Heliyon 9 (2023) e16779

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Meta theories of technological innovation based on the analysis of classic texts

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ARTICLE INFO

Keywords:
Technological innovation
Meta-theoretical analysis
Typology
Classic text

ABSTRACT

This study aims to investigate the classification of technological innovation meta-theories based on classical texts, as well as the relationships between various classifications. Both qualitative and quantitative methods are employed. From the perspective of technological innovation, using scientometric methods, 105 pieces of classic texts from the 1930s–2010s are extracted from the references of 3862 pieces of high-quality literature from the 1900s–2020s. As a result, based on a combination of qualitative data analysis and topic model analysis, we developed a typology with eight meta-theories of technological innovation, including performance-based, resource-based, knowledge-based, capability-based, network-based, technological-innovation-system, dual-innovation, and dynamic-sustainability views. Then we analyzed 1) the evolution, reification, and confusion relationships between different meta-theories; 2) the causes of technological innovation's concept jungle; and 3) an integrated framework of technological innovation meta-theories. This study analyzed the benefits of the meta-theoretical analysis on the future study of technological innovation. Additionally, the results of this study can help to measure technological innovation, construct new theories, and improve the efficiency of the connection between the practical problems of innovation and potentially useful theoretical frameworks.

1. Introduction

More than a few researchers have demonstrated that social science, including technological innovation studies, suffers from a problem of concept confusion problem [1–3]. Technological innovation research encompasses a wide range of disciplines, and its research scopes and problems go beyond Schumpeter's initial definition. For instance, the research scopes open innovation [4], dual-innovation [5], and notational innovation system [6] are distinct from each other. The meanings of eco-innovation [7,8], sociotechnical innovation [9], and fintech innovation [10] have expanded Schumpeter's concept of innovation. The issue of interest is the avoidance of confusion in concepts during cross-theoretical communication [11]. Although this study does not directly address this issue, its results are highly valuable in clarifying the problem of conceptual confusion. It seems that exploring and analyzing classic texts is an effective method to enhance clarity in the concepts of confusion in previous studies.

Classic texts hold utility in streamlining the process of conceptual clarification [12]. An example is the conceptual analysis method (CAM) developed by Tähtinen and Havila [13], which aims to identify conceptual confusion and elucidate multiple terms and concepts

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https://doi.org/10.1016/j.heliyon.2023.e16779
Received 4 August 2022; Received in revised form 24 May 2023; Accepted 26 May 2023
Available online 27 May 2023
2405-8440/

by tracing their theoretical roots. In comparison, limited attention has been given to meta-theoretical analysis for the cross-disciplinary learning problems in technological innovation studies. However, it has proven to be useful in technological innovation studies in the works of Cherp, Vinichenko, Jewell, Brutschin and Sovacool [14], Davies, Manning and Söderlund [15], and Sovacool, Hess and Cantoni [16].

In this study, we aim to combine the advantages of both classic texts and meta-theoretical analysis regarding technological innovation studies. To our knowledge, this is the first study to undertake such an approach in the field of technological innovation. There are three major aims of this study. 1) Mining classic texts in the field of technological innovation. The main challenge for this question is the comprehensiveness of the classic texts being unearthed. For the traditional systematic review, there are too many studies in the field of technological innovation to complete the comprehensive search process due to sample selection problems [17]. Emerging scientometric methods can help identify essential literature, but there are problems in interpreting the results and developing typologies [18]. 2) Develop the typology construct of the meta-theories and define the relationship between different technological innovation meta-theories. On the one hand, a combined method of qualitative data analysis and a network of citing relationships is attempted to use to classify various meta-theories. On the other hand, finding the independence of different background theories and improving the repeatability of the classification process are the main challenges. 3) Learn from the integrating meta-theoretical framework for future studies and practices. In connection with this matter, technological and practical implications are made from the perspective of the functions of both classic text analysis and meta-theoretical analysis.

This study offers contributions to the field as follows: 1) To enhance the credibility and repeatability of the classic text refinement process, this study employs a combined methodological approach incorporating qualitative data analysis and scientometrics. By leveraging the strengths of each method, we achieve a more robust understanding of the topic at hand. 2) This study analyzes the similarities and differences among the eight classifications of technological innovation meta-theories through varied lenses, including evolution, reification, confusion, and research background. Therefore, an integrated framework of technological innovation meta-theories is constructed based on the results. 3) The meta-theoretical framework of technological innovation proposed in this study serves as a valuable tool for integrating technological innovation knowledge from different disciplines, and it is facilitating efficiency in connecting practical problems of innovation and potentially theoretically sound solutions.

The rest of this study is organized as follows: The next section is a literature review to analyse the necessity of a meta-theory study of technological innovation. This is followed by a description of the research design, including the data collection and methodology description. Subsequently, we present the results and follow up with a discussion section. Finally, we summarize our conclusions, implications, and limitations in the final section.

2. Literature review

2.1. The centrality of the classic texts in social science

In the realm of social science research, the term “classic text” denotes research outcomes that wield considerable and enduring influence [19]. Alternatively, a text that attains the status of a classic work contributes significantly to theory-building, enjoys widespread recognition among influential scholars, and garners substantial academic citation rates [20]. In social science research, reliance on classical texts endures, as researchers constantly produce such works to establish a relatively scientific research paradigm [21]. By invoking classic texts, we are able to situate the research content with in a common discourse system.

To address the aforementioned questions in the introduction, analyzing the entirety of technological innovation research documents is a convoluted endeavor. Prior scholarship suggests that examining the theoretical roots of key concepts and terms presents a more efficacious approach, as divergences in their respective ontological and theoretical origins may indicate a multiplicity of sources [13]. Existing technology affords us to undertake a meta-theoretical classification of the knowledge base in technological innovation [22]. Building upon prior literature [23,24], this study regards classic texts within a given field as the foundation for meta-theoretical classification.

2.2. Meta-theoretical studies of technological innovation

The theoretical system poses another challenge in this study. A meta-theoretical analysis is an incipient analytical method of meta-studies [25], which encompasses classic text mining, theoretical foundation analysis, and topic [26] or field [27] classification. It can be construed as a re-study of a collection of primary theoretical studies. The meta-theoretical analysis concentrates on the fundamental theories that make up the various theories of the common problems [28,29]. Such analysis facilitates the integration of domain knowledge and also helps to alleviate the schism and discord between researchers and practitioners [30]. A meta-theory of technological innovation is a theoretical framework that can recapitulate a sequence of concepts, theories, arguments, and conclusions from technological innovation research [31].

On the one hand, the meta-theory of technological innovation serves to clarify the evolutionary path of technological innovation as a research domain. Some studies that concentrate on the theoretical classification of innovation have also become classic texts with substantial influence [1,32]. On the other hand, the meta-theory analysis of technological innovation can promote the dissemination of knowledge from the field of technological innovation to other research fields [15,33,34].

3. Research design

To address the issue of the typology of meta-theories of technological innovation raised above, this study designed a technical routine (shown in Fig. 1) and an accompanying research framework.

