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## Postprint: Research Advances in Technology Opportunity Discovery from a Holistic Perspective of Technological Innovation

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### Abstract

[Purpose/Significance] Technology opportunity discovery holds significant importance for market competition, technology layout, regional innovation, and industrial development. Reviewing the research progress in this field can clarify its developmental limitations, thereby further promoting its optimization and healthy development. [Method/Process] From a holistic perspective of technological innovation, this study synthesizes various elements of the innovation process and reviews domain-related research across four dimensions: knowledge base for technological innovation, innovation environment, innovation approach, and innovation type. It also summarizes the characteristics of analysis units for technology opportunity discovery from the perspective of technological innovation elements, and identifies existing problems and development trends in current research. [Results/Conclusions] The internal attribute of technology opportunity discovery is the knowledge base for technological innovation, while its external attribute is the technological innovation environment. Technology emergence, technology fusion, and technology breakthrough represent common approaches to technological innovation. Technology opportunities are categorized into three types: emerging technology opportunities, incremental technology opportunities, and disruptive technology opportunities. In the future, foundational research on scientific knowledge will be further strengthened, the synergy of various resource factors will become an innovation trend, the means of technology opportunity discovery will become more composite and targeted, the discovery process will be more standardized, and its results will be more credible.

Full Text

Preamble

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**Research Progress on Technology Opportunity Discovery from the Full Perspective of Technological Innovation**

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**Abstract:**

[Purpose/Significance] Technology opportunity discovery is of great significance to market competition, technology layout, regional innovation, and industrial development. Reviewing the research progress in this field can clarify its developmental limitations and further promote optimization and healthy growth. [Method/Process] From a full perspective of technological innovation, this study integrates various elements of the innovation process and systematically reviews relevant research from four dimensions: the knowledge base of technological innovation, innovation environment, innovation methods, and innovation types. It also summarizes the characteristics of analysis units for technology opportunity discovery from the perspective of technological innovation elements and identifies existing problems and development trends. [Result/Conclusion] The internal attribute of technology opportunity discovery is the knowledge base of technological innovation, while its external attribute is the innovation environment. Technology rebirth, technology fusion, and technology breakthrough are common innovation methods. Technology opportunities are classified into three types: emerging, progressive, and disruptive. In the future, foundational research on scientific knowledge will be further strengthened, the coordination of various resource factors will become an innovation trend, discovery methods will become more composite and targeted, the discovery process will be more standardized, and results will be more credible.

**Keywords:** technology opportunity discovery; technological innovation; innovation foundation; innovation environment; innovation method; innovation type

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In today's world of increasingly fierce technological competition, identifying opportunities for technological advancement and occupying the commanding heights of science and technology has undoubtedly become a key concern for na-

tions and enterprises. Technology opportunity discovery (TOD), as an emerging research branch in fields such as technology forecasting and technology futures analysis [1], holds significant strategic importance for technological competition, market layout, regional innovation, and industrial development.

Research in technology opportunity discovery has a history of over 20 years and is currently in a period of rapid development [2], with notable progress in both basic theories and analytical methods. Conceptual research on technology opportunities has primarily focused on explaining technological progress [3], with mainstream thought using technological renewal and advancement as the fundamental basis for measuring opportunities. Concepts such as industrial understanding [4], enterprise innovation, technological paradigm shifts [5], and technology morphology emergence [6] all represent important aspects of current research and future healthy development in this field.

Chinese scholars have actively studied and summarized relevant research on technology opportunity discovery both domestically and internationally, attempting to review the field from perspectives such as comparative studies [1-2] and methodological discovery [7]. However, existing reviews tend to overemphasize general research content and development patterns while lacking integration of technology's own growth characteristics and additional features, which hinders in-depth exploration of the essence of technology opportunity discovery. Han Yan et al. from Nanjing Agricultural University [8] pointed out that technology opportunity discovery must focus on the necessary foundations, methods, and manifestations in the process of new technology formation, but did not delve deeper into these aspects. The authors argue that the most fundamental approach to technology opportunity discovery should be grounded in the nature of technology and the innovation process, grasping various technological innovation elements to truly understand its connotation. Therefore, this study adopts a full perspective of technological innovation to review existing research by sorting out various innovation conditions and characteristics, with particular attention to the internal and external conditions and methods of technological innovation—including what innovation conditions are utilized, what evolutionary pathways are followed, and what types of innovation opportunities are ultimately obtained—to clarify the current state and uncover new perspectives, pathways, and content for technology opportunity discovery.

