have argued that this may occasionally yield inadvertent adverse consequences, such as the emergence of structural irregularities and gatekeeping. Thus, TTIs may professionally engage in the act of discerningly disseminating or filtering information, knowledge flow and resources, thereby impeding the potential for collaboration and interdependence within the ecosystem (Haas, 2015). The phenomenon of boundary-spanning may result in gatekeeping under circumstances where TTI typically assert a monopoly over the dissemination of knowledge, allocation of funding, or the facilitation of connections among relevant complementary actors (Awazu, 2004). Moreover, there is a contention that this monopoly over the dissemination of knowledge may stem from an individual's formal position or their competence in personal social networking (Stovel & Shaw, 2012). Yet, the significance of the boundary-spanning function in transferring technology research to industry can never be trivialized, as existing literature suggests that innovators who maintain the role of intermediaries demonstrate higher levels of productivity compared to ordinary inventors (Gonçalves et al., 2023). Additionally, these

intermediaries are shown to generate inventions of superior quality (Gonçalves et al., 2023; Le Gallo & Plunket, 2020).

4 The organizing networks

The organizing network in TTIs lies in a constellation of complementary actors functioning within the TTI market connecting knowledge and business ecosystems (Janusz et al., 2018). Within this web of operation, TTIs assume the role of a system integrator, partaking in cooperative endeavors, consolidating their resources, and establishing a strategic alliance (Botchie et al., 2018; Zhuang et al., 2021). In recent years, there has been a notable surge in the scholarly pursuit of understanding the complexities surrounding organizing networks within the technology transfer ecosystem. This increasing popularity of organizing networks has been attributed to the profound influence of the synergistic effect on the technology/knowledge transfer ecosystem (Noh & Lee, 2019). Thus, to achieve optimal efficiency in research commercialization, it is imperative for all complementors to actively engage, foster communication, and seamlessly integrate diverse forms of knowledge emanating from both academic and industrial spheres (Schaeffer & Matt, 2016; Villani et al., 2017). The extant literature thus suggests that efficient technology transfer network comprises of a distinctive fusion of an individual's competencies, encompassing the art of forging connections and embodying a sense of virtuous conduct (Bercovitz & Feldman, 2006). For example, Collien (2021) argued that entities possessing the combinatorial qualities of cultural, interpersonal, and linguistic competence possess the capacity to manifest a vastly expanded array of projects, rendering them more coveted than those possessing solely cultural aptitude. Thus, the possession of requisite skills, knowledge, and competence to effectively collaborate with complementary producers, and the unyielding passion and resilience required to fulfil network responsibilities, collectively contribute to the network's significance level (Comacchio et al., 2012).

Establishing this relational network often starts through informal mechanisms, such as social networks, which progressively metamorphose into more formal avenues, such as consultancy and sponsored research agreements (Bercovitz & Feldman, 2006; Ozman & Parker, 2023). It is crucial to acknowledge that social networks ought not to be regarded as a surrogate for the sacred rituals of formal organizing network practices (Kereri & Harper, 2019). Hence, it is widely acknowledged that formal networks play a substantial role in facilitating the advancement of innovation and the successful commercialization of research endeavors (Battaglia et al., 2017; Good et al., 2019). According to Stovel and Shaw (2012), individuals within the TTI derive advantages from occupying structural positions that facilitate networking with industry players. Such positions have been observed to allow them to establish connections with key stakeholders within the industry (Ozman & Parker., 2023). Yet, formal networking has long been associated with a heightened degree of rigidity and the active engagement of individuals with advanced expertise (Ferrer-Serrano et al., 2022).