First, regarding the data collection process illustrated in Fig. 1, the inquiry employed the search formula “TS = (techn* innovation)” to scrutinize the core collections of the Web of Science during a predetermined timeframe, from the 1900s–2020s. The search yielded an excess of 9000 documents, which were subsequently refined to ensure a heightened focus on technological innovation. To achieve this end, only publications that contained five or more documents on technological innovation are retained [35]. Then, the results are further screened according to the quality of the literature was accessed based on the sources eminence and the literature’s importance, as indicated by the literature characteristic indicators [36]. More specifically, the JCR’s (journal citation reports) quartile comparison function is utilized to distinguish sources from JCR’s Q1 and Q2 categories, which led to a collection of 3432 documents. Thereafter, the documents were subjected to further scrutiny based on the number of citations received within the Q3 and Q4 categories. Only documents that were cited ten or more times were remained, leading to a final collection of 430 articles. Overall, after these screening, 3862 high-quality documents were obtained.

Second, this study employs a hybrid approach that utilizes scientometric analysis, qualitative data analysis, and topic model analysis. Specifically, the investigation leverages Reference Publication Year Spectroscopy (RPYS) analysis technique to explore the distribution of cited documents in the field of technological innovation and their publication year frequency, thereby uncovering the research’s historical origins and impact [37]. However, the present application of RPYS analysis measures theoretical importance solely based on the cited number of a document, which makes it arduous to classify and correlate the theoretical background. As such, this article augments RPYS with qualitative data analysis, wherein classic texts are coded and classified, and conducts a robustness test of classification results through topic model analysis.

Third, this study discusses the results in a synthesis, including 1) the interplay between evolution, reification, and confusion in distinct meta-theories; 2) a comparative analysis of the respective research background of these meta-theories; and 3) an integrated framework for meta-theories concerning technological innovation.

Forth, this study encapsulates its conclusions and implications through the lens of theoretical significance, while also proffering suggestions for future research and practical implications.

4. Results

4.1. Identification of core scholars in technological innovation studies

The software, CRExplore (Thor et al., 2016), is employed to conduct an analyse of references cited in the original documents utilizing the RPYS method. The results of the RPYS show that there are over 146,300 references that have been cited in 3862 pieces of high-quality technological innovation documents, spanning the time period between 1848 and 2020. The results of the RPYS analysis offer an opportunity to screen the classic texts of technological innovation studies.

First, previous co-citation methods usually take the document as the unit of analysis [38]. However, a researcher’s theoretical framework may be supported by multiple documents. Simultaneously, a document’s worthiness can only discernible through its long-standing and perpetual pertinence. Therefore, this study considers three factors for the literature screening: the author’s cumulative contributions, the contributions of an individual document, and whether these contributions are sustainable. To achieve these three goals concurrently, this study executed the following steps.

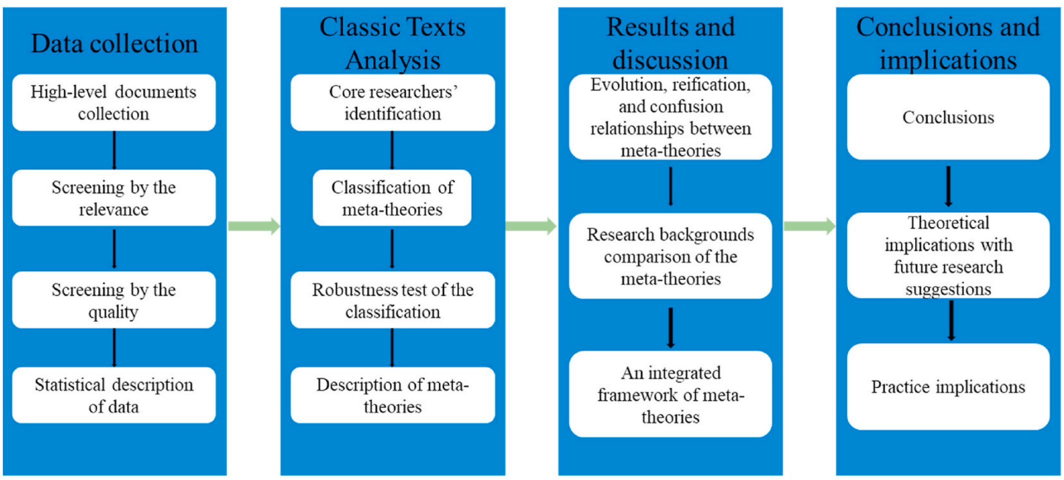

Fig. 1. Technique map of this study.

Step 1: The H-index indicator [39] is utilized to measure the contribution made by each author. This study identifies the first author of each reference and their corresponding H-index is calculated.
Step 2: The cumulative value of an author's H most cited articles (H equals the value of the H-index of an author) is computed, thereby providing a more nuanced assessment of scholarly impact. Unlike the simple H-index value, the cumulative value only accounts for an author's most influential works, thereby mitigating bias. Moreover, the cumulative value effectively addresses the potential for important publications to be overlooked among authors with low aggregate H-index scores.