## 1. Several Perspectives on Technology Opportunity Discovery

This study's understanding of technology opportunity discovery draws on W.B. Arthur's insights into technological complexity [9], the nature of technology, and technological evolution mechanisms [10]. Arthur argues that today's technology and economy have become highly complex, with technological complexity becoming a central point of numerous conflicts and confusions in real life [11]. Regarding the nature of technology, he explains that technology represents a purposeful programming of phenomena—a collection of captured and utilized

phenomena—while technological evolution follows a “autopoietic” (self-creating) mechanism [10]. He also introduces concepts such as “technology and science share the same origin,” “technology is constituted by technology,” “technological invention is the linking of needs and phenomena,” “recursive combination,” and “domains” [10], which provide important insights for revealing technological innovation and discovering technology opportunities.

### 1.1 Knowledge Base of Technological Innovation

The foundation is the root or starting point of development. Arthur’s “nature of technology” thesis emphasizes that technology’s programming of phenomena generates countless applications, while science provides theories and methods for observing, capturing, and predicting phenomena. It is evident that the key foundation for technology formation is “knowledge,” such as scientific knowledge and technological knowledge, whose operation, configuration, and mutual transformation create the internal conditions for technological innovation and opportunity discovery. The linear sequence theory of science and technology discovery-push (Discovery-push) 很早就揭示了基础研究在新产品、新工艺技术上的应用模式. R.R. Nelson [12] pointed out that technology opportunities are closely related to the characteristics of technology itself (such as past development trajectories and survival time) and its connections with foundational science, representing important prerequisites for technology establishment. Regarding the relationship between science and technology in innovation, Arthur’s [10] concept of “technology and science sharing the same origin” indicates that science and technology evolve symbiotically.

The carriers of scientific and technological knowledge bases for innovation are generally papers or patents. Based on the interweaving of basic knowledge elements, the knowledge base can be divided into single-knowledge-based research and multi-knowledge-based research according to hierarchical relationships. The differences between the two are shown in Table 1 . Single-knowledge-based research only considers a single knowledge base, either scientific or technological, while multi-knowledge-based research involves bidirectional studies of both scientific and technological knowledge.

**Table 1. Differences Between Single-Knowledge-Based and Multi-Knowledge-Based Research**

	Single-Knowledge-Based	Multi-Knowledge-Based
Dimension	Research	Research
Knowledge Elements	Scientific or technological knowledge elements	Both scientific and technological knowledge elements
Data Sources	Primarily patents	Papers and patents

Dimension	Single-Knowledge-Based Research	Multi-Knowledge-Based Research
Focus	Technical characteristics themselves	Exploring associations or gaps between science and technology
Research Emphasis	Pre-technical scientific foundations	Multi-dimensional analysis

## 1.2 Innovation Environment

The innovation environment comprises external conditions for technological innovation and opportunity discovery. Complex society and economy influence the construction of complex technological systems, encompassing various complex factors such as markets, innovation actors, and resources. Many theories reflect the complexity of the innovation environment. For instance, the demand-pull innovation theory emphasizes that market demand can create countless opportunities for technological innovation, while opportunity creation theory [13] recognizes that opportunities are essentially created by entrepreneurs who gather resources and capabilities to overcome risks and transform ideas into products and services. Evidently, the comprehensive nature of complex technological innovation processes is extremely high, as all complex technologies have witnessed the co-evolution of technology with the organizational networks of its developers and users [14].

This study divides the innovation environment into market environment and resource environment. The market environment, based on market circulation actors, is further divided into technology implementers, technology carriers, technology users, and technology drivers. Technology implementers refer to technology developers, primarily enterprises, while universities and research institutions outside the industrial chain also provide numerous opportunities. Technology carriers are products or processes, technology users typically include customers, and technology drivers are governments and their policies. The relationships between market actors and technological innovation are illustrated in Figure 1 [Figure 1: see original paper].

The resource environment refers to the integration of various material elements such as talent, R&D, information, and capital, representing the cost-benefit structure of technological innovation [13]. Its optimal combination plays a crucial role in influencing the innovation system or the capabilities of innovation actors.