In addition, a concern about proximity has been highlighted and associated with organising network in the technology transfer ecosystem. Proximity, which encompasses various dimensions including institutional, organizational, cultural, social, geographical, and technological aspects, have distinctive effects on the interconnectedness of participants within the technology transfer network (Knoben & Oerlemans, 2006). Related studies (e.g. Good et

al., 2019; Villani et al., 2017) also suggest that it is important to highlight proximity in organizing networks as organizations enhances their competencies, capabilities, and resources using networking, inter-organizational information sharing, transfer, and technology acquisition. Intermediaries who possess closer proximity and a more comparable level of authority to the source of knowledge are more likely to exhibit a greater degree of knowledge transfer as they leverage on their stance to for a denser network (Ferrer-Serrano et al., 2022). Such mature interactions within and between various forms of proximity could play a crucial role in facilitating the operation and commercialization of scientific research (Knoben & Oerlemans, 2006). Geographical proximity also could confer advantages to TTIs and industry relations, particularly when direct, in-person interactions is necessary to exchange knowledge (Alexandre et al., 2022). Likewise, in instances where organizations pursue predominantly codified knowledge, such as patents, the influence of geographical proximity becomes instrumental in facilitating such process (Bishop et al., 2011).

Furthermore, TTIs predominantly direct their efforts towards enhancing cognitive and organizational dimensions of proximity (Villani et al., 2017). Thus, in the context of inter-organizational networking, participating actors often possess distinct systems of representation, sets of beliefs, routines of behavior, and rules. Also, the level of organizational distance frequently exhibits a considerable magnitude, thereby rendering interpersonal interaction arduous and challenging (Bishop et al., 2011; Quiñones et al., 2019). Relatedly, social proximity, both micro and macro levels, resides in the recognition that social connections not only facilitate the coordination of transactions but also function as conduits for the dissemination of knowledge, owing to the presence of mutual trust, familial ties, and shared experiences. Social ties thus facilitate the harmonious flow of resources from external sources.

5 Organizing structures of TTIs

The institutional configurations the provider ordered interactions through which research and knowledge are exchanged and extracted for value form the underlying structure upon which the TTIs organize and execute their roles (Ozman & Parker, 2023). This organisational structure can spur creativity from scientists to TTI across the entire ecosystem (Battaglia et al., 2017). A plethora of formal structural arrangements have been defined, including a dichotomy between integrated and separation structures, the trichotomy of centralized, decentralized, and hybrid structures, as well as the prevalence of network structure (Battaglia et al., 2017; Good et al., 2019). Drawing on the parent-subsidiary and control analogy, the literature considers the TTI structure as a structure comprising at least two distinctive spheres, the integrated and the separation (Brescia et al., 2016; Battaglia et al., 2017). According to Derrick (2015), for example, research organizations can either outsource their commercialization expertise through the separation model or maintain it within their organizational structure through the integration model. This implies that a research institution adopting an integrated model will possess complete ownership and exert full control over the operations of the TTI.

The fundamental insight in integrated structure is how institutional dynamics (e.g., norms, attitudes, values, and resources) interact with academic entrepreneurship dynamics (Meoli & Vismara, 2016; Link et al., 2007). The significance of this view arises from the fact that numerous knowledge commodification decisions (e.g., licensing, copyright, patenting, and

spinouts resource mobilization and strategy adoption) and knowledge development activities (e.g., scientific research) are influenced by institutional norms and national regulatory frameworks (Brescia, 2016; Sengupta & Ray, 2017). The organizational structure of numerous TTIs predominantly adheres to a centralized administrative framework (Arqué-Castells et al., 2016), thereby leading to the influence exerted by research institutions functioning as anchor tenants, which typically embrace a centralized organizational framework. Arqué-Castells et al. (2016), for instance, argued that most universities are inclined to embrace an integrated approach to implement a centralized structure, allowing them to mold the principles and ideals governing the research and commercialization process.

Conversely, in the case of a separation structure, the research institution finds itself bereft of any semblance of control or authority over the intermediary institution (Derrick, 2015). Thus, it becomes perceptible that TTIs operate in a domain separate from the purview of research institutions' governance—regarding their ownership structure and decision-making processes (Litan et al., 2007). Here, the practice of 'outsourcing' vital internal functions and processes is increasingly regarded as a pivotal element within contemporary business models (Nugent & Chan, 2023; Stevens, 2017). Thus, universities gain advantages that transcend swift commercialization and enhanced IP management practice by outsourcing to far superior external TTIs (Nugent & Chan, 2023). During the contractual duration, TTIs also improve their practice and enhance the competencies of their internal TTI personnel. Disclosures and provisional applications continue to occur even after the termination of agreements with the external entity responsible for outsourcing (Nugent & Chan, 2023; Stevens, 2017).

