

Review

TIC antecedents, dynamic capabilities, and uncertainty in manufacturing SMEs

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Abstract: This systematic literature review examines how organisational and CEO or Top Management Team (TMT) antecedents relate to technological innovation capability (TIC) in manufacturing SMEs, and how dynamic capabilities (DCs) are conceptualised and operationalised as mechanisms linking these antecedents to innovation outcomes under environmental uncertainty. Following PRISMA 2020, the review searched Scopus and Web of Science for English-language journal articles published between 2016 and 2025. Twenty-nine studies met the inclusion criteria and were analysed through descriptive mapping and thematic analysis. Environmental uncertainty was coded using an evidence mapping scheme covering market, technological, regulatory, and general turbulence conditions. The reviewed studies identify several recurring antecedents, including organisational structure and governance, resource configuration and reallocation, learning-oriented culture, and CEO or TMT attributes such as innovation orientation, strategic cognition, risk propensity, and prior experience. Although many studies invoke DCs as explanatory constructs, only a narrower subset explicitly defines and measures DC dimensions or formally tests mediation and moderation pathways. A recurrent finding is that the conceptual and empirical boundary between DCs and TIC remains unclear, with overlapping measurement items weakening mechanism-level inference. This review contributes by adopting a three-level analytical structure that separates antecedent conditions, DC mechanisms, and TIC outcomes. It identifies construct overlap between DCs and TIC as a central problem in the field and proposes an evidence-informed interpretive framework that synthesises patterned tendencies across a heterogeneous evidence base rather than confirming a unified causal model.

Keywords: manufacturing SMEs; technological innovation capability; environmental uncertainty; organisational antecedents; CEO or TMT antecedents; dynamic capabilities

1. Introduction

Manufacturing SMEs must repeatedly adapt their products, processes, and production systems in response to technological and market change (Mazzucchelli et al., 2021; Albis Salas et al., 2023). Technological innovation capability (TIC) refers to a firm's capacity to develop, assimilate, and deploy new technologies to improve products, processes, and operational systems (Kim et al., 2018). Definitions of TIC vary in scope across the literature. Some studies define innovation capability narrowly in terms of research and development activity or new product output (Dooley et al., 2017; Sahoo, 2019). Others adopt a broader framing that encompasses the absorption, integration, and application of technologies across products and production processes (Kim et al., 2018; Mazzucchelli et al., 2021). This review follows the broader

definition because manufacturing SMEs typically engage in applied adaptation and process upgrading rather than frontier research. In manufacturing contexts, TIC supports cost efficiency, quality assurance, delivery reliability, production flexibility, and the adoption of advanced technologies (Mazzucchelli et al., 2021). TIC is therefore a central determinant of whether manufacturing SMEs can sustain competitiveness under changing conditions. However, the factors that enable or constrain TIC development remain insufficiently understood, especially under volatile environmental conditions and persistent resource constraints (Albis Salas et al., 2023).

Environmental uncertainty is directly relevant to TIC development because the same organisational arrangement or leadership attribute may not produce the same innovation outcome across different environmental conditions. Market uncertainty stems from unpredictable shifts in customer demand and competitive intensity. Technological turbulence arises from rapid advances in production technologies and digitalisation. Policy and institutional uncertainty follows from changes in regulations and government support (Kim et al., 2018; Corsi and Prencipe, 2019). Uncertainty can restrict TIC by raising perceived risks, but it can also push firms to innovate when performance gaps demand a response (Taleb and Pheniqi, 2023). The direction and strength of antecedent effects on TIC are therefore contingent on the type and level of uncertainty a firm faces. Any synthesis of TIC antecedents that does not account for uncertainty risks producing conclusions that cannot generalise across contexts.

