RESEARCH ON BOUNDARY-SPANNING SEARCH AND INNOVATION RESILIENCE IN TECHNOLOGY-BASED FIRMS : THE MEDIATING ROLE OF KNOWLEDGE INTEGRATION AND THE MODERATING ROLE OF ENVIRONMENTAL TURBULENCE*

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Abstract

Against the backdrop of accelerating technological change and growing environmental uncertainty, enhancing the innovation resilience of technology-based firms has become a key pathway to ensuring their sustained competitiveness. This paper systematically explores the mechanism of Boundary-spanning search on innovation resilience and its boundary conditions. From the perspective of knowledge sources, this paper divides Boundary-spanning search into boundary-spanning search for technology.

Knowledge and Boundary-spanning search for market knowledge, and divides innovation resilience into two dimensions: innovation stability and innovation adaptability. The empirical analysis is based on data collected from the Credamo platform. After preliminary testing on a small sample, reliability and

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validity tests were conducted, and the results showed that the scale has good internal consistency and structural validity. Further using mediation and moderation effect models, the empirical results indicate: (1) Boundary-spanning search significantly and positively influences the innovation resilience of technology-based firms; enterprises with stronger Boundary-spanning search capabilities are better able to maintain the continuity and stability of innovation activities in uncertain environments; (2) Knowledge integration mediates the relationship between Boundary-spanning search and innovation resilience, as heterogeneous knowledge must be integrated to be effectively converted into innovation outcomes; (3) Environmental volatility negatively moderates the relationship between Boundary-spanning search and innovation resilience, meaning that the positive effects of Boundary-spanning search are more easily weakened in unstable environments. This study deepens research on corporate innovation resilience from the perspectives of open innovation and dynamic capabilities, expands the theoretical application space of Boundary-spanning search, and provides targeted management insights for technology-based firms to enhance innovation stability and adaptability in complex environments.
Keywords: Technology-based firms, Innovation resilience, Boundary-spanning search, Knowledge integration, Environmental turbulence

Introduction

Innovation has become essential for sustainable development in firms, helping firms identify market opportunities, adapt to environmental changes, and maintain competitive advantage (Wu et al., 2024). However, innovation involves high returns as well as high input, long cycles, and high risks (Li et al., 2022). Combined with complex and dynamic market environments, this makes innovation a major challenge. Simply possessing innovation capabilities is no longer sufficient for long-term competitiveness-what is more critical is a firm's ability to maintain and enhance its innovation capacity under adversity, i.e., innovation resilience (Luo et al., 2024). Unlike innovation capacity, innovation resilience refers to an enterprise's ability to maintain stable and sustainable innovation amid shocks.Technology-based firms, as primary producers of technological achievements, use intellectual property not only to build competitive advantage but also as strategic resources contested globally. They are core drivers of national economic transformation and technological progress. Therefore, enhancing the innovation resilience of technology-based firms is of practical importance for strengthening the real economy and improving international competitiveness.

Existing literature has explored the impacts of factors such as knowledge network embeddedness (Peng & Jia, 2024), digital transformation (Luo et al., 2025), embeddedness in R&D collaborations (Li et al., 2024), infrastructure development (Li et al., 2024), and uncertainty perception (Liu et al., 2024) on innovation resilience. However, few studies systematically examine how boundary-spanning search influences innovation resilience and its mechanisms in technology-based firms.As an essential component of open innovation, boundary-spanning search is considered an effective strategy for coping with uncertainty and competition. It helps firms identify potential market opportunities, expand technological knowledge, and maintain competitive advantage (Sidhu et al., 2004). However, the heterogeneity of knowledge acquired through boundary-spanning search requires effective integration (Flor et al., 2018; Broersma et al., 2016). Moreover, environmental turbulence—representing external uncertainty-may diminish the positive effects of search (Calantone et al., 2003).

Therefore, this study introduces knowledge integration as a mediating variable and environmental turbulence as a moderating variable. From the perspective of boundary-spanning search, we explore the influencing factors and pathways of innovation resilience in technology-based firms. This contributes to theoretical development in innovation resilience and offers theoretical and practical guidance for effective innovation management.