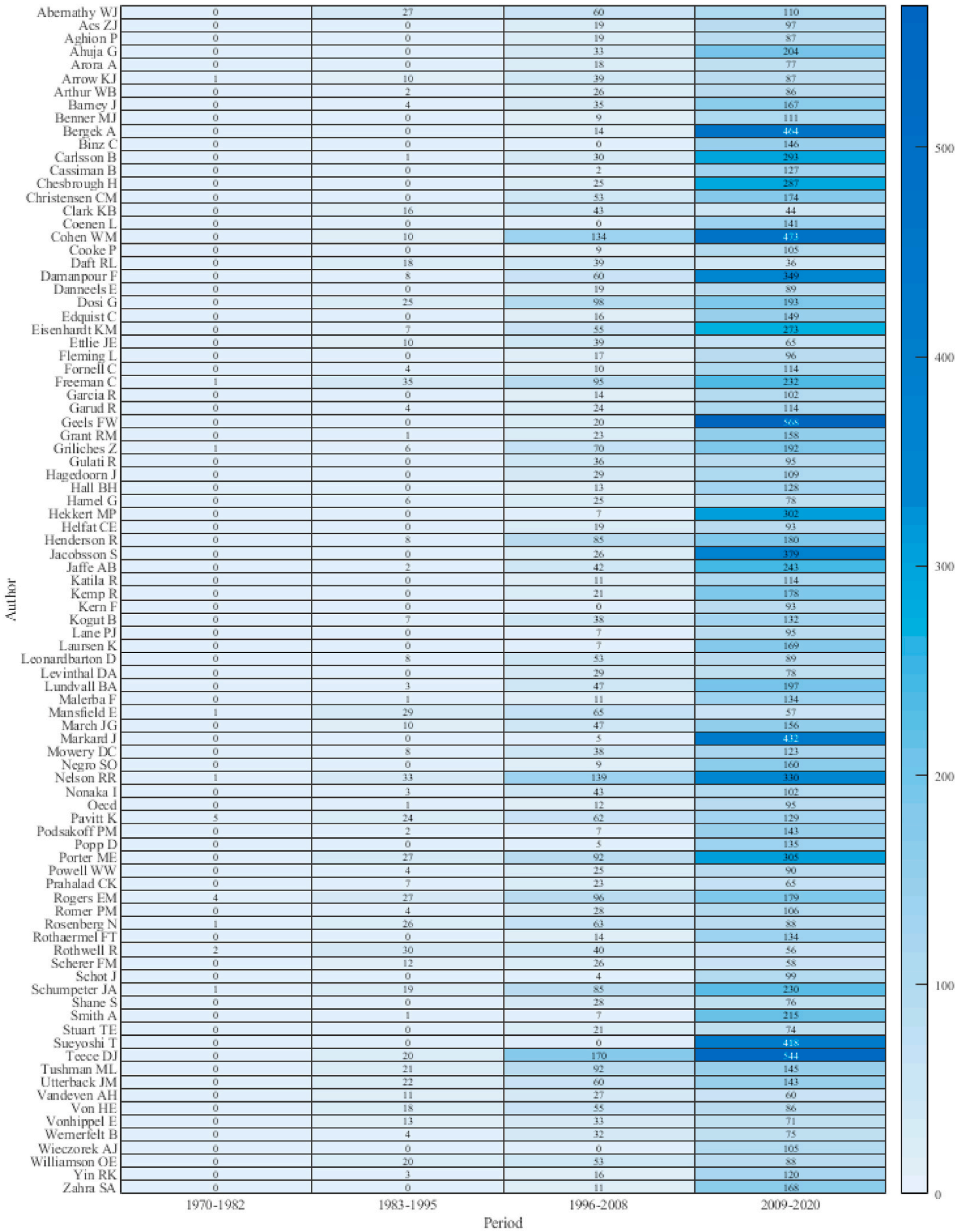

Fig. 2. Times cited by core scholars in technological innovation.

Step 3: Applying the 80/20 rule in the core collection screening process [40,41], scholars with a cumulative value greater than 100 are identified as core scholars. This process results in the screening of 620 publications authored by 90 individuals. Fig. 2 depicts a heat map reflecting the frequency with which each author was cited across different time periods.

Second, the second-order references of 620 publications are identified and analyzed. References cited in the original documents are termed first-order references, while those cited in the first-order references are defined as second-order references. The cumulative H-index of the cited authors in the second-order references is also calculated. The results indicate that the core attributes of the first-order reference authors are retained in the second-order references.

4.2. *Classification of meta-theories based on classic texts*

Following the process of qualitative data analysis [42], the core publications of core researchers are subject to encoding and classification. The ensuing measures are as follows.

Step 1: Further refining the number of core documents to identify classic texts. In accordance with the criteria outlined in section 2.2, we have established two standards that a document must meet to be considered as a classic text. Firstly, the document should have a significant and enduring impact on technological innovation. Second, the document should make a great direct contribution to the establishment of theories related to the phenomenon of technological innovation. Each core document is coded and analyzed based on various factors including its type of study (whether it is empirical, review, theoretical, or hybrid), whether it expands upon the concept of technological innovation, whether it introduces new variables relevant to technological innovation, whether it raises new theoretical questions about technological innovation, and whether it is a representative theoretical document core authors with relation to technological innovation. As a result, we have excluded 13 documents authored by three individuals, as these publications solely focused on method development (e.g. Yin [43]). Other 105 documents from 87 authors are screened out as their classic texts.

Step 2: The establishment of theoretical coding's fundamental principles stems from three perspectives. a) Classic texts are sorted in chronological order based on their date of publication. The earliest documents and the author's theory are designated as the initial meta-theoretical classification. b) Classic texts are scrutinized sequentially to determine whether the theory developed from the text aligns with a pre-classified meta-theory. If the document either augments the pre-classified meta-theory or supplements it, the text is incorporated into the corresponding meta-theory. Otherwise, if it cannot be classified into an existing theory, then a new meta-theory classification is established. c) when a classic text incorporates or advances two or more classified meta-theories, its classification is determined by the number of each meta-theoretical text cited and the research backgrounds of the authors and co-authors.

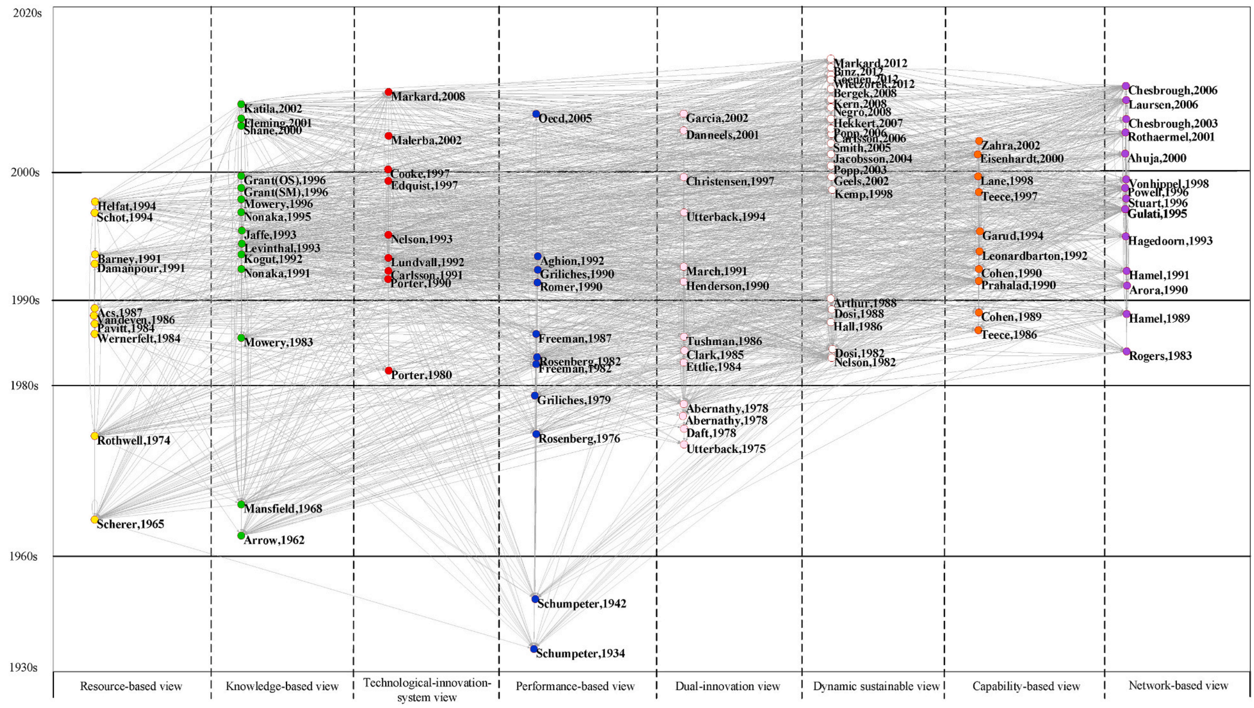

Fig. 3. Typology of meta-theories and the cited network of classic texts.