Scholars have examined a range of TIC antecedents at two levels. At the organisational level, these include decentralisation, resource allocation, learning orientation, and external networks. At the leadership level, relevant factors include CEO or Top Management Team (TMT) innovation orientation, risk propensity, and industry experience (Taleb and Pheniqi, 2023; Kim et al., 2018). Despite this breadth of inquiry, findings remain dispersed across levels of analysis and are often context-dependent. Most studies examine individual antecedents in isolation rather than specifying how organisational conditions and leadership attributes jointly shape TIC. The mechanisms through which these antecedents translate into innovation outcomes are rarely identified with precision. As a result, the evidence has not yet accumulated into a coherent theoretical pattern.

Dynamic capabilities (DCs) offer a theoretical lens that can address this mechanistic gap. The DC framework, built around sensing, seizing, and reconfiguring processes (Teece, 2018), provides a basis for explaining how firms convert internal resources and leadership intentions into adaptive innovation responses under uncertainty. In this review, DCs are not treated as an additional antecedent of TIC. Rather, they are positioned as mechanism-level processes that connect organisational and CEO or TMT antecedents to TIC outcomes. However, the existing literature presents a significant problem. Prior studies invoke DCs as background logic, mediators, or moderators, but construct boundaries between DCs and TIC are often unclear. Several studies use overlapping measurement items for both constructs, and inconsistent operationalisation complicates cross-study comparison (Mazzucchelli et al., 2021; Oh et al., 2025). When the mechanism and the outcome share the same empirical indicators, mediation claims risk tautology and the explanatory power of DC theory is weakened. This boundary problem is not merely a measurement limitation. It is a theoretical challenge that must be addressed if the field is to produce more

cumulative knowledge about how manufacturing SMEs develop TIC under uncertainty.

Prior systematic reviews have examined innovation in SMEs broadly, but few focus specifically on manufacturing contexts. Fewer still integrate uncertainty systematically with internal antecedents or offer mechanism-level synthesis (Johnson and Schaltegger, 2020; Xi et al., 2024). More fundamentally, prior work has not clearly separated antecedent conditions, dynamic capability mechanisms, and realised TIC outcomes within a single analytical framework. This review therefore addresses a theoretical problem rather than only a coverage gap. It synthesises evidence on TIC in manufacturing SMEs under uncertainty, maps organisational and CEO or TMT antecedents explicitly, and evaluates how DCs are conceptualised and operationalised as mechanisms connecting antecedents to TIC.

1.1. Conceptual positioning of antecedents, dynamic capabilities, and TIC

This review adopts a three-level analytical structure that distinguishes antecedents, dynamic capability mechanisms, and TIC outcomes. Antecedents refer to organisational and managerial conditions that enable or constrain capability development. At the organisational level, these include structural features such as decentralisation and formalisation, resource allocation practices, learning orientation, and external network ties. At the leadership level, they include CEO or TMT antecedents such as innovation orientation, strategic cognition, risk propensity, and prior industry or entrepreneurial experience. In this review, antecedents are treated as enabling conditions.

DCs are defined as adaptive, higher-order routines through which firms sense environmental changes, seize emerging opportunities, and reconfigure organisational assets in pursuit of innovation (Teece, 2018). They are positioned as mechanism-level processes that connect antecedent conditions to TIC outcomes. TIC, by contrast, refers to the firm's realised capacity to generate, assimilate, and implement technological innovation in products, processes, or operational systems (Kim et al., 2018). It is treated in this review as the focal innovation capability outcome.

This distinction is central to the analysis because the reviewed literature does not always maintain clear empirical separation among these categories. This review therefore applies the three-level distinction as an analytical lens throughout the synthesis. Where reviewed studies maintain clearer construct boundaries, mechanism-level inferences are treated with greater confidence. Where boundaries are blurred, the review identifies this limitation and interprets the associated findings with caution.

1.2. Theoretical contributions relative to existing DC literature

This review advances the literature in three related ways. First, it adopts a three-level analytical structure that explicitly separates organisational and CEO or TMT antecedents as enabling conditions, DCs as mechanism-level processes, and TIC as the focal innovation capability outcome. Prior reviews have often catalogued antecedents without clearly distinguishing them from the mechanisms through which they operate or the outcomes they are expected to produce. By maintaining this

separation throughout the synthesis, the review provides a more precise basis for assessing which antecedent–mechanism–outcome relationships are supported by reviewed evidence and which remain more tentative or inferential.