Objectives

1. Investigate the Relationship Between Boundary-Spanning Knowledge Search and Innovation Resilience
2. Assess the Mediating Role of Knowledge Integration Capability
3. Examine the Moderating Role of Environmental Turbulence
4. Provide Practical Recommendations and Strategies
5. Enrich Theories in Innovation Management and Organizational Resilience
6. Support Strategic Decision-Making in Firms

Methodology

1. Research Design

This study adopts a quantitative research approach using structured questionnaires to provide objective, reproducible, and statistically testable evidence. While qualitative designs can suffer from subjectivity and limited replicability, the quantitative approach leverages standardized procedures and statistical controls to examine relationships among variables and to identify potential causal pathways through model-based inference. In particular, we employ regression-based models to test the effects of boundary-spanning search on the innovation resilience of technology-based firms, including the mediating role of knowledge integration and the moderating effect of environmental turbulence.

2. Population and Sample

The population comprises technology-based firms (TBFs), which compete primarily through continuous technological innovation, rapid R&D cycles, and cross-domain knowledge integration amid dynamic and uncertain markets. These conditions make innovation resilience strategically salient. Sampling follows a simple random sampling strategy enabled by a multi-channel online survey platform to ensure broad coverage.

Sample size is determined using Cochran's formula for proportions:

$n_0 = (Z^2 \times p(1 - p)) / e^2$

Assuming Z = 1.96 (95% confidence), p = 0.5 (conservative), and e = 0.05, the minimum required sample size is approximately 385, with a planned target of ≥ 400 valid responses to ensure adequate statistical power.

3. Questionnaire Design

Validated scales from prior studies are adopted to enhance content validity, reliability, and comparability. An English questionnaire was developed and translated into Chinese using double translation and back-translation. Except for control variables, all constructs use a seven-point Likert scale (1 = strongly disagree to 7 = strongly agree).

3.1 Principles of Questionnaire Design

- Content validity ensured via extensive literature review and preference for empirically tested scales, followed by a pilot test and refinement.
- Reliability and convergent validity enhanced through multi-item constructs; anonymity and careful wording mitigate social desirability bias.
- Pre-distribution checks on wording and layout were performed to reduce measurement error.

3.2 Background of Questionnaire Design

TBFs operate amid rapid technological change and evolving market demands. Sustainable and cross-disciplinary innovation requires boundary-spanning search to obtain heterogeneous external knowledge and to integrate it effectively, thereby strengthening innovation resilience.

4. Variable Measurement

4.1 Boundary-Spanning Search (BSS)

Boundary-spanning search captures the extent to which firms explore knowledge across technological, market, and geographic boundaries. Two sub-dimensions are assessed on seven-point Likert scales:

A) Boundary-Spanning Search for Technology Knowledge (TS):

TS1 The company keeps trying new knowledge.

TS2 The company seeks new knowledge to break through existing limitations.

TS3 The company pursues improvement and perfection of existing technology.

TS4 The company masters domestic and foreign industry technologies and new product R&D.

TS5 The company tracks other technological developments that may affect the industry.

B) Boundary-Spanning Search for Market Knowledge (MS):

MS1 The company regularly participates in international exhibitions and seminars.

MS2 The company understands changes in customer needs and preferences.

MS3 The company uses customer feedback data on products and services.

MS4 The company grasps customers' innovation activities in product/service processes.

MS5 The company tracks competitors' (or partners') product development and service provision.

4.2 Knowledge Integration (KI)

Knowledge integration reflects firms' ability to categorize, absorb, reorganize, and apply dispersed knowledge. Measured with nine items using a seven-point Likert scale:

KI1 Effectively analyze market demand and technological dynamics.

KI2 Effectively absorb external knowledge and experience from different sources.

KI3 Establish convenient and rapid knowledge acquisition channels.

KI4 Maintain an IT system for knowledge storage and systematic management.

KI5 Regularly update knowledge resources (e.g., retiring outdated technology/market information).

KI6 Identify, analyze, and summarize best practices.

KI7 Information sharing inspires new insights and ideas.

KI8 Standardized processes/mechanisms help apply newly acquired knowledge to problem solving.

KI9 Effectively use new knowledge for product development and service innovation.

4.3 Environmental Turbulence (ET)

Environmental turbulence captures the perceived speed, magnitude, frequency, and unpredictability of changes in customers and technology. Measured with six items:

ET1 Customer needs and desires change rapidly.

ET2 Customers tend to look for new products.

ET3 Customer buying behavior changes rapidly.

ET4 Technological change creates great opportunities for our industry.

ET5 Technology in our industry changes rapidly.

ET6 Technological breakthroughs enable many new product ideas.

4.4 Innovation Resilience (IR)

Innovation resilience is measured across two dimensions: Stability and Adaptability.