Step 3: Fig. 3 is drawn to show the final classification of meta-theories and the cited network between the classical texts contained in each meta-theory.

4.3. Robustness analysis of the meta-theories classification

To access the soundness of the proposed classification, this study employs the following robustness test through a topic modeling process. a) We compile a comprehensive list of all documents that cite each classic text authored by the respective scholars and extract their relevant keywords, which include both author keywords and the Web of Science's keyword plus. b) These keyword data are then utilized as the primary corpus for a latent Dirichlet allocation model (LDA [44]), with the number of categories set to 8, and the resulting categories are compared with the classification obtained from the manual coding analysis. c) The cloud map depicted in Fig. 4 showcases the prominent topics associated with each classification.

Fig. 4 has denoted the salient keywords that are characteristic of each cloud map. The LDA classification results, when juxtaposed with our manual coding classification results, manifest a near-perfect correspondence between the two. To be more precise, topic 1 corresponds to the resource-based view; topic 2 is associated with the knowledge-based view; topic 3 is commensurate with the network-based view; topic 4 aligns with the performance-based view; topic 5 is congruous with the capability-based view; topic 6 is

Fig. 4. Results of the LDA model.

aligned with the dual-innovation view; topic 7 is congruent with to the dynamic sustainable view; and topic 8 corresponds to the technological innovation system view. The matching degree of the document category attribution probability corresponding to each LDA category results with the manual classification reaches 80%.

4.4. Description of technological innovation meta-theories

4.4.1. X-factor-based views

The X-factor-based views postulate that technological innovation emanates from a pivotal factor denoted as X, which subsequently drives technological advancements. Then, the result of technological innovation serves this factor X alternately. This study has identified five meta-theories that are grounded in the X-factor-based framework. In general, the theoretical framework of technological innovation from this perspective can be divided into two parts: the discussion of factor X and its theoretical frameworks, and the correlation between factor X and technological innovation. Out of the eight mate-theories expounded in this study, the five X-factor-based views are as follows:

Performance-based view. — The first category of concern that has captivated the attention of scholars investigating technological innovation studies pertains to the intersection between innovation and the economy. The main feature of the performance-based view lies in the subjects, behaviours, and factors involved in technological innovation activities are expressed via classic economic concepts and models [45,46]. The improvement of economic performance is the primary objective of technological innovation activities [32,47,48]. From an economic analysis perspective, the research on the economic performance-based view includes two aspects. The first aspect investigates the nexus between innovation and economic performance [49–51], while the second aspect explores methods of evaluating the relationship between innovation and economic performance [52,53].

Resource-based view. — From a narrow perspective, resources related to technological innovation may comprise of market power, firms' profitability, product diversification, and innovation opportunities [54]; scientists and engineers, planning, and management technology [55]; organizational management attributes [56]; market commitment, experimentation, and technical connections [57]; and R&D investment [58]. From a broad perspective, resources can encompass all tangible or intangible assets, capabilities, organizational processes, firm attributes, information, and knowledge that organizations utilize to implement strategies to improve efficiency and influence capabilities [59]. Research on the resource-based view suggests that technological innovation results from the operation of resource advantages. The classic texts have demonstrated that different organizations or heterogeneous innovations need different resource configurations [60,61]. Concurrently, the resource-based view claims that technological innovation is an effective way to form resource location barriers [62] and attain sustainable competitive advantage [59].

Knowledge-based view. —Technological innovation research involves various forms of knowledge, such as market information produced by basic research and invention [63,64], new ideas [65], organizational intelligence [66], patents [67], and technical know-how [68]. These forms of knowledge can be explicit or tacit and can be transformed into each other [63,69]. T knowledge-based view assumes that knowledge is transferability, can be aggregation, can be appropriated, requires specialized acquisition, and is essential for production [70]. Knowledge creation is not necessarily a specialized activity, but creating knowledge is a process of innovation [69,71]. Classic texts argue that learning and public knowledge creation are both important factors in knowledge creation activities [66,72]. From the aspect of the application of knowledge [65], the influencing factors mainly emphasized by classic texts include absorptive capacity and transformation ability [70,73], network connections [68], the breadth and depth of search knowledge [74], and geographic location limitation [67]. However, the same information may have different effects on individuals due to the differences in knowledge accumulation [75]. Moreover, knowledge may lead to a decline in the overall quality of invention [76].

Network-based view. — Networks can be comprised of individuals and diverse organizations, such as firms, government departments, or universities [77]. The type of network connection can be cooperation with competitors [78], cooperation between firms and universities [77], strategic alliance networks [79], social relations networks [80], and interfirm networks of open innovation [81]. The formation of networks is predicated upon the interdependence of past cooperative relations and strategies [82]. Networks' influence on innovation can be divided into heterogeneous links effect [77,79,83,84], network learning effects [85,86], and the firm's network centrality positively effects [87,88]. The impact of innovation on networks' foundation depends on factors such as trust [82], knowledge accumulation [86,87], and open innovation strategies [81], with highly technology-intensive firms mainly forming technology networks, while low-technology-intensive firms tend to gravitating market cooperation networks [79].

Capability-based view. — Capability is a frequent concept in management research. However, it is typically discussed in conjunction with other concepts. Day [89] posited that an organization's capability is a distinctive characteristic that sets it apart from others with similar traits. The capabilities related to technological innovation mainly include dynamic capabilities [90], absorptive capabilities [91], relative absorptive capabilities [92], core competence [93], and transformative capability [94].

4.4.2. Dual-innovation view

Research on the duality of technological innovation has proposed a variety of innovation typology constructs, including 1) product innovation and process innovation [95]; 2) incremental innovation, radical innovation, and evolutionary innovation [96]; 3) innovation from the bottom up and innovation from the top down [97]; 4) modular innovation and architectural innovation [98]; 5) exploratory innovation and exploited innovation [99]; and 6) sustaining technologies and disruptive technologies [100]. The main point of the dual innovation view of technological innovation is how to understand the reason and pattern of the duality of technological innovation [97,101,102]. From previous classic texts, we can also find how to take effective measures to deal with the risks caused by the duality of innovation [95,100,103,104].

4.4.3. Technological-innovation-system view

Technological innovation systems are usually used to analyse innovation phenomena at the macro level and in a systematic manner. There are various forms of technological innovation systems, such as national innovation systems [105,106], technological systems [107], sectoral systems of innovation [108], and technological innovation systems [109]. Classic texts in technological innovation system view main developed the diamond theory [110], the learning theory in a national system of innovation [106], and the typology of national innovation systems [105].