## 1.3 Innovation Methods

Innovation methods are specific pathways for technological innovation and primary sources of technology opportunity discovery. G.S. Altshuller [15] proposed

that technological systems are constantly evolving. Regarding evolution mechanisms, Arthur [10] identified two main forms: First, “combinatorial evolution,” where combinations of existing technologies provide potential supplies for new technologies, enabling evolution through the combinability and recursiveness of technology’s own structure in a self-cycling manner—reflecting the idea of technology fusion. Second, the summoning of new technologies by technology opportunity niches (defined as niches that technology can effectively occupy), because technology often triggers indirect problems, creating new demands or opportunities for technical support or solutions—that is, contradictions or obstacles that, when resolved, bring certain technological progress and breakthroughs, highlighting the importance of breakthrough methods. Additionally, Arthur [10] noted that new technologies provide potential new elements that may trigger new organizations and pathways—that is, technology rebirth. Synthesizing these perspectives, innovation methods are categorized into three types: technology rebirth, technology fusion, and technology breakthrough. Technology rebirth represents innovation from 0 to 1, technology fusion is the main and fundamental manifestation of technological evolution and innovation, and technology breakthrough can significantly enhance technical performance or create entirely new opportunities. These three methods are not entirely independent; for example, attention to technology fusion and rebirth may lead to breakthrough opportunities, while breakthroughs may trigger a series of technology rebirths or fusions. The key difference of technology breakthrough is its emphasis on existing obstacles, whereas technology rebirth and fusion do not focus much on prerequisites for innovation.

#### 1.4 Innovation Types

Innovation types can be viewed as the results and manifestations of technological innovation and evolution. R. Foster’s [16] technology life cycle model indicates that random jumps easily occur at the front end of the technology evolution S-curve, forming “breakthrough technologies” that evolve into emerging technologies after market introduction and mature through cumulative improvements. Arthur’s [10] “domain” theory suggests that a new domain is initially filled with various emerging technologies. As it develops, the emerging domain gradually enters “adolescence” and even “adulthood,” bringing small but useful progressive improvements. With further maturity, the domain stabilizes until it is replaced by another new domain in its old age. However, not all domains complete this cycle; they may mutate, break the cycle, and cause fundamental changes in key domain technologies, bringing re-domainization—that is, disruptive technological change [16-17]. Based on this, this study categorizes innovation types into emerging, progressive, and disruptive technologies, as shown in Figure 2 [Figure 2: see original paper].

Emerging technologies emphasize novelty, rise, and development [17] and represent advantageous sources of innovation. Progressive technology is a form of incremental innovation and optimization—non-revolutionary minor changes in

technology. Disruptive technology [18] corresponds to thoroughly innovative technological possibilities with characteristics of fundamental innovation and eventual replacement. While both emerging and disruptive technologies involve novelty and rise, their main difference lies in that disruptive technology's eventual innovation force brings substitution. Compared with emerging technology's judgment of new and rising technological progress potential, discovering disruptive technology and its opportunities is more challenging, with factors such as technical performance breakthroughs, technological frontiers, external factor coordination, technology fusion, influence, and acceptance rates all playing important roles. Moreover, various indicators and measurement factors are more focused than for emerging technology, with significant impact and fundamental replacement being more prominent.

**Table 2. Discrimination of Three Technology Innovation Types**

Type	Definition	Key Characteristics
Emerging Technology	Innovative technologies based on science that may create a new industry or transform an old one [19-20]	Novelty, relatively rapid growth, high uncertainty, significant impact
Progressive Technology	Incremental innovation and optimization; non-revolutionary minor changes in technology	Highly path-dependent, follows specific technological trajectories [63]
Disruptive Technology	Technologies corresponding to thoroughly innovative possibilities with fundamental innovation and replacement characteristics	Multiple existing technology intersections or new technologies formed in major paradigm shifts [21]; initially lower performance than mainstream technologies, primarily affecting uncovered markets [22]; changes original performance standards, introduces breakthrough criteria, forms new value systems, and gradually replaces existing technologies [23]