Furthermore, the internal organizational structures of TTIs are commonly categorized as the trichotomy of centralized, decentralized, and hybrid structures (Ozman & Parker, 2023). The centralized structure of TTIs is characterized by the existence of a strong and efficient central administrative entity (Cortes & Herrmann, 2021), thereby directing decision-making authority to upper echelons. While it facilitates trade-off assessments, it concurrently restricts and slows information patterns and impedes access to lower-level expertise (Mihalache et al., 2012). In instances where intellectual property (IP) exhibits a high degree of complexity, encircling sophisticated licensing considerations and the possibility of future litigation, the adoption of a centralized framework becomes apt and prudent as it expedites decision-making and also decisions are made in alignment with interest of the research institution strongest interest (Carlsson et al., 2008).

In addition, prior research suggest that most public research institutions adopt a centralized structure and retain control of intellectual property rights, with the commercialization of inventions ultimately dependent on TTIs (Arqué-Castells et al., 2016; Belenzon & Shankerman, 2009; Chang et al., 2022). Yet, while a centralized organizational structure is more favorable for the preservation of patent expertise (Carlsson et al., 2008), the process of utilizing patents and intellectual property across different divisions can be characterized by slowness and a lack of responsiveness to the specific needs of each division. In light of the challenges posed by the centralized and decentralized structures, scholars and practitioners have advocated for adopting a hybrid structure, which unites the strengths of traditional hierarchical organizations with the agility of decentralized systems (Battaglia et al., 2017; Huyghe et al., 2014). This may model features a central TTO at the university level alongside specialized units in research groups and departments (Fai et al., 2018; Huyghe et al., 2014). Teams within this framework could operate with a degree of independence while

receiving the necessary support from the central authority, promoting flexibility and access to vital resources and expertise (Brescia et al., 2016; Good et al., 2019). The central authority in this hybrid arrangement offers limited technical support, empowering decentralized units to manage their operations, which not only enhances efficiency but also places the responsibility on them to secure their resources (Debackere & Veugelers, 2005).

Also, hybrid structures allow the research groups to be actively involved and engaged in the commercial exploitation of their own research findings (Brescia et al., 2016). Such involvement not only strengthens engagement but also mitigates informal commercialization, encouraging more structured and recognized methods for translating research into practical applications (Audretsch et al., 2006; Derrick, 2015; Nilsson et al., 2010). Nonetheless, complexities in decision-making that arise when leaders navigate the intersection of centralized oversight and decentralized autonomy could strain information processing capabilities, resulting in bottlenecks that may impede effective governance (Bercovitz & Feldmann, 2006). It is however worth noting that certain management advancements, including ecosystem implementations, may not align well with hybrid organizational forms, as they can inadvertently lead to fragmentation, complicating coordination efforts and potentially undermining the advantages of the hybrid model (Holgersson et al., 2022).

6 Organizing practices

Formalizing the dissemination of knowledge and technology frequently necessitates the participation of scientific researchers and personnel from TTI within educational establishments (Du et al., 2014; Vesci et al., 2020). In the given framework, the acquisition of technological knowledge or infrastructure, is initiated by scientists (front of innovation) and disseminated to industry stakeholders with the aid of TTIs (Brock et al., 2020; Chang et al., 2022). The prevailing convention practice to measure the performance of however is defined within the number of the patents or license issued through a particular TTI. For example, according to Walter et al. (2018), a prevailing notion persists that the licensing and commercialization of intellectual property (IP) generated by universities will sufficiently offset the expenses incurred in its creation, thereby assisting governmental funding efforts. On a broader scale, quantifying scientific knowledge and outputs would require measuring and assessing the extent and impact of scientific advancements and outcomes (Tseng & Raudensky, 2014). This encompasses drawing on calculative methodologies such as performance indicators and benchmarking, which are progressively employed to assess and appraise the standard of commercialization achievements (Bi et al., 2017; Sarpong et al., 2017). Also, practice of measuring TTI performance has led to attempts to align practices of one TTI with those of comparable institutions (Siegel et al., 2003). Gumbi (2010), in their review of performance standard measurement on TTIs, emphasized that this approach benchmarking fosters a culture of academic excellence and innovation while incentivizing TTIs to refine their processes for effectively commercializing research concepts.