4.4.4. Dynamic-sustainable view

The main problem of the dynamic-sustainable-view study is the relationship between technological innovation activities and time. There are two perspectives to explain dynamic sustainability. The first perspective explains the concept from the dynamics and sustainability of certain technological changes [111,112]. The second way explains the dynamic sustainability of the environment and socioeconomic development, such as energy system transformation [113] and sustainable sociotechnical transitions [114]. The former perspective introduces fundamental concepts such as routine, search, selection, technological paradigm, and technological trajectory [115,116]. Empirically, a significant research question is whether the sustainability of technological innovation can be deliberately controlled at the firm level to achieve stable growth [117,118]. The latter perspective has received increasing attention in recent years regarding the relationship between environmental sustainability and technological innovation [114,119–125].

5. Discussion

The principal purpose of this study is to alleviate the tension between complex concepts and theoretical systems regarding technological innovation. In light of this context, this study puts forth three specific questions and addresses them by means of exploring and establishing a typology construct of technological innovation meta-theories. This study employs a combined methodology to divide the technological innovation meta-theory into eight types: which include five X-factor basic views (performance-, resource-, knowledge-, capability-, and network-based views), dual-innovation view, technological innovation system view, and dynamic-sustainable view. Through the analysis of the concepts, perspectives, backgrounds, and main ideas presented in the classic texts of these meta-theories, several noteworthy characteristics of the meta-theories of technological innovation can be delineated.

5.1. The evolution, reification, and confusion between the meta-theories

First, from a broad perspective, technological innovation meta-theories exhibit significant characteristics of period division, allowing for the identification of development trends in technological innovation theories. As shown in Fig. 3, during the first stage before the 1960s, the earliest classic texts were limited to the performance-based view conducted by Schumpeter [45] and Schumpeter [46]. In the second stage, spanning from the 1960s–1980s, saw the formation of classical texts of the knowledge-based view, resource-based view, dual-innovation view, and technological-innovation-system view in succession. During the third stage, from the 1980s to the 1990s, earlier classic texts on dynamic sustainability, network-based view, and capability-based view emerged. Between the 1990s–2000s, classic texts on various types of meta-theory co-increased, with the knowledge-based view, technological innovation system view, and network-based view having the highest number of classic texts during this period. Since the 2000s, there has been little increase in classic texts on resource-based view, while the dual-innovation view, capability-based view, performance-based view, and knowledge-based view have experienced relatively slight increases. In contrast, the number of classic texts in dynamic-sustainable view, network-based view, and technological-innovation-system view has continued to grow.

Second, there exist reification relationships between certain meta-theories. The term “reification” denotes exogenous entities detached from their origins [35]. The “reification relationship” means that a meta-theory of technological innovation produced later is utilized, combined, referenced, or altered from an earlier type(s) of meta-theory. Reification can usually be divided into two parts: the reification of the existing meta-theory in the past and the reification of external theories. Each meta-theory differs in the proportion of inheritance from the past and the combination of external theories. Specifically, the performance-based view introduced technological innovation concepts and ideas under the economic theory framework. In contrast, the resource-based view, which evolved from the performance-based view based on strategic management theory, focuses on studying how to gain sustainable advantages at the organization level through the management of technological innovation. The performance-based view focuses on how technological innovation influences economic activities, but it rarely considers how technological innovation is produced and how innovation can emerge more efficiently. Therefore, there are two meta-theories, the knowledge-based view and the network-based view, which concentrate on how to produce innovation based on knowledge and how to make the process of technological innovation more efficient at the base of the network, respectively. The capability-based view’s arguments are based on the comprehensive utilization of knowledge and resources, and a dual-innovation view is established to explain why innovative activities conducted for a certain purpose do not always result in successful innovation. Across these theories, the classic texts of the knowledge-based view and dual-innovation view mainly employ economics and management theories. The primary theoretical source of the network view is sociology-related research, and the capability view is mainly combined with management theories. To clarify the complexity and dynamics of the issues involved in technological innovation, the classic performance-based view is reified to the theories and methods of the technological innovation system view and the dynamic sustainability view. These two theories also combine theories of economics, system theory, and environmental science.

Third, a lack of clarity exists regarding the meta-theories of technological innovation. The confusion relationship is referenced from the confusion matrix in computer science and statistics [126]. It is a means of measuring the degree of aggregation within a category and the dispersion between categories. To demonstrate this confusion relationship, Fig. 5 has been depicted to exhibit the proportions of other meta-theoretical classics cited by a single meta-theory. Fig. 5 reveals that the percentage of internal citations in the category of classic texts of each meta-theory is the highest amongst all citations, apart from the resource-based view. This indicates both the rationality of the classification as well as the varying levels of confusion between different meta-theories. The rationale of the citing relationship to analyse confusion lies in the following fact: on the one hand, the definition of the conceptual confusion rests on studies that focus on the same phenomenon [13], while the citing relationship implies a consistency of concerns. On the other hand, because the reification of one meta-theory's texts may become the foundation of another meta-theory's reification, a confusion relationship exists between the meta-theories share citation relationships. This study presents a network relationship diagram, illustrated in Fig. 6, which reflects the level of confusion in the connections between various technological innovation meta-theories. The red lines with arrows depict the most frequently cited external meta-theory in relation to the citing meta-theory, while the blue lines with arrows indicate the second most cited external meta-theory. Fig. 6 demonstrates that, when the performance-based view is taken as the centre, the meta-theory of technological innovation has been split into two major clusters, which correspond to the location distribution of the Big Dipper and the North Star. In the handle portion of the dipper, the first cluster's nucleus is the dynamic-sustainable-view, which is most frequently cited by the technological-innovation-system view and the resource-based view. The dynamic-sustainable view mainly cites the classic texts of the technological-innovation-system view. The core of the second cluster at the head of the dipper is the dual-innovation view. The performance-based view and the dynamic-sustainability view are cited most by the capability-based view and the knowledge-based view. The knowledge-based view and capability-based view further extend the position of North Star. That is, the knowledge-based view and capability-based view are the main citation sources for the network-based view.

5.2. *The reason for the typology jungle of technological innovation*

In the literature review section, this study referred to the conundrum of classifying technological innovation according to jungle