## 2. Research Progress in Technology Opportunity Discovery

### 2.1 Knowledge Base of Technological Innovation

**2.1.1 Single-Knowledge-Based Research** Single-knowledge-based research involves analyzing single knowledge elements—considering only scientific

knowledge or technological knowledge. For example, Wang Guifang [24] and Pan Donghua et al. [25] used bibliometrics and CiteSpace software to analyze key technology nodes and domain hotspots in journal papers to discover opportunities. J. Ma explored patent compilations to analyze patent topic words for identifying potential innovation opportunities [26]. B. Yoon proposed an analysis method for discovering technology opportunities by visualizing patent information (such as documents and citation relationships) and using patent maps and link prediction [27]. Kang Yuhang constructed a patent coupling-cocitation hybrid network from a heterogeneous mixed network perspective, analyzing technology opportunities by discovering deeper knowledge structures in new technologies [28]. These studies commonly extract technical knowledge information (keywords, IPC codes, citations, etc.) and analyze technology trends and frontiers through text clustering, co-word analysis, outlier detection, morphology analysis, and patent maps [29] to identify possible opportunities. Their characteristics include introducing objective panel data, having relatively systematic analysis frameworks, and objectively identifying technology themes or morphologies, though they still require expert validation. Additionally, few studies use only journal papers to discover opportunities, as scholars focus more on technology characteristics themselves. Moreover, considering only scientific or technological knowledge elements may omit important technology components during opportunity discovery. Notably, single knowledge elements do not mean single data sources; for instance, patent documents, often considered representatives of technology, may cite scientific knowledge, making scientific knowledge obtainable from patents as well. However, research using full-text or citation content from journal papers and patents for technology opportunity discovery has not yet begun, and effective data acquisition for the knowledge base of technological innovation needs further optimization.

**2.1.2 Multi-Knowledge-Based Research** Multi-knowledge-based research involves comprehensive analysis of multiple knowledge elements, specifically science and technology. It is widely recognized that science and technology have complex bidirectional interactions [30]; thus, comprehensive analysis may reveal new possibilities for technological development. Currently, the main approach involves exploring associations between papers and patents or comparing sub-field differences between them. Topics already reflected in papers but not yet in patents are generally considered to represent potential technology development opportunities. In early research, N. Shibata et al. [31] compared the citation network structures of scientific publications and patents to identify potential technology commercialization opportunities, with subsequent researchers conducting a series of improvements and expansions, including using text clustering [32], similarity/correlation calculations [33], and technology combinations [8] to determine gaps between science and technology for opportunity discovery. While exploring science-technology differences is considered effective, research methods are relatively singular, analysis models are somewhat fixed, and discovered opportunities are coarse-grained.

## 2.2 Innovation Environment

**2.2.1 Market Environment** Based on market circulation actors, market environment elements in technology opportunity discovery include technology implementers, carriers, users, and drivers.

- (1) **Technology Implementers:** These are the natural persons who judge technology development and implement innovation, generally referring to enterprises. Universities and research institutions outside the industrial chain also provide numerous opportunities. The main research approach involves examining R&D layouts, competition [34-35], capabilities [36], and industry-university-research cooperation [37] of innovation actors to discover possibilities. For example, Kou Cuicui et al. [36] analyzed enterprises based on technology similarity and capability, constructing forward-looking technology assessment indicator systems to identify opportunities using K-means and text mining.
- (2) **Technology Carriers:** Products or processes are the ultimate manifestations of technological innovation. More market-demand-aligned opportunities can be discovered from commercial applications and products [38-39], with functional analysis being the primary method. J. Yoon et al. [38] proposed a function-based technology opportunity discovery framework using semantic similarity relationships between technologies and products to identify potential opportunities. Although functional methods rely on natural language processing to extract functional knowledge with complex processes, their structure clearly represents system relationships.
- (3) **Technology Users:** These generally include suppliers and users within industries who influence product, process, and technology improvements [3], primarily through demand analysis. For instance, Wu Min and Feng Lijie mined target user needs and extracted technology elements to form a market-oriented disruptive innovation opportunity identification path [40-41]. B. Jeong et al. used social media data with topic modeling and sentiment analysis to discover potential market product improvement opportunities [42]. However, such research is relatively scarce, making it difficult to meet diverse needs through demand trajectory analysis.
- (4) **Technology Drivers:** Government policies and R&D guidance are important innovation factors, mainly by studying regional technologies and policies to evaluate market innovation environments. Jiang Man [37] noted that government-guided innovation enhances collaborative innovation to discover opportunities, with industrial policies and inter-regional technology exchanges promoting technology opportunity discovery.