Also, the current TTI practices encompasses an intellectual property management framework that predominantly revolves around adopting patent protection as the primary and principal avenue for the commercialization of research (Holgersson & Aaboen, 2019). For many researchers, intellectual property management practices are the cornerstone of research commercialization. The allocation of intellectual property rights pertaining to inno-

vations formulated within a research institute may be conferred onto diverse individual entities (Ouellette & Weires, 2019). Yet, a persistent trend in intellectual property (IP) management practices has been observed, leading to several researchers cautioning that the complete reproducibility of these practices may not guarantee successful commercialization in different settings (Posen et al., 2020; Walter et al., 2018). Consequently, TTI institutions in emerging economies frequently display a tendency to exhibit a penchant for embracing a single and all-encompassing approach in the management of IP arising from science-based research institutions (e.g., patents, trademarks and copyrights) (Jefferson et al., 2017). In stark juxtaposition, a segment of institutions in developed economies uphold distinct policies pertaining to patents, copyrights, and trademarks. While this observed disparity in practice is largely be attributed to divergent regulatory frameworks (Ouellette & Weires, 2019), it also directs attention to need for institutional intellectual property regulations explicitly define the individuals responsible for the creation of said intellectual property and establish a comprehensive framework for its apportionment and governance within the precincts of the institution (Jefferson et al., 2017).

Furthermore, there are accounts on several practice of informal commercialization (Nilsson et al., 2010), where researchers choose not to disclose their invention to internal TTI if they perceive significant obstacles impeding the disclosure process (Derrick, 2015; Link et al., 2007). This informal practice where the researcher can collaborate directly with an industry contact to commercialize the invention, is aimed at bypassing the TTI as intermediary institution (Nilsson et al., 2010). This tends to serve as a valuable alternative for scientists because it leapfrogs the impediments that prevent scientist and their research findings from reaching the industry (Audretsch et al., 2006), and even creating academic spin-offs (Meoli & Vismara, 2016). It is also marked by significant growth and transformation from research to industrialization, specifically in the transfer of tacit knowledge. Thus, the industry benefits from better accessibility to scientists who can furnish complementary information (tacit knowledge) in support of interpreting codified knowledge. In this regard, establishing a denser connection with the industry could allow scientists and TTIs who engage in consultation and collaboration with the industrial sector exhibit a higher propensity to secure patents for their discoveries (Goel & Göktepe-Hultén, 2013). Also, researchers who possess a significant proportion of their portfolio funded by the industry tend to generate more patents (Lawson, 2013). Such efforts could also help nurture the ability to research and their practical implementations, thereby enhancing efficiency and outcomes.

7 Envisioning new pathways

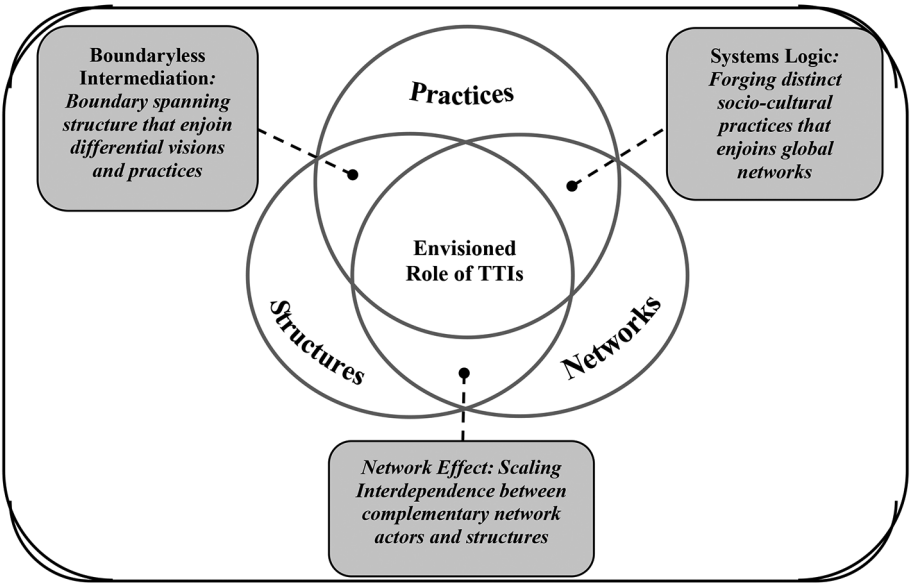
Against the background of several scholarly insights on the role, structure, networks, and practices that cumulatively shape and situate TTIs within the broader innovation ecosystem, we now contend with how to construct a shared vision of the role TTIs in the current sustainability transition, as well as ensure utmost socio-economic benefit. While defining avenues of situating TTIs in the pursuit for sustainable socio-technical system may suggest an attempt to construct expressions that are not substantiated by occurring events (Ramaswamy & Ozcan, 2018; Van der Helm, 2009), we build our envisioning perspective by generating novel insights from the extant contemplation on TTIs and sustainability transition (Kivimaa et al., 2019; Schulz et al., 2021; Watkins et al., 2024). This endeavor thus initiates