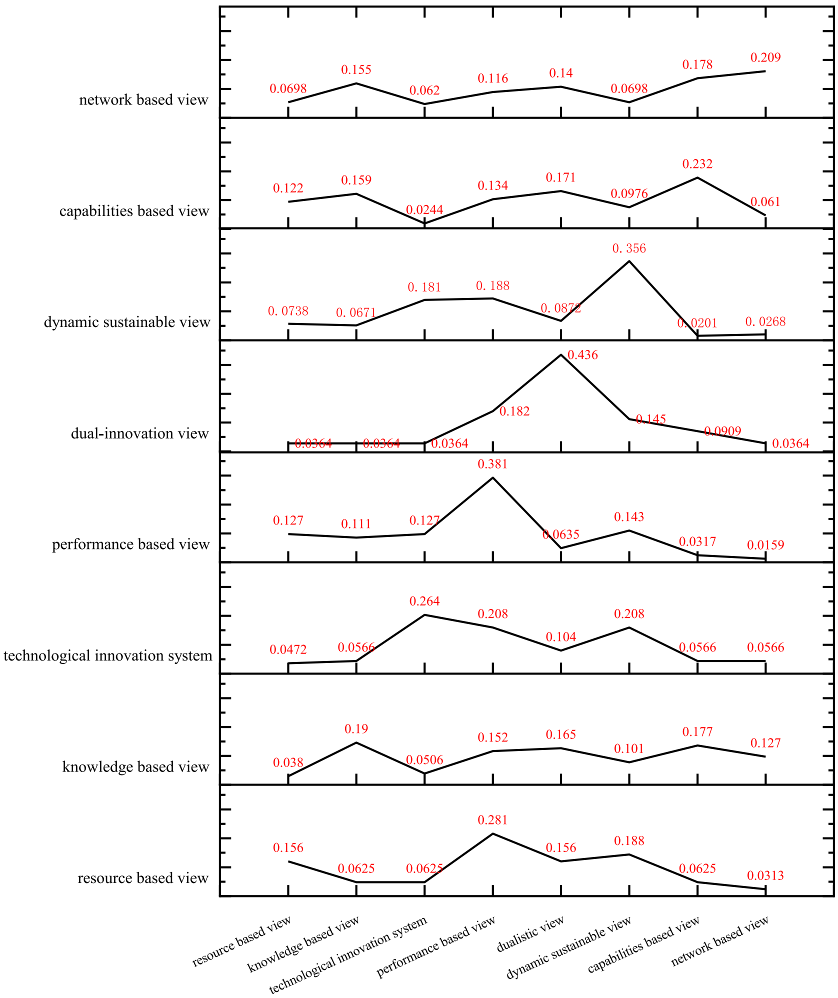

Fig. 5. The confusion relationship between meta-theories.

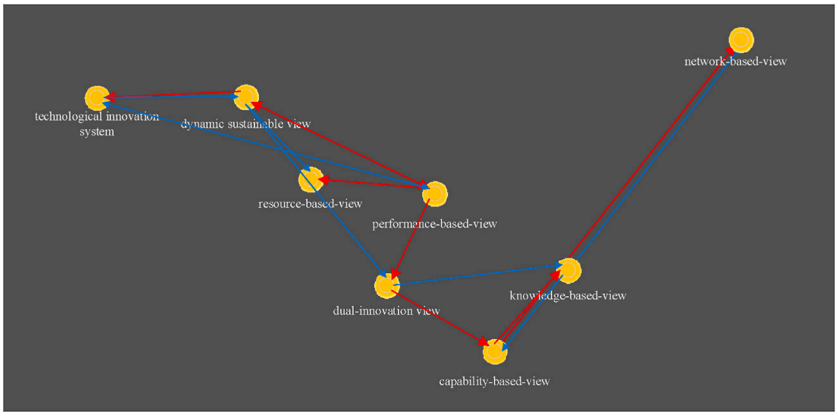

Fig. 6. Map based on the confusion relationship between meta-theories.

typology. Research on the technological innovation meta-theory is conducive to elucidating the full meaning of technological innovation. Distinct meta-theories are characterized by their distinct theoretical backgrounds, research foci, and research goals. According to the substance-attributes definition method [127], various meta-theories espouse the same views on the essence of innovation. Thus, it is scarcely tenable to contend that the substance exceeds the Schumpeter's definition. The disparity in the interpretation of technological innovation among various meta-theories arises from differences in the attributes of the new combination and the process. This differentiation can be analyzed from the following two perspectives.

Regarding the research object of various meta-theories, Fig. 7 depicts the research levels of 105 classic texts on technological innovation. The coding results in Fig. 7 indicate that the primary research subjects addressed in these classic texts encompass individuals, firms/organizations, networks/alliances, industries, and countries/regions. In general, innovation research at the firm level dominates, followed by research on the national/regional and network/alliance levels, with the industry and individual levels occupying the third and fourth places, respectively. Different types of meta-theories show significant differences in terms of research levels. The performance-based view, technological innovation system view, and dynamic sustainability view mainly concentrate on the firm and country/region levels, with limited attention given to the industries and network/alliance levels. The resource-based, knowledge-based, capability-based, and dual-innovation views exhibit a more substantial emphasis on the firm level. In contrast, the network-based view focuses on both the firm and network/alliance levels.

To comprehend the function and characteristics of technological innovation, the performance-based view suggests that it encompasses conceptual and theorized internal factors that act as the driving force of economic activities. The technological innovation generates and affects the allocation and flow of new factors in the economic system, thereby making it a variable in both the micro- and macro-level production functions. Additionally, the dynamic-sustainable view and the technological-innovation-system view consider the basic units of technological innovation at both the firm and national levels. While the former view pays more attention to the cyclic and evolutionary nature of technological innovation, the latter is concerned with the influence of different departmental subsystem behaviours on overall technological innovation. In contrast, other meta-theories assert that the organization or firm is the basic unit of technological innovation. According to the knowledge-based view, technological innovation involves a transformation process from the knowledge stored in individuals to normal productive activities within an organization or firm. Furthermore, the network-based view broadens the scope of this knowledge transfer to alliances or networks. The resource-based view considers technological innovation as a strategic means, with the basic unit is also the organization or firm. Similarly, the capability-based view regards technological innovation as the more effective result of integrating knowledge and resources to obtain or exert ability.

Therefore, to a certain degree, the variance in research levels and divergent interpretations of technological innovation activities has resulted in the proliferation of the "concept jungle" of technological innovation. Furthermore, there exists a complimentary relationships among the differing meta-theoretical perspectives on technological innovation.

5.3. An integrated framework of technological innovation meta-theories

Fig. 6 depicts the inter-citation relations among diverse meta-theories of technological innovation, revealing that while technological innovation meta-theories exhibit considerable independence, they also evince intricate reification and confusion relations. These relationships offer the possibility of constructing an all-inclusive meta-theoretical framework. At the same time, establishing a unified integration framework would advance the standardization and cohesion of technological innovation research [128]. However, this unified framework generates varying outcomes from different perspectives. Fig. 8 illustrates one such framework, which considers the main tasks of different meta-theories in technological innovation activities. The upper portion of Fig. 8 showcases the interrelations among meta-theories, while the table columns beneath represent the core elements of each meta-theory at diverse research levels, such as nations/regions, industries, networks/alliances, firms/organizations, and individuals. In this framework, resources, knowledge, capability, and networks constitute the determining factors driving innovation activities, giving rise to dual innovation with different attributes. Innovation activities influence performance, which in turn affects dynamic changes and sustainable pursuits, shaping the