**2.2.2 Resource Environment** Inputs of capital, talent, R&D, and other resources all represent the cost-benefit structure of technological innovation [13]. Commonly used resource indicators include research investment, knowledge, organizational management, and usage benefits. Wang Jinfeng et al. believed that

R&D opportunities should focus on research input, technological advancement, usage frequency, and benefits, combined with patent morphology analysis and evaluation weights to obtain more effective and objective domain opportunities [43]. Jiang Man et al. considered that innovation resource subsystems in opportunity identification mainly include knowledge, technology, capital, and information elements, which must flow optimally within the system to achieve functionality [37]. Currently, research on technology resources focuses more on analyzing their impact on opportunities, with few studies utilizing various resources to achieve optimal allocation for assisting opportunity discovery.

## 2.3 Innovation Methods

**2.3.1 Technology Rebirth** Technology rebirth often arises from discovering technology gaps, where domain experts use technology matrices [44], patent maps, and morphology analysis methods [7] to identify unaddressed areas and further combine them with future development potential to discover opportunities. B. Yoon et al. used technology keywords to build GTM patent maps to mine technology blank spots for preliminary opportunities, combined with link prediction algorithm evaluation metrics to measure opportunity value for further screening [27]. S. Lee and Gong Huiqun et al. used principal component analysis to generate multi-dimensional technology blank patent maps for industries, supplemented by patent values around blank technologies to evaluate opportunity importance and trends [45-46]. These methods, regardless of how they reduce technology dimensions into patent maps, embody technology rebirth thinking. However, current mining methods are relatively fixed, and more sophisticated big data dimensionality reduction methods or additional rebirth technology mining means need enrichment. Moreover, while technology rebirth can discover many opportunities, its development has high uncertainty [37], requiring strengthened evaluation and follow-up tracking.

**2.3.2 Technology Fusion** Technology fusion in opportunity discovery research includes intra-domain and cross-domain forms. Intra-domain fusion involves convergence between different technology branches within the same field, using combination analysis, knowledge association, and morphology analysis to extract, judge, combine, and represent possible opportunity components. Han Yan et al. used edge centrality indicators and knowledge unit integration methods to find opportunities in the form of “knowledge association” fusion [8]. B. Yoon et al. discovered new domain opportunities through morphology methods by changing shapes (specific attributes of technology variables) and dimensions (technology variables) [47]. These analyses can obtain fine-grained opportunities but face issues such as difficulty in standardizing technology keyword selection, heavy reliance on expert experience, combinatorial explosion, and simplistic evaluation [48-49].

Cross-domain fusion expands from specific technology fields to heterogeneous domains, broadening discovery scope, generally characterizing technologies from

citation, classification, and topic perspectives. Early fusion research measured technology convergence degree and monitored trends to discover opportunities—that is, measuring technological convergence [50]. Recently, future-oriented fusion analysis emphasizing potential and prediction has gained attention. I. Park used bibliographic coupling and edge betweenness to represent predicted technology knowledge flow (TKF) directions, extracting potential and emerging knowledge flow links to predict potential TKF between heterogeneous domains for analyzing fusion opportunities [51]. Zhai Dongsheng et al. used new or enhanced citations between IPCs to define opportunities under knowledge flow and predicted new or future deeper fusion technologies using SVM and linear regression link prediction models [52]. It is foreseeable that future-oriented fusion will more efficiently assist opportunity discovery, though heterogeneous knowledge fusion still faces data and relationship limitations, with multiple objects, relationships, and large data volumes being breakthrough directions.

**2.3.3 Technology Breakthrough** Attention to technology fusion [52] and disruptive technologies may bring breakthrough opportunities, but technology breakthrough emphasizes pre-existing technical obstacles. Huang Lucheng believed that technical obstacles are prerequisites for opportunities and serve as incentives for innovation [53]. Such research generally tracks industrial paths [54], identifies key technologies [54-55], finds breakthrough patterns, and solves bottlenecks or obstacles. TRIZ innovation methods [56] and morphology analysis [57] are relatively effective and can yield specific, targeted opportunities. However, analyzing technical obstacles relies heavily on domain expert knowledge and capabilities during morphology mining, making methods that handle large data volumes and reduce expert dependence worth exploring. For example, Wang Xuefeng et al.'s new morphology analysis effectively addressed these pain points, transforming traditional morphology matrix attributes into domain key technical problems and solutions to provide beneficial ideas for opportunity discovery [55].