a new conversation that seeks to broaden the scope and organizing of TTIs to consider a more global effort which is evidently fundamental to the drive towards a sustainable world (Audretsch et al., 2014; Palaco et al., 2022).

The orientations of innovation ecosystem have undergone a profound transformation, where the emphasis on the commercialization of innovation output has found a renewed dedication towards sustainability (Nylund et al., 2021). The realization of this goal has thus situated TTIs center-stage to facilitate speedy transition of the existing socio-technical system towards sustainable ends (Kivimaa et al., 2019). In this regard, recent studies have set focus on the possibility for TTIs to encourage convergence of complementary actors with the objective of cultivating shared ambition to realize a global scale intermediation (Palaco et al., 2022; Kivimaa et al., 2019). This involve providing resources and support for joint technology transfer initiatives across multiple regions (Palaco et al., 2022), which could enable a nurturing new expertise among complementors within a global system of "transition intermediaries" (Kivimaa et al., 2019) to develop, commoditize and commercialize sustainable technologies suitable for the needs of each context.

Thus, within their existing roles, TTIs in mature markets could broaden their organizing networks to include those within developing context, and structure their operational motive around expertise development and guidance in commercializing cross context-relevant sustainable technologies (Audretsch et al., 2014; Palaco et al., 2022). This may require close partnering with regional TTI entities to provide better access to new knowledge and expertise to drive innovation through multiple channels. Nonetheless, we argue that this perceived structure is made up of dimensions, the most essential of which is the organizing network composed of social actors (human and research institutions) and the chains of interdependence connecting them (Battaglia et al., 2017). Although, TTIs connect these complementors, the complementary actors are the nodes within the network, and their interactions are responsible for establishing, maintaining, modifying, and dissolving their relationships (Ozman & Parker, 2023). Thus, how context-specific nuances enables TTI actors to perceive, categorize, and create the rules and meanings that guide their sustainability focused agenda becomes essential.

Therefore, we argue that exploring the relationships between people, practices, and institutions could enhance our understanding of the organizing practices that underlie cross-border intermediary activities could be shaped by collective agreements, contextual nuances, and exhibit flexibility. Beyond a simple processes or attributes of the institutions involved, this reconfigured approached may elicit broader stakeholder actions that intersect to form the core activities of the sustainability transition process (Waroonkun & Stewart, 2008; Watkins et al., 2024). This also implies that a cross-border TTI may conform to certain discourses or power relations prevalent in innovation ecosystems, industry or sector as a means of gaining legitimacy or enhancing collaboration toward a shared vision. Yet, fostering a large scale collaborative TTI market, encompassing actors from diverse contexts, necessitates the adept integration of disparate institutional logics (Durand & Thornton, 2008). These logics furnish TTIs within a global network with cognitive models, schemata, and standard practices that actors may utilize as interpretative frameworks to navigate and lend meaning to their active participation in sustainability transitioning. Here, TTIs may define hybridized logics by incorporating relevant practices to facilitate the effective organization of technology transfer activities that ensures widespread socio-economic benefit.