A) Stability (ST):

ST1 Clear innovation rules and regulations.

ST2 Corresponding support platforms for the innovation process.

ST3 Oversight mechanisms for innovation.

ST4 Core technological capabilities.

ST5 Clear innovation strategy and direction.

ST6 Shared vision for innovation.

B) Adaptability (AD):

AD1 Talent diversification.

AD2 Integration of diversified resources during innovation.

AD3 Use of open innovation.

AD4 Emphasis on win–win relationships with stakeholders.

AD5 High market sensitivity.

AD6 Customer-oriented innovation.

AD7 Flexible organizational structure.

AD8 Existence of innovation teams.

AD9 Authorized innovation teams.

AD10 Employees are active and creative during innovation.

5. Data Collection Method

Data are collected via an online questionnaire distributed through a multi-channel platform (e.g., social media, email, and firm networks). The questionnaire contains six parts: (1) respondent background; (2) innovation resilience; (3) boundary-spanning search; (4) knowledge integration; (5) environmental turbulence; and (6) measurement anchors. A small-scale pilot test and iterative revisions were conducted prior to full deployment.

6. Data Analysis Method

6.1 Tools and Descriptive Statistics

Data cleaning and descriptive statistics assess distributional properties, normality, and basic relationships. Reliability is examined using Cronbach's alpha; sampling adequacy via KMO; and factorability with Bartlett's test. Harman's single-factor test checks common method bias. Multicollinearity is evaluated via VIF (threshold < 10).

6.2 Measurement and Structural Tests

Confirmatory factor analysis (CFA) tests convergent and discriminant validity of constructs. Ordinary Least Squares (OLS) regressions estimate the effects of boundary-spanning search on innovation resilience. Mediation through knowledge integration is examined using the three-step procedure, and moderation by environmental turbulence is tested via interaction terms. Bootstrapping with 1,000 resamples provides robust inference for indirect effects.

Results

Objective 1: Investigate the Relationship Between Boundary-Spanning Knowledge Search and Innovation Resilience

Key Finding: Both technological (TS) and market (MS) boundary-spanning searches exhibit strong, positive associations with both dimensions of innovation resilience—innovation stability (ST) and innovation adaptability (AD).

Evidence (Benchmark Regressions):

ST on TS: $\beta = 0.726$, $p < 0.001$ (with/without controls similar).

ST on MS: $\beta = 0.696$, $p < 0.001$ (with/without controls similar).

AD on TS: $\beta \approx 0.716–0.719$, $p < 0.001$.

AD on MS: $\beta \approx 0.730–0.732$, $p < 0.001$.

Objective 2: Assess the Mediating Role of Knowledge Integration Capability

Key Finding: Knowledge integration (KI) significantly mediates the effects of TS and MS on both ST and AD.

Evidence (Path/Mediation Analyses):

KI ⟶ ST: **β** ≈ 0.524–0.599, $p < 0.001$.

TS ⟶ KI: **β** ≈ 0.668–0.687, $p < 0.001$; MS ⟶ KI: **β** ≈ 0.771–0.781, $p < 0.001$.

KI ⟶ AD: **β** ≈ 0.577–0.585, $p < 0.001$; TS/MS retain positive indirect effects.

Bootstrap tests: Indirect effects' CIs exclude 0 for TS⟶KI⟶ST/AD and MS⟶KI⟶ST/AD.

Objective 3: Examine the Moderating Role of Environmental Turbulence

Key Finding: Environmental turbulence (ET) weakens (negatively moderates) the positive effects of TS and MS on both ST and AD.

Evidence (Interaction Models):

TS × ET ⟶ ST/AD: interaction **β** = -0.002 (significant at 0.1%–1%).

MS × ET ⟶ ST/AD: interaction **β** ≈ -0.001 to -0.002 (significant at 0.1%–1%).

Interpretation: As ET increases, the resilience gains from boundary-spanning search diminish.

Objective 4: Provide Practical Recommendations and Strategies

1) Intensify Boundary-Spanning Search Portfolios: Maintain balanced investments in both technological and market knowledge search to strengthen both stability (process continuity) and adaptability (strategic agility).

2) Institutionalize Knowledge Integration: Build routines, platforms, and roles (e.g., cross-functional integrators) to translate external knowledge into action—this is the key mechanism converting search into resilience.

3) Manage by Environmental Regime: Under high ET, prioritize rapid sensing, shorter feedback loops, and minimal viable experiments; under lower ET, deepen exploitation and standardization to fully harvest resilience gains.