Technology anomaly detection is another breakthrough form, typically considering anomalies as potential innovations breaking established rules, mainstream trends, and patterns [57], using methods such as LOF [56] and ABOD [58] for outlier patent detection. Huang Lucheng used anomaly detection methods and patent market value assessment systems to discover potential anomalous patent opportunities [58]. Relatively speaking, discovering opportunities through anomalies focuses more on identifying existing opportunities, but how breakthrough these opportunities are, their transformation strength, and market value remain unknown. Current evaluations mostly rely on expert experience or qualitative judgment combined with TRIZ technology system evolution laws [56], making them highly subjective and requiring further assessment.

## 2.4 Innovation Types

**2.4.1 Emerging Technology** Emerging technology opportunity discovery emphasizes the “emerging” aspect. Current research focuses on two aspects: first, identifying opportunities within emerging industries using common patent analysis, bibliometrics, and web mining methods [54, 59]. For example, Li Qianrui used SAO (subject-action-object) semantic analysis to identify technical solutions for major research problems in emerging technology industries and built technology roadmaps to discover opportunities [54]. Second, establishing feature-selection-centered opportunity discovery models by identifying indicators with new and rising technological progress potential. Y. Geum et al. used novelty detection techniques to analyze emerging technology patterns to determine opportunities [60], while Ren Zhijun et al. built a TOD model consisting of an emerging technology discovery model (ETD) and a technology life cycle discovery model (TLCD) to identify opportunities by selecting emerging technologies and predicting maturity [61]. These rule-based studies depend on the accuracy, representativeness, and comprehensiveness of indicator establishment, potentially overlooking valuable opportunities measurable by other indicators. Additionally, technology evolution [54] and patent citation networks [62] can identify emerging opportunities, but citation networks may miss key information because emerging technologies require time to form scale networks.

**2.4.2 Progressive Technology** Progressive technology is the most common innovation type, achieving innovation through cumulative improvements under existing technology trajectories and paradigms. A key characteristic is high path dependence, following specific technological trajectories [63], making time-change detection methods such as technology evolution [64] and patent citation analysis [28] important for opportunity discovery. For example, J. Choi used sequential pattern mining to capture focal technology dynamics to identify candidates and opportunities [34]. Another characteristic is solving local conflicts and improving performance [65], making opportunities often discovered through technical contradictions and breakthroughs—similar to breakthrough innovation methods. Typical approaches include technology efficacy [64], TRIZ [54], and innovation maps [66]. For instance, Yue Junju et al. built a two-level multi-dimensional technology innovation map based on hidden relationships in innovation elements and expert experience to identify more specific and feasible domain opportunities [66], though this process requires substantial manual experience, limiting replicability and expandability. Overall, progressive technology opportunity discovery is relatively common, but less attention is paid to subsequent opportunity development, making it relatively easy to grasp.

**2.4.3 Disruptive Technology** Corresponding to thoroughly innovative possibilities with fundamental innovation and replacement characteristics, current disruptive technology opportunity discovery focuses on concepts, features, and operational mechanisms, using technology evolution, roadmaps, scenario planning, Delphi methods, multi-indicator assessment models, and bibliometrics [18]

to identify disruptive technologies. However, specific research on disruptive opportunity discovery is limited, with most studies focusing more on technology prospect detection or disruptive discrimination. Since disruptive features are difficult to define accurately, judgments relying on thin historical data affect timeliness and accuracy. Some scholars have taken alternative approaches, integrating market characteristics based on disruptive innovation's market demand features and technical characteristics [40-41]. For example, Feng Lijie et al. analyzed low-end market user needs and technology life cycles to identify pathways for low-end market disruptive innovation opportunities [41]. However, building a more comprehensive discovery framework that grasps both internal and external disruptive technology features remains a significant challenge.

### 3. Analysis of Research Progress

By analyzing progress in technology opportunity discovery, this study answers the initial questions:

The internal and external attributes of technology opportunity discovery include the knowledge base and innovation environment of technological innovation. The knowledge base refers to scientific and technological knowledge as internal conditions, while the innovation environment includes market environments with various actors and resource environments comprising material elements.