Source: Authors

Fig. 1 A conceptual model of envisioned TTI

We present these insights on Fig. 1 to tease out how to envision the organization of technology and competency transfer on a global scale. The conceptual model elucidates the interplay between the organizing networks, structures, and practices of TTIs in a shared vision that leads to a pursuit of developing sustainable new technologies and competencies. The model highlights the potential interconnected outlook for how practices, networks and structures could shape the role of TTIs on a global scale to drive the transition toward sustainable socio-technical system. In this model we conceive a global TTI system based on distinct socio-cultural practices within varying geographical boundaries yet enjoins global network of actors to enable shared vision. Such systems could benefit from an architecture of network effects that would allow a broader participation to scale up the interdependence between complementary TTI network actors. Thus, a global TTI network ties that allow for interdependence between complementary actors and collective participation on a global scale hold the potential to setting forth a widespread sustainable innovation. This could then yield a boundaryless intermediary role of TTIs that spans enjoin differential visions and practices across the economies and regions to drive sustainable socio-technical transition ambition. While this reveals the notion that facilitating technology and competency transfer embodies a complex sociotechnical framework (Comacchio et al., 2012; Kivimaa et al., 2019), this envisioned role, we argue, could ensure widespread benefit from the activities of TTIs and secure a sustainable future.

8 Discussion and conclusion

In this paper we have sought to provide a new conceptualization of TTIs to enable us to envision their role in socio-technical transition towards a sustainable end. We achieved this by first unpacking core literature on TTIs in innovation ecosystem along three main themes including roles, organizing structure, networks, and practices. We sought to discuss and extend these existing themes, which cumulatively define the established discourse on TTIs, to draw into view how the effort to transition to a sustainable socio-technical system could benefit from a global approach to technology transfer intermediation (Janusz et al., 2018; Takata et al., 2022). We argued that such approach would not only enable a widespread application of sustainable technologies, but also socio-economic from innovation outputs are brought to scale. The arguments we submit are, in part at least, inspired by insights from existing arrangement in the TTI markets and innovation ecosystem which has yielded geographical inequality in the commercialization and application of technological innovation, as well as economic benefit from innovation outputs (Sarpong et al., 2023). Hence, while an ambition to rebuild the socio-technical arrangements into a sustainable system requires collective efforts across borders, we have argued that such efforts would need considerations for a much broader arrangement for technology and competency transfer.

We went on to reconceive the specific roles, organizing networks and structures that co-constitute TTIs, and practices that shape their intermediary activities within a global TTI architecture. We therefore relied on the divergent literature on TTIs to gather valuable insights that serves as a springboard on which to (re)envision the role of TTIs within a global framework. This approach thus allowed us to emphasize how the interconnectedness of the existing TTI architecture could be broadened on global scale to facilitate the enduring effort of achieving sustainable socio-technical transition. we delineate how TTIs hold a core role in the intermingling of social and technical components to enable the translation of ground-breaking sustainable innovation concepts into viable commercial outputs. Here, we perceive cross-border configuration of TTI markets as benefiting from network effect that deliver widespread value. This endeavor led to develop a conceptual model that fully captured these insights. We now discuss the core contributions of this study.

8.1 Research contributions

This paper presents three core contributions to the discourse on innovation management and knowledge/technology transfer. First, the categorization of themes identified in the literature serves to provide clarity to enable discourse surrounding the various structures, networks and practices in which TTIs is established. Thus, this paper teases out the existing underlying operational logics and mechanisms for intermediation that lead to commercial success of new cutting-edge technological innovation to drive economic growth. Nonetheless, as we heed to a reconceptualization agenda, we also recast the extant understanding as having a limited effect in securing a sustainable transition. Hence, we reconceived the core tents of the discourse on TTI in a facilitating the development and commercialization of sustainable innovation within a global system that aims at achieving socio-technical transition (Kivimaa et al., 2019; Palaco et al., 2022; Park et al., 2024). This attempt sets forth an envisioned system that set out a global TTI market for the exchange of technological capabilities across regions to allow for a collective drive toward sustainable transition. This insight comple-

ments existing efforts to define a coherent international TTI framework that allows effective negotiations and exchange between contexts where these sustainable new technologies are commonly produced and those that seek to develop such technologies (Palaco et al., 2022).