4) Align Resources and Metrics: Track TS/MS search intensity, KI cycle times, and resilience KPIs (time-to-recovery, variance in innovation throughput) to guide continuous improvement.

Objective 5: Enrich Theories in Innovation Management and Organizational Resilience

Contributions:

Establishes boundary-spanning search as a robust antecedent to both stability and adaptability facets of resilience.

Identifies knowledge integration as the central transmission mechanism translating search into resilience outcomes.

Specifies environmental turbulence as a boundary condition that attenuates search⟶resilience effects, refining contingency theory.

Distinguishes resilience facets (ST vs. AD) empirically with consistent patterns across models.

Objective 6: Support Strategic Decision-Making in Firms

Decision Guidelines:

If ET is high: emphasize breadth in TS/MS scanning, faster KI cycles, modular architectures, and option-based investments.

If ET is moderate/low: concentrate on deepening KI to standardize and scale validated knowledge for resilience compounding.

Always monitor multicollinearity and measurement reliability to ensure valid diagnostics for portfolio adjustments.

Data & Reliability Notes

Sample: 434 valid responses (from initial 530) across 30 provinces; diverse industries and firm profiles. Reliability and validity are strong (Cronbach’s **α** generally > 0.69; KMO > 0.70). Multicollinearity is unlikely (VIF mean ≈ 2.37, max ≈ 3.06).

Discussion

Objective 1: Boundary-spanning search and innovation resilience

The benchmark regressions show that both technological (TS) and market (MS) boundary-spanning searches are strongly and positively associated with innovation stability (ST) and adaptability (AD) (e.g., ST on TS **β**=0.726; ST on MS **β**=0.696; AD on TS **β**≈0.716–0.719; AD on MS **β**≈0.730–0.732; all p<0.001). These patterns align with research on external search and openness, which finds that scanning broadly across technological and market domains increases the variety and recombinability of knowledge inputs, improving the reliability of existing innovation routines (stability) and the capacity to adjust them when conditions change (adaptability) (Laursen & Salter, 2006; Katila & Ahuja, 2002; Rosenkopf & Nerkar, 2001; Fleming & Sorenson, 2001). Conceptually, resilience comprises both robustness and agility (Holling, 1973; Sutcliffe & Vogus, 2003; Lengnick-Hall et al., 2011). The symmetric strength of the TS/MS coefficients on ST and AD suggests that boundary-spanning search can underwrite ambidextrous resilience-supporting both continuity and change-consistent with ambidexterity theory (March, 1991; O'Reilly & Tushman, 2013). Market-oriented search, in particular, may translate user needs and competitive signals into timely adjustments (Narver & Slater, 1990; von Hippel, 2005; Priem et al., 2012), while technological search expands the feasible solution set through recombination and distant search (Katila & Ahuja, 2002; Rosenkopf & Nerkar, 2001).

Objective 2: Knowledge integration (KI) as the transmission mechanism

Mediation analyses indicate that KI significantly carries the effects of TS and MS to both ST and AD (e.g., TS⟶KI **β**≈0.668–0.687; MS⟶KI **β**≈0.771–0.781; KI⟶ST **β**≈0.524–0.599; KI⟶AD **β**≈0.577–0.585; all p<0.001), with bootstrapped indirect effects whose CIs exclude zero. This is theoretically coherent with the knowledge-based view and absorptive capacity: external knowledge has value only when it is assimilated, combined with existing knowledge, and deployed in routines (Grant, 1996; Cohen & Levinthal, 1990; Zahra & George, 2002). KI routines-shared codes, boundary objects, integrator roles, and cross-functional forums-bridge specialized domains to turn scanned information into reliable processes (stability) and reconfigurable options (adaptability) (Nonaka, 1994; Okhuysen & Eisenhardt, 2002; Kogut & Zander, 1992; Tiwana, 2008). Methodologically, the use of resampling for indirect effects follows best practice for mediation in nonexperimental designs (Shrout & Bolger, 2002; Preacher & Hayes, 2008).