Second, the review identifies the construct boundary between DCs and TIC as a first-order theoretical problem rather than a secondary measurement concern. The Introduction documents specific instances in which reviewed studies use overlapping indicators for both constructs, and the Discussion examines the consequences of this overlap for mediation claims and cross-study comparison. Rather than treating this issue as a methodological footnote, the review treats construct separation as a necessary condition for more cumulative theory development. In this way, the DC-TIC boundary problem is elevated to a central analytical finding with direct implications for how mechanism-based claims in this field should be evaluated.

Third, the review proposes an evidence-informed interpretive framework rather than a validated causal model. The integrated framework developed in this study synthesises recurrent patterns across the 29 reviewed articles and maps how organisational and leadership antecedents relate to TIC through dynamic capability processes under different forms of environmental uncertainty. However, the framework should not be read as a statistically validated causal architecture. The underlying studies differ in construct operationalisation, analytical design, sectoral scope, and geographic setting. The framework therefore serves as an interpretive device for organising existing evidence and for identifying where convergence appears stronger and where it remains more provisional.

On this basis, the review advances a set of review-based mid-range propositions. These propositions are not presented as universal causal laws. They are evidence-informed interpretive statements derived from recurrent patterns in a heterogeneous body of studies and are intended to guide future empirical testing.

Proposition 1. Different forms of environmental uncertainty appear to condition the relative salience of different dynamic capability processes in manufacturing SMEs. Across the reviewed evidence, technological turbulence is more often associated with sensing-related responses, market uncertainty with seizing-related responses, and institutional or regulatory pressure with reconfiguration-related demands, although these patterns remain provisional rather than uniformly established.

Proposition 2. Organisational antecedents and CEO or TMT antecedents appear more likely to support TIC when they operate as reinforcing configurations rather than as isolated predictors. The reviewed evidence suggests that leadership attributes such as innovation orientation, strategic cognition, and prior experience are more likely to translate into TIC when organisational conditions such as learning orientation, flexible structures, and supportive resource allocation also enable sensing, seizing, and reconfiguring activities.

Proposition 3. The explanatory value of DC-mediated pathways to TIC is stronger when studies maintain clearer analytical and empirical separation between antecedent conditions, mechanism-level processes, and innovation capability outcomes. Where DC and TIC are measured through overlapping indicators, mechanism-based explanations become less reliable and cross-study comparison becomes more difficult.

Proposition 4. Institutional environments appear to shape the salience of particular antecedents and dynamic capability processes in the development of TIC. This suggests that antecedent–DC–TIC relationships are context-dependent rather than institutionally neutral, especially across settings that differ in industrial policy support, regulatory structure, and resource constraints.

Taken together, these contributions clarify what this review adds relative to existing dynamic capability literature. Rather than simply restating the general sensing–seizing–reconfiguring logic, the review shows that progress in this field depends on clearer construct separation, more explicit mechanism-based explanation, and more cautious interpretation of patterned evidence under heterogeneous uncertainty conditions.

Two research questions guide the review. RQ1 asks: what internal organisational and CEO or TMT characteristics have been examined as antecedents of TIC in SMEs, and how do these patterns vary across sectors and in studies that consider dynamic or uncertain environments, with particular attention to manufacturing contexts? RQ2 asks: how have DCs been conceptualised and operationalised as mechanisms linking internal characteristics, uncertain environments, and TIC in SMEs, particularly in manufacturing settings? RQ1 draws on the full evidence base of 29 studies. RQ2 is addressed using a coded subset of studies that explicitly define or measure DCs as mechanisms.

2. Methodology

The review follows PRISMA 2020 guidelines to ensure transparency and replicability (Page et al., 2021). Research questions were formulated first, followed by the development of search strings for each database. The search covered Scopus and Web of Science, restricted to English-language peer-reviewed journal articles published between 2016 and 2025. Search terms targeted the intersection of TIC, SME context, environmental uncertainty, and manufacturing or production sectors. In Scopus, terms were applied to titles, abstracts, and keywords. The Web of Science search used the same scope, logic, and time frame. Full search strings are presented in **Table 1**.

Table 1. Search Strategy and Database Coverage.

Database	Search string
Scopus	TITLE-ABS-KEY (("technological innovation capability" OR "technological innovation capability" OR ("innovation capabil*" AND technolog*) OR "innovation capability" OR "innovation capabilities" OR "product innovation capability" OR "process innovation capability") AND (SME* OR "small and medium-sized enterprise" OR "small and medium-sized enterprises" OR "small and medium enterprises" OR "small enterprise" OR "small enterprises" OR "small business" OR "small businesses") AND (uncertain* OR turbulen* OR dynamism OR volatility OR "environmental change" OR manufactur* OR "manufacturing sector" OR "manufacturing firm" OR "manufacturing firms" OR "industrial firm" OR "industrial firms")) AND PUBYEAR > 2015 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final"))
Web of Science	TS = (("technological innovation capability" OR "technological innovation capability" OR ("innovation capabil*" AND technolog*) OR "innovation capability" OR "innovation capabilities" OR "product innovation capability" OR "process innovation capability") AND (SME* OR "small and medium-sized enterprise" OR "small and medium-sized enterprises" OR "small and medium enterprises" OR "small enterprise" OR "small enterprises" OR "small business" OR "small businesses") AND (uncertain* OR turbulen* OR dynamism OR volatility OR "environmental change" OR manufactur* OR "manufacturing sector" OR "manufacturing firm" OR "manufacturing firms" OR "industrial firm" OR "industrial firms")) AND PY = (2016–2025) AND DT = (Article) AND LA = (English)

2.1. Justification of review scope

The search was conducted in Scopus and Web of Science. These two databases were selected because they provide broad and widely recognised coverage of peer-reviewed journal literature in management, innovation, and technology studies. Prior systematic reviews in related areas have also relied on this two-database combination, which supports its acceptability for evidence identification in this field (Johnson and Schaltegger, 2020; Xi et al., 2024). Although additional databases such as EBSCOhost or ProQuest could have broadened coverage marginally, the combination of Scopus and Web of Science is widely accepted as adequate for systematic reviews in management research.

The restriction to English-language publications reflects the central role of English in international publication in innovation and management journals. The majority of peer-reviewed research on TIC, DCs, and SME innovation is published in English, and restricting the search to English-language articles is consistent with standard practice in systematic reviews in this field (Johnson and Schaltegger, 2020; Xi et al., 2024). This restriction may exclude relevant work published in other languages, particularly studies from non-Anglophone research traditions in Asia, Latin America, and continental Europe. This is acknowledged as a limitation.

Grey literature, including conference papers, dissertations, book chapters, and working papers, was excluded to ensure that all included studies had undergone peer review. While the exclusion of grey literature may introduce publication bias by favouring studies with statistically significant results, the decision prioritised the verifiability and quality assurance associated with the peer review process.

The review covers articles published between 2016 and 2025. This time window was selected to capture the most recent decade of empirical research on TIC in manufacturing SMEs, a period characterised by accelerating digital transformation, heightened environmental volatility, and growing scholarly attention to dynamic capabilities in SME contexts (Albis Salas et al., 2023; Mazzucchelli et al., 2021). Foundational contributions to DC theory and innovation capability research predate this window and are cited where relevant in the conceptual framing. However, the review focuses on recent empirical operationalisations in order to assess the current state of construct measurement, mechanism testing, and evidence accumulation rather than to revisit established theoretical foundations. The implications of these design choices are discussed further in the Conclusion. Eligibility criteria were applied in two stages. The first stage addressed the full evidence base for RQ1. The second identified a focused subset for RQ2. Studies were included if SMEs were the main unit of analysis, defined by legal, financial, or narrative criteria, or if SME-specific results were central to the analysis. Only studies examining TIC or closely related constructs were retained. These included product innovation capability, process innovation capability, digital innovation capability, and research and development capability. Each study was required to examine at least one internal organisational antecedent or CEO or TMT antecedent. Environmental uncertainty or dynamism had to be explicitly addressed as a contextual or analytical variable. Eligible publications were peer-reviewed English-language journal articles published between 2016 and 2025. Conference papers, book chapters, dissertations, reports, non-English publications,