Second, we have set clear in this paper the central role of TTIs in achieving socio-technical transition towards sustainability. In doing this, we have drawn attention to the important role of TTIs in facilitating the commercial success of existing innovation output and ensuring economic growth. We problematize this system to argue that there exists geographical dominance in the design and organizing of the innovation ecosystem, and hence the economic benefits from existing innovation (Sarpong et al., 2023; Wang & Zhang, 2020). We therefore draw attention to the need to address this challenge as we focus on sustainability transition (Civera et al., 2024). More importantly, given that this socio-technical transition requires inclusive participation on a global scale, we highlight the role of TTIs as serving an important transition role (Kivimaa et al., 2019) that enjoins several stakeholders on a global scale. Hence, the benefit reaped from TTIs in the existing innovation commercialization efforts could be replicated in a sustainability transition on a global scale if TTI markets are redefined and established with international orientation.

Third, the fundamental logics for the functioning of a globalized TTI framework which we advocate here is dependent on a boundary spanning operational structure that enjoins differential visions across varying contexts (Palaco et al., 2022). Thus, notions of "semantic translation of domain specific knowledge [and] co-production of new knowledge" (Comacchio et al., 2012: 945) may all be conceived within a globalized system that enjoins distinct and siloed TTI structure and priorities. Palaco et al. (2022) acknowledges the impediments of facilitating technology transfer on a global scale without defining a system within which an innovation intermediary takes the on international orientation. Thus, a boundary TTI system could prove significant through a system that bridges regional differences in innovation orientation and established a TTI market that connects technological needs to those with the capabilities (Kivimaa et al., 2019; Palaco et al., 2022). This effort is further facilitated by incorporating distinct socio-cultural practices towards global orientations. Thus, acknowledging and addressing the varying materials, competencies, and meanings that characterize TTIs in different context could serve as a basis for easing out the complexities of defining globalized TTI structure.

8.2 Limitations and future research

This paper has some limitations which also open important avenue for future research to explore. First, our methodological requirement to establish clear parameters for the assessment ultimately resulted in the need to make explicit determinations regarding what should be excluded. It is important to recognize that employing a systematic review technique to examine the literature is inherently reductionist. This approach, may eliminate some themes and perhaps result in an underrepresentation of, for example historical studies, which are frequently published. As the TTI ecosystem represents an ever-evolving intellectual domain thereby resulting in vast array of themes, models, theories, and research subjects encompassing the complementary actors, we may have missed out on some important arguments. Furthermore, our envisioning approach only sets up an abstracted view of TTI functioning on a global scale without empirically testable measures to account for its viability.

In this regard, we argue there exist further opportunities to delve into underlying features and the evolving patterns of the TTI operation that define their practices, networking systems, and evolving structures. Our research could also serve as a springboard to systematically capturing the agile pattern for TTI markets and frameworks. A path for prospective investigation could entail a comprehensive exploration of TTI structures, prioritizing an analysis of sizes and geographic proximity, could be exploited. In the context of sizes, scholars may direct their attention towards the study of administrative personnel and their intricate composition. When examining the proximity of TTIs to industry stakeholders, scholars may direct their attention towards both the physical and cognitive dimensions of distance (Brescia et al., 2016). This, we surmise, could help define clear actionable paths to achieving a global scale TTI framework. Using Delphi test to draw some expert insights on the viability this approach could also be beneficial.

8.3 Conclusion

This paper sought to explore existing research on TTIs to identify key constructs and synthesize current knowledge and offered critical analysis of independent but related streams of research on TTIs. Our study has further problematized the organizing structure, practices, and networks of TTIs in light of their role in the global effort to achieving sustainability transition. The paper has thus ignited a provocative stance that looks to conceive a global scale TTI market which would encourage collective participation and ensure widespread economic benefit. We anticipated that this study would catalyze researchers to further explore this transitioning role of TTIs.

Author contributions Author ContributionElias Osei: Conceptualising, literature search and selection, analysis, research contributions, writing—first draft and revisions, and editing. Derrick Boakye: Conceptualising, research contributions, writing—first draft and revisions, and editing. Kwadwo Asante: Analysis, research contributions, writing—first draft and revision, and editing.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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