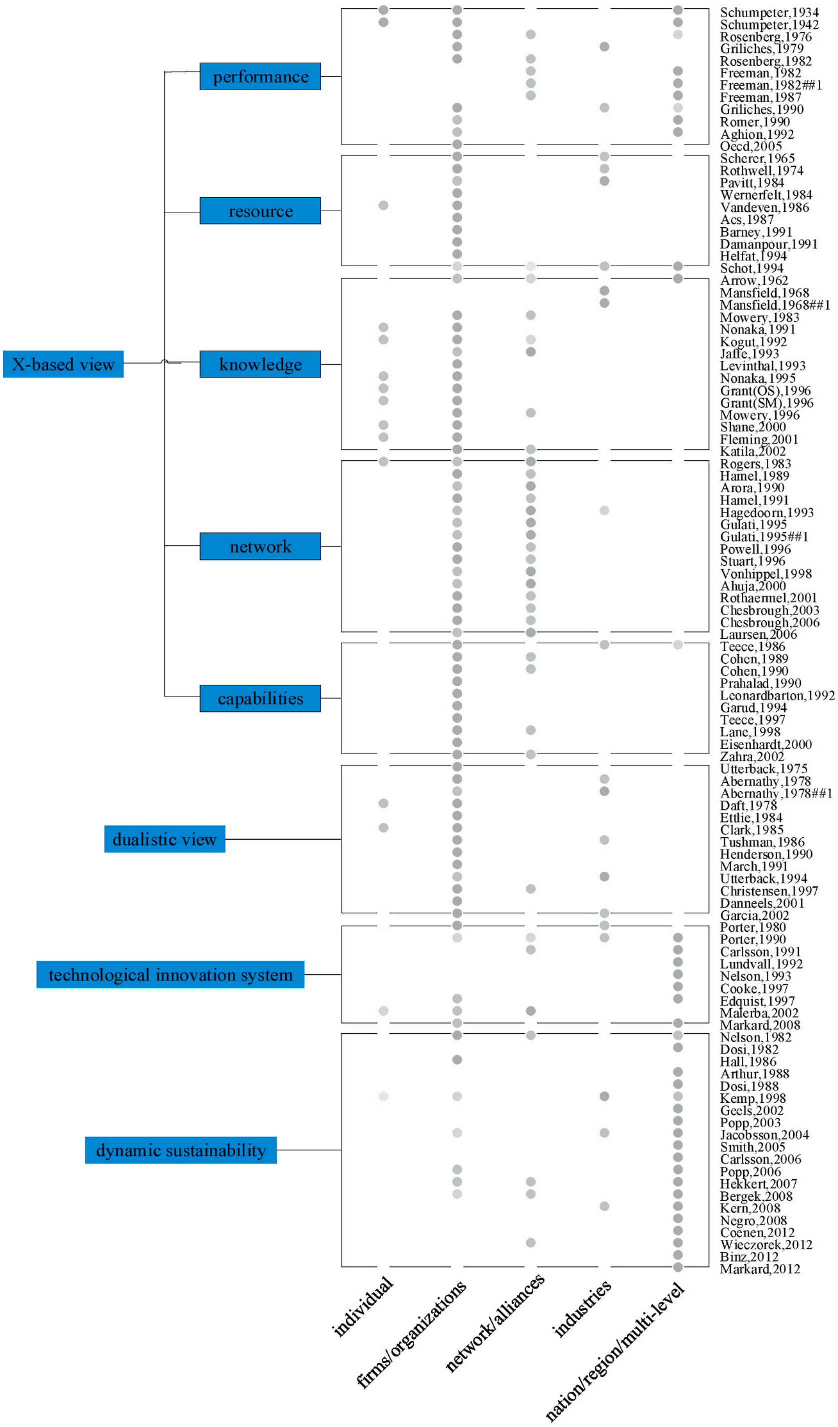

Fig. 7. Research level of each meta-theory and classic text.

values, goals, and institutional frameworks that govern the operation of the technological innovation system. The establishment of a new combination of the determining factors is necessary to facilitate a new wave of technological innovation.

5.4. How the mate-theories analysis beneficial to the future research

A paradigm refers to a set of representative issues and their corresponding resolutions that guide a scientific community's fundamental approach to their subject of study [129]. Examination in Section 4.4 demonstrates that each meta-theory can elucidate

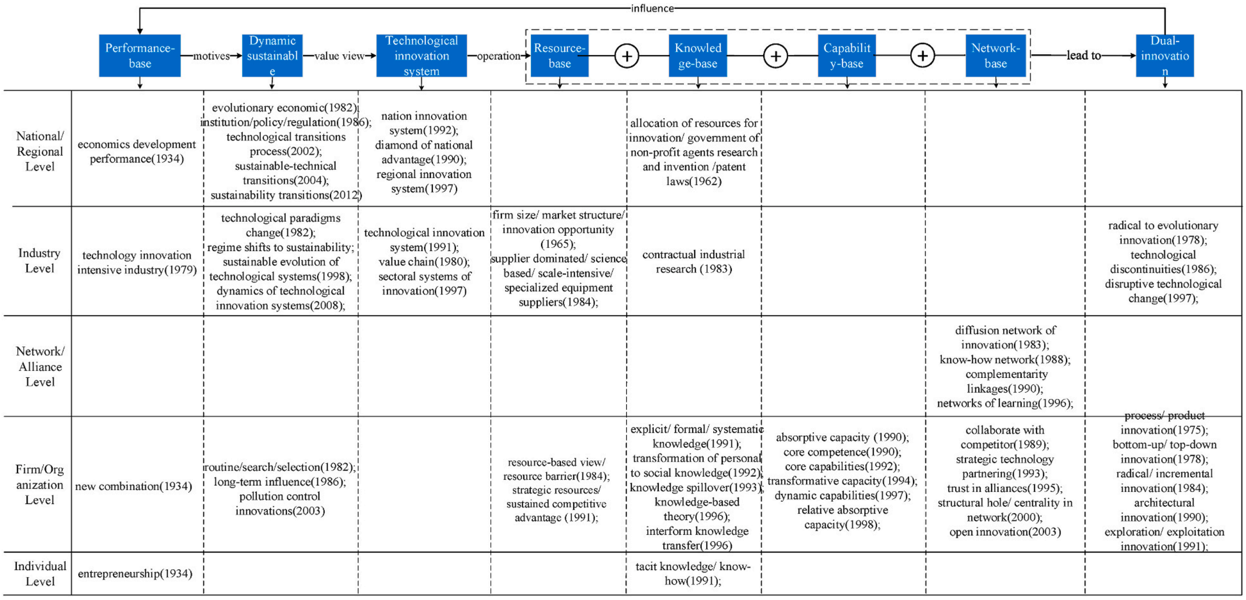

Fig. 8. An integrated framework of meta-theories.

various technological innovation phenomena from distinct vantage perspectives. Understanding these meta-theoretical paradigms bears significant implications for future research. For example, Overton [130] posits that a scientific paradigm, consisting of nested meta-theories with Relationism at the broadest level and Relational-Developmental-Systems as a mid-range meta-theory, constitutes a more progressive conceptual framework for developmental science. Houston [131] examines and defines the spectrum of meta-theoretical premises concerning risk and their influence on risk practices for children encountering various hazards in social life. Furthermore, several studies have enriched their field's paradigms by creating a framework through a meta-theoretical typologies analysis [132,133], as exemplified by Fig. 6.