Objective 3: Environmental turbulence (ET) as a boundary condition

Negative and significant TS×ET and MS×ET interactions ($\beta \approx -0.001$ to -0.002) indicate that turbulence weakens the positive returns of boundary-spanning search to both ST and AD. In contingency terms, fit between information processing requirements and integrative capacity matters (Lawrence & Lorsch, 1967; Duncan, 1972). Under high turbulence, noise rises, signal coherence falls, and cognitive/coordination overload can blunt the conversion of scanned knowledge into resilient outcomes (Eppler & Mengis, 2004). Dynamic capability logic similarly predicts that sensing without commensurate seizing/reconfiguring can fail to yield performance in high-velocity contexts (Eisenhardt & Martin, 2000; Teece, 2007). Our results therefore refine this view: external search is generally beneficial, but its realized effect on resilience depends on (i) how efficiently the organization integrates knowledge (Objective 2) and (ii) the environmental regime. This echoes evidence that environmental dynamism moderates search/ innovation relationships and the efficacy of organizational designs (Jansen et al., 2006; Brown & Eisenhardt, 1997). Practically, simple-slope logic implies flatter TS/MS⟶resilience slopes at high ET; managers should expect diminishing marginal benefits of "more scanning" unless KI cycles are accelerated and decision architectures simplified (Aiken & West, 1991; Eisenhardt, 1989).

Objective 4: Managerial implications

First, maintain balanced TS/MS search portfolios to support both resilience facets (March, 1991; Laursen & Salter, 2006). Second, institutionalize KI via integrator roles, shared taxonomies, and digital collaboration platforms; these mechanisms are the critical conversion layer from search to outcomes (Grant, 1996; Nonaka, 1994; Okhuysen & Eisenhardt, 2002). Third, manage by regime: in high ET, emphasize rapid sensing, shorter feedback loops, modular product/process architectures, and option-based resource commitments (Eisenhardt, 1989; Schilling, 2000; Kogut & Kulatilaka, 2001; Teece, 2007; Ries, 2011). In moderate/low ET, deepen codification and standardization to harvest compounding resilience gains. Finally, align metrics with mechanisms: track TS/MS breadth and depth, KI cycle times, and resilience KPIs such as time-to-recovery and volatility in innovation throughput (Williams et al., 2017; Sheffi, 2005).

Objective 5: Theoretical contributions

The study (i) establishes boundary-spanning search as a robust antecedent to both stability and adaptability components of innovation resilience (Laursen & Salter, 2006; O'Reilly & Tushman, 2013); (ii) identifies KI as the central transmission mechanism, sharpening the knowledge-based explanation of how search becomes capability (Grant, 1996; Zahra & George, 2002); (iii) specifies ET as an attenuating boundary condition, contributing a contingency to the otherwise generally positive search⟶innovation narrative (Duncan, 1972; Eisenhardt & Martin, 2000); and (iv) empirically distinguishes resilience facets (ST vs. AD), which complements resilience theory's dual emphasis on robustness and agility (Holling, 1973; Sutcliffe & Vogus, 2003; Lengnick-Hall et al., 2011).

Objective 6: Decision guidance for firms

When ET is high, breadth of scanning, accelerated KI, modular architectures, and real-options logic are prudent (Eisenhardt, 1989; Schilling, 2000; Teece, 2007; Kogut & Kulatilaka, 2001). When ET is moderate/low, emphasize exploitation and scaling of integrated knowledge to reinforce stable, efficient innovation pipelines (March, 1991; O'Reilly & Tushman, 2013). Across regimes, managers should watch multicollinearity, reliability, and construct validity to keep diagnostics trustworthy for portfolio tuning (Hair et al., 2010; Nunnally & Bernstein, 1994).

Data quality and methodological notes

The sample (n=434 valid responses across 30 provinces) and diagnostics suggest sound psychometrics and estimation. Cronbach's **α** values >0.69 and KMO >0.70 meet conventional thresholds for internal consistency and sampling adequacy (Nunnally & Bernstein, 1994; Kaiser, 1974). Mean VIF ≈2.37 (max ≈3.06) lies well below conservative cutoffs (Hair et al., 2010). Future work could fortify causal claims via longitudinal designs, instrumented or experimental manipulations of search/KI, multi-source data to mitigate common-method bias (Podsakoff et al., 2003), and tests for potential nonlinearities (e.g., inverted-U in search breadth; Laursen & Salter, 2006) and ET thresholds.

Recommendation

Academic Recommendations

Weave a framework of Dynamic Capabilities, Absorptive Capacity, and Ambidexterity to explain how "Technological Search (TS)" and "Market Search (MS)" influence "Innovation Stability (ST)" and "Adaptability (AD)" through "Knowledge Integration (KI)" at different time/organizational levels.

Practical Recommendations

Establish a "knowledge broker" and a "cross-functional squad" to connect R&D, marketing, and supply chains, along with a community of practice.

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