Technology rebirth, fusion, and breakthrough are common innovation methods for discovering opportunities. Technology rebirth involves 0-to-1 innovation; technology fusion involves convergence or combination of different technology branches or components; and technology breakthrough emphasizes solving pre-existing obstacles to enhance performance. These evolutionary forms differ but are also interwoven.

Technology opportunity types include emerging, progressive, and disruptive technologies. Emerging technologies emphasize novelty and rising characteristics, progressive technologies involve incremental innovation and optimization, and disruptive technologies correspond to thoroughly innovative possibilities with eventual replacement characteristics.

Overall, the field is forming a relatively standardized and systematic research paradigm, with technological evolution laws widely applied. Certain innovation elements have formed relative advantages, such as emerging and disruptive technologies gradually establishing their own dominance. Additionally, analyzing each innovation element reveals common analysis units including data sources, discovery methods, opportunity definitions, representation units, evaluation indicators, and granularity, as detailed in Table 3 .

#### **Table 3. Analysis Units for Technology Opportunity Discovery from the Full Innovation Perspective**

Innovation Element	Research Type	Data Source	Discovery Method	Opportunity Definition	Representation Unit	Evaluation Indicator	Opportunity Granularity	Representative Literature
Knowledge Base	Single-knowledge	Papers	Patent maps, outlier detection	Keywords clustering, SAO, IPC	Keywords IPC, SAO	Expert experience, TRIZ evolution laws	Multi-dimensional analysis	Li Hui [29]
								Multi-knowledge
Innovation Environment	Market environment	Patent product description, user data	Function analysis, similarity methods	Technological similar actors	SAO structure, keywords, patent clusters	Novelty, complexity, importance, business models	Coarse-grained, directional	J. Choi [34]; Kou Cuicui [36]; J. Yoon [38]
								Resource environment
Innovation Methods	Technology birth	Patent blanks	Blank analysis, adjacent patents, outlier detection	Sparse/blank technologies	HRC, keyword clusters	Importance trend analysis	Coarse-grained but evaluable	J. Yoon [38]; Gong Huiqun [46]

Innovation Element	Research Type	Data Source	Discovery Method	Opportunity Definition	Representation Unit	Evaluation Indicator	Opportunity Granularity	Representative Literature
	Technology Innovation	New combinations	Novelty detection, TRIZ, link prediction	(Potential) new citations or keywords combinations	Keywords, SAO, IPC pairs	Novelty, importance, fusion potential	Multi-dimensional more specific	B. Kim [50]
	Technology Innovation	Breakthrough obstacles	TRIZ, anomaly detection	Technology breakthrough barriers or outliers	Technology solutions, expert judgment	Potential value, feasibility	Multi-dimensional more specific	Wang Xuefeng [55]
Innovation Types	Emerging technology	Patent survey data	Technology roadmap, TOD models	Technology meeting novelty features	Patent quantity, growth trends	Multi-dimensional combination	Relatively specific	Li Qianrui [54]
	Progressive technology	Patent keywords, SAO	Technology evolution, efficiency matrix	Technology with development potential	IPC combinations, technical terms	Potential value, novelty, feasibility	Relatively specific	Zhu Lin [64]; Kang Yuhang [28]
	Disruptive technology	Patent market data	Market demand analysis	Technology meeting uncovered user needs	Innovation dimension combination	Expert qualitative judgment	Less involved	Wu Min [40]; Feng Lijie [41]

From these analysis units, several issues require attention:

- (1) **Imbalanced attention to knowledge base elements:** Early-stage science lacks attention and emphasis. Arthur noted that science and technology are intertwined and interdependent when explaining technology's nature, with science built on technology and technology applied to science [10]. However, research has focused heavily on technology itself, with data

concentrated in patent literature and methods developed specifically for patent texts, which is not conducive to early-stage foundational discovery.