Additionally, in Fig. 3, it is demonstrated that the domain of technological innovation theory remains a thriving area of research, evidenced by the citation rates of recently published classic texts that are comparable to those of classic texts from decades ago. As such, fresh research questions continue to arise, and novel concepts and theories are regularly formulated [e.g. Ref. [134]]. Most of the current research scopes and problems on various meta-theoretical types have surpassed the earliest meta-theoretical literature. This makes the establishment of new theories more necessary to analyse the differences, connections, and possible causality between historical concepts and theoretical frameworks. This study proposes multiple theoretical implications and research suggestions for future research in the following chapter.

6. Conclusions and implications

This study aims to develop an analysis framework for the identification, classification, and association analysis of meta-theories. The analysis framework combines multiple methods, including bibliometrics, RPYS, knowledge map, natural language processing, and qualitative data analysis. This study applied this set of methods in the field of technological innovation. Compared with previous studies, this multi-method framework enhances the credibility and repeatability of the classic text refinement and classification process. The conclusions and implications can be made as follows.

6.1. Conclusions

This study presents a comprehensive overview of the meta-theories in technological innovation research by extraction and analysis of classic texts. The types of meta-theories include the performance-based view, resource-based view, knowledge-based view, capability-based view, network-based view, dual-innovation view, dynamic-sustainable view, and technological-innovation-system view. Each of these meta-theories emphasizes and interprets the source, function, background, and relationships between technological innovation with other variables differently. Moreover, these meta-theories display complex evolution, reification, and confusion relationships, indicating heterogeneous distances among them. Specifically, the earliest meta-theory, the performance-based view, is connected to the dynamic-sustainable and dual-innovation views. The dynamic sustainability view is at the core of a cluster combined with the technological-innovation-system-view and the resource-based view. In contrast, the dual innovation view is at the core of another cluster combined with the knowledge-based view, the capability-based view, and the network-based view. Additionally, the research scope, objects, and purposes of these meta-theories have led to distinct definitions and research paradigms of technological innovation.

6.2. Theoretical implications and future research suggestions

In this study, an integrated framework of technological innovation meta-theories is constructed. Each meta-theory's perspective can complement the others. This study contends that this framework can stimulate future research from at least three aspects: first, a deeper comprehension of the concept of technological innovation; second, an examination of prevailing problems through the combination of different meta-theories; third, an exploration of the cutting-edge field of technological innovation under a holistic framework. Consequently, we propose three potential research themes as follows.

6.2.1. The evaluation of innovation and its related factors

Dziallas and Blind [2] summarized two limitations on innovation indicators in their study, namely, a) the study's sample is based on a restricted range of selected keywords, and b) the relevant literature used in their study comprises a wide and extensive spectrum of publications, nevertheless, several factors and indicators are occasionally presented ambiguously in these publications and hence are difficult to apply in practice. To tackle the first limitation, the strategy of seeking documents from the perspective of classic texts could decrease the sampling error. Specifically, the sample collection could be divided into two stages: after searching for the sample using keywords, researchers could find the citing documents of the classic texts of technological innovation that are not included in the sample, and then conduct further screening of the target sample based on these documents. As for the second limitation, the meta-theoretical analysis enables researchers to unearth the root of ambiguous factors and indicators, thus providing a better understanding of the indicators' landscape. Moreover, meta-theoretical analysis is conducive to improving the understanding of the innovation process, which is crucial for evaluating innovation in both academia and business.

6.2.2. Unearthing new technological innovation theories

One of the notable findings of this study is the varying distances across meta-theories. Drawing from the weak ties theory [135] and the structural holes theory [136], the meta-theoretical network shows the presence of structural holes that stem from weak ties with unequal information, thus presenting an opportunity to develop new theories. As illustrated in Fig. 5, the technological-innovation-system view and the resource-based view are each other's least cited meta-theories. The main reason is that the former mainly examines macro level problems, while the latter mainly focuses on micro-organization level. Few studies have combined these two views, yet such a combination could be highly valuable. For example, Kang and Park [137] integrated the national innovation system approach and a resource-based view to define a framework that can be used to assess the influence of government R&D support and inter-firm collaborations on innovation in SMEs.

6.2.3. Investigating sustainable technological change

Sustainability includes two dimensions: the sustainability of resources and environment as defined by environmental science, and the steady and sustainable advancement of technological changes. At the macro level, the topics covered the comparison of the sustainability of technological innovation in different institutional and cultural contexts, the development of policy tools, and the public-private sector synergy. At the micro-level, it involves how organizations respond to disruptive technological innovations and strike a balance between exploration and exploitation activities to achieve stable development. This is among the most popular research fields in today's technological, economic, and environmental scenarios [138]. Innovation is an uncertain phenomenon, and current research is still in the exploratory phase. Every meta-theoretical research aims to identify the decisive factors of technological innovation and methods to control it. Although technological innovation has become a stable variable in economic models, current achievements cannot predict its impact on the economy or anticipate the effects of changes in taxes, currency, or interest on the economy. Meta-theory can offer more theoretical perspectives for research in this field and help to unify related research paradigms.

6.3. Practical implications

At least, in relation to participants involved in innovative practical activities, the analysis of the meta-theory of technological innovation in this study can serve as a popular science document while also furnishing support for the optimization of innovation activities.

On the one hand, this study helps prevent participants in innovation activities from getting lost in the "concept jungle" of innovation. The summary and introduction of meta-theories in this study facilitate non-professionals in gaining a prompt understanding of the technological innovation domain. If they seek to gain deeper insights into any given theory or concept, they can effortlessly trace it back to the corresponding classic texts or the citing literature of the classic texts. In this way, participants in innovation activities can seamlessly correlate their specific innovation activities with innovation theories.

On the other hand, the meta-theoretical integration model propounded in this study can provide sound support for decision-making and innovation activity optimization. For example, policymakers who tend to consider problems primarily from a macro perspective can be made cognizant of the duality of micro-level innovation outcomes and the principles governing an organization's utilization of external resources. Furthermore, factors such as networks, knowledge, resources, capability, and performance may all serve as double-edged swords. Thus, policymakers can make policies from a more comprehensive and scientific perspective. With respect to innovation participants in micro-organizations, this study's results can be linked to the impact of macro-level factors on the shifting trends of decisive innovation factors to formulate a sustainable and sensible innovation strategy.

7. Limitations

This study is subject to several important limitations that must be taken into consideration. First, the criteria for theoretical classification in the qualitative data analysis are still open for discussion. In this study, we primarily categorized the research themes of classical texts based on their chronological order, and while the results align well with those of the LDA model, different criteria in manual or algorithmic classification could yield different results. It is hoped that future research will arrive at a greater consensus on this issue. Second, although an analysis based on historical classic texts is useful for uncovering the theoretical foundations of current research. However, our study does not offer sufficient analysis of current research trends and emerging theories since the limited capacity and methods available to process a large volume of text data. This will be an important avenue for further research in the future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the National Natural Science Funding of China [grant number 72102121].

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