and articles outside the time window were excluded. For RQ2, a subset of studies that conceptualised or operationalised DCs as linking mechanisms was identified for further analysis. Inclusion in the RQ2 subset required that a study explicitly define and measure at least one core DC dimension, namely sensing, seizing, or reconfiguring, or operationalise a close functional equivalent such as innovation ambidexterity, knowledge integration, or resource orchestration, and link it directly to TIC outcomes under uncertainty.

The search returned 247 records. After removing duplicates, 165 unique articles remained. Title and abstract screening reduced this to 93. Ninety full texts were retrieved, and full-text screening yielded 29 studies for synthesis. The selection process is illustrated in **Figure 1**.

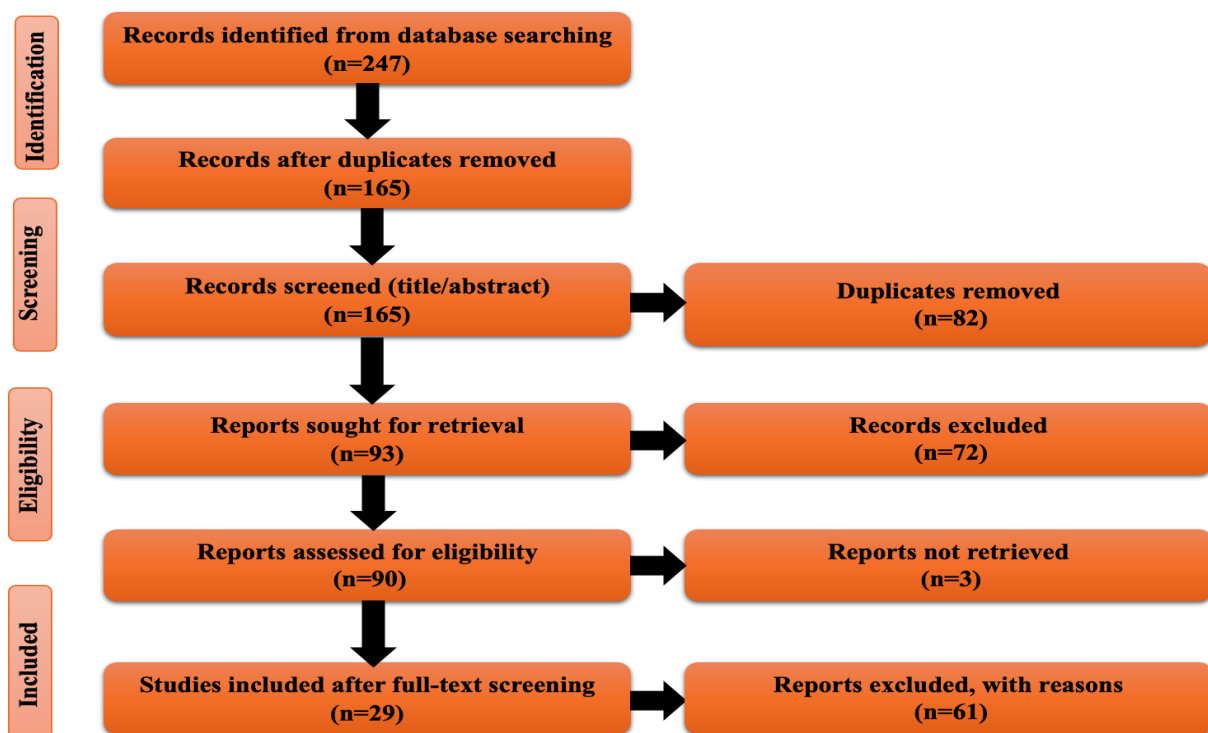


Figure 1. PRISMA Flow Diagram for Study Selection.

Reference lists of included studies were checked to identify any highly relevant articles not captured by the database search. No formal forward citation search was conducted. The reference list check provided a supplementary safeguard against omission of highly cited studies within the review scope. Throughout the selection process, contextual features were carefully coded. These included manufacturing or technology production environments and the operationalisation of uncertainty. DCs were recorded as a separate analytical dimension.

2.2. Data extraction and coding procedure

Data extraction used a predetermined coding template aligned with the review questions. The template included bibliographic information, country, manufacturing context, sample characteristics, research method, theoretical framing, TIC measurement approach, uncertainty measurement approach, organisational

antecedents, CEO or TMT antecedents, DC constructs and their operationalisation, and main findings. Coding proceeded in two phases. In the first phase, one researcher extracted data from each study using this template and assigned initial descriptive codes to antecedent variables, DC constructs, and uncertainty descriptions. In the second phase, these initial codes were grouped into higher-order categories through iterative comparison across studies. Antecedents were classified into two levels: organisational antecedents, covering structural, resource, cultural, and relational factors; and CEO or TMT antecedents, covering individual-level attributes such as innovation orientation, strategic cognition, risk propensity, and prior experience. DC constructs were mapped onto the sensing, seizing, and reconfiguring dimensions of the DC framework (Teece, 2018) or identified as close functional equivalents where the original study used a different label but described a comparable adaptive process. Environmental uncertainty was coded using five evidence mapping categories (EU1 to EU5) based on how each study characterised and operationalised uncertainty: EU1 for market and competitive turbulence, EU2 for technological turbulence, EU3 for institutional and regulatory pressure, EU4 for general environmental turbulence, and EU5 for high-uncertainty environments described without dimensional specification. These EU codes were used as descriptive labels to capture how each study framed uncertainty rather than as standardised measurement constructs.

2.3. Operational criteria for distinguishing DC and TIC constructs

The coding of DC constructs and TIC indicators followed an explicit set of operational criteria. A variable was coded as a dynamic capability if the original study described it as an adaptive process through which the firm identifies environmental changes, commits resources to emerging opportunities, or realigns organisational assets and routines. This includes variables labelled as sensing, seizing, reconfiguring, or close functional equivalents such as knowledge integration, innovation ambidexterity, or resource orchestration, provided that the study positioned them as process-based mechanisms rather than outcome indicators. A variable was coded as TIC when the original study described it as the firm's realised technological innovation capability or closely related capability outcome in products, processes, or operational systems. Studies relying primarily on innovation output proxies were retained in the broader evidence base, but their evidentiary strength for TIC-specific inference was interpreted more cautiously. Where a study used the same measurement items or overlapping indicators for both DC and TIC constructs, this was recorded as a boundary overlap case. Such cases were not excluded from the review. They were flagged during coding and interpreted with additional caution in the synthesis, consistent with the three-level analytical distinction described in the Introduction.

The EU codes are not mutually exclusive. A single study may be assigned more than one code where multiple forms of uncertainty are addressed. EU5 operates at a higher level of abstraction than EU1 to EU4. It captures studies that describe high uncertainty as a general environmental condition without specifying the particular dimension of turbulence involved. The full definitions of these codes are presented in **Table 2** below.

Table 2. Definitions of Evidence-Mapping Categories for Environmental Uncertainty.

Code	Uncertainty type	Definition
EU1	Market and competitive turbulence	Unpredictable shifts in customer demand, competitive intensity, or market structure
EU2	Technological turbulence	Rapid changes in production technologies, digitalisation, or technical standards
EU3	Institutional and regulatory pressure	Changes in regulations, government policy, or institutional support structures
EU4	General environmental turbulence	Broad environmental dynamism or volatility characterised across multiple dimensions without a single dominant type
EU5	High-uncertainty environment (unspecified)	Study describes high uncertainty as a contextual condition but does not specify the particular dimension of turbulence. Operates at a higher level of abstraction than EU1 to EU4

The second researcher reviewed all extracted data and coding assignments on a study-by-study basis, checking each field against the original article. Disagreements in classification, particularly regarding the distinction between DC constructs and TIC indicators, and the assignment of uncertainty categories, were resolved through discussion between the two researchers until consensus was reached. No formal inter-rater reliability statistic was calculated. The item-level verification process nevertheless ensured that all coding decisions were traceable to specific textual evidence in the original studies. The methodological implications of this approach are addressed in the subsection on methodological limitations below.

2.4. Evidence quality and strength assessment

The review did not apply a formal risk-of-bias instrument or standardised quality appraisal checklist. However, evidence strength was assessed interpretively during the synthesis process. Studies were treated as providing stronger evidence when they met the following conditions: explicit definition of the focal constructs, transparent measurement with reported scale items or validated instruments, formal testing of mediation or moderation pathways, and analytical alignment between theoretical framing and empirical operationalisation. Studies were treated as providing weaker evidence when they relied on conceptual discussion without empirical measurement, used proxy indicators without clear construct justification, reported cross-sectional associations without mechanism testing, or exhibited overlap between DC and TIC measurement items. This assessment was not used to exclude studies from the review. It was used interpretively to calibrate the confidence placed in specific findings during the thematic synthesis. Findings supported by studies with stronger evidence profiles were interpreted with greater confidence in the formulation of the integrated framework and in the identification of recurrent patterns.

2.5. Methodological limitations of the review process

Several methodological limitations of the review process should be acknowledged explicitly. First, no formal inter-rater reliability statistic was calculated. Coding decisions were instead checked through item-level verification by a second researcher, and disagreements were resolved through discussion until consensus was reached. Disagreements arose most frequently in the classification of variables at the DC–TIC boundary, particularly where overlapping indicators were used for both

constructs, and in the assignment of TIC measurement categories for studies in which innovation capability was not explicitly operationalised or was embedded within broader constructs. This procedure improved traceability and consistency, but it does not provide a quantitative measure of coding agreement. Second, no standardised quality appraisal checklist or risk-of-bias instrument was applied. Evidence strength was assessed interpretively during synthesis, which allowed construct-specific calibration of confidence but is less formalised than established appraisal tools. In addition, no formal forward citation search was conducted. Future reviews in this area could strengthen methodological rigour by combining explicit coding rules with formal inter-rater reliability assessment, a standardised quality appraisal instrument, and more systematic citation tracking.

2.6. Handling heterogeneity

The 29 included studies are heterogeneous in several respects. They span multiple geographic regions, manufacturing subsectors, research designs, and approaches to construct operationalisation. TIC and related innovation capability constructs are measured differently across studies, ranging from multi-item reflective scales to output-based proxies and qualitative assessments. Environmental uncertainty is operationalised through validated multi-dimensional scales in some studies and through single-item proxies, secondary data indicators, or contextual description in others. This heterogeneity precludes effect-size aggregation or formal meta-analytic pooling. The review therefore adopts a narrative and thematic synthesis approach. The integrated framework presented in this review reflects patterned tendencies identified across the evidence base. It does not represent statistically pooled causal estimates.

2.7. Synthesis approach

Evidence was synthesised through descriptive mapping and thematic analysis. Descriptive mapping captured the distribution of studies by year, geography, methodology, sector, and coverage of uncertainty and manufacturing contexts. Thematic analysis examined patterns and gaps in how internal antecedents relate to TIC, and how DC mechanisms have been defined and tested across studies. Screening criteria applied at the title and abstract stage are presented in **Table 3**. Criteria used during full-text screening are presented in **Table 4**.

Table 3. Title and Abstract Screening Criteria.

Type	Criterion	Key definition
Include	SME focus	Explicit reference to SMEs in title or abstract
Include	Innovation capability focus	Focus on (technological) innovation capability
Include	Firm-level unit	Firm is the main unit of analysis
Include	Journal article, English, 2016–2025	Peer-reviewed, in English, published 2016–2025
Exclude	Macro/industry level only	No firm-level or SME data
Exclude	No innovation focus	No innovation capability or outcome
Exclude	Not SME-related	No reference to SMEs
Exclude	Non-article	Not a journal research article