- (2) **Insufficient integration of multi-dimensional factors:** Most studies do not fully combine technology, innovation environment, and innovation methods, lacking systematic research with fragmented perspectives. C. Elizabeth pointed out that technology's complexity and the comprehensive nature of innovation require opportunity discovery to neglect no detail [67]. Arthur's combinatorial evolution theory [10] suggests that combining different elements in the innovation process can create new opportunities, but multi-dimensional, multi-factor research remains limited. Future research should focus on how different dimensions affect opportunity discovery, the mechanisms and effectiveness of multi-factor influences, and strengthening technology collaborative innovation.
- (3) **External constraints hindering evolution:** Not all technologies follow complete development curves, and innovation methods neglect social selection in technological evolution, including market and government selection that interact with evolution to affect opportunity discovery. Arthur noted causal circular relationships between economy/society and technology, with mutual influence and adjustment [10]. Additionally, technology and institutions share similar natures with strong path dependence that "locks in" existing technological paths, making it challenging to break existing constraints to discover opportunities [10].
- (4) **Limited reach of discovery methods:** Many methods have low impact on innovation progress. While citation analysis, network analysis, and patent analysis are used, more advanced methods such as full-text analysis, deep learning, and knowledge graphs [69] are needed. These can reveal internal structures and hierarchical relationships, showing strong vitality for handling large-scale heterogeneous data.
- (5) **Issues in the discovery process:** Early definitions follow single rules, representation units (IPC, keywords, SAO) have varying expressive power, and most units are extracted from titles, abstracts, or keywords, insufficiently reflecting technology development. Evaluation is simple, lacking assessment of feasibility, timeliness, risk, and demand, with different criteria for different opportunity types. Some studies use simple data validation, expert opinions, or literature comparisons, making evaluation validity difficult to judge. Opportunity granularity is often coarse, focusing on new or possible progress directions.

## 4. Future Outlook

Based on the review, future development trends include:

- (1) **Enhanced scientific knowledge foundation research:** Focusing on scientific innovation opportunities, especially possibilities in scientific

knowledge bases related to patented technologies, may achieve “comprehensive yet focused” effects. Future research can concentrate on deep comparisons to understand specific differences and connections between opportunities discovered from papers versus patents.

- (2) **Coordinated resource factors for cross-domain discovery:** Collaborative innovation integrates and optimizes resource elements from various dimensions, beneficial for practical operations. Future combinations and interactions between different elements [37] will be effective approaches. Industrial factors will become more prominent, with multi-industry fusion, analogy, or common technology [68] analysis providing new insights. Market-oriented opportunities will gain momentum later, not only promoting early discovery but also incentivizing transformation.
- (3) **More composite and targeted analytical methods:** First, analyzing more expressive technical texts including industrial economic data, social media data, and technology requirement documents (which directly show innovation needs). Second, targeted mining of text segments containing technological progress, such as conclusions in review papers or technical backgrounds in patents that discuss current deficiencies, directions, and prospects. Third, dynamic, semantic, and composite methods will combine multiple analytical approaches for complementary advantages, such as full-text analysis for papers and integrated citation-collaboration networks for patents. Patent science citation analysis, complex network analysis, and data mining will enhance effectiveness.
- (4) **More standardized processes with more credible results:** Definitions and boundaries will become clearer, distinguishing between domain-specific opportunities, R&D opportunities, and market expansion opportunities, each forming dominant methods. Evaluation and follow-up will gain importance, with multi-dimensional evaluation indicators improved, especially for feasibility, risk, timeliness, and demand. Optimization algorithms can discover optimal opportunities [7], and discovery-validation will emphasize practicality [39].

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**Author Contributions:**

Yi Huifang: Responsible for framework design, research, and paper writing.

Liu Xiwen: Topic selection, design, and guidance on writing, revision, and finalization.

Long Yixuan: Revision of content and format.

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**Book Notice:**

How to conduct research using content analysis both normatively and innovatively? *The Content Analysis Guidebook* (2nd edition) by Kimberly Neuendorf, translated by Li Wu et al., was published by Chongqing University Press in December 2020. As one of the world's most popular content analysis textbooks, this book represents the culmination of the author's years of teaching and research. It not only details technical content such as message units, sampling, variable selection, validity testing, and reliability analysis but also comprehensively analyzes the method's development issues in the digital interactive media era and its applications in various communication contexts. Notably, the author systematically elaborates on the content analysis integration model—how to systematically integrate message data obtained through content analysis with data obtained through other methods (such as surveys and experiments). This approach breaks through the traditional limitation of content analysis only describing phenomena (such as message content and formal features) to achieve scientific research's explanatory and predictive purposes (such as explaining or predicting which messages have better communication effects). The book has reference value for both beginners and experts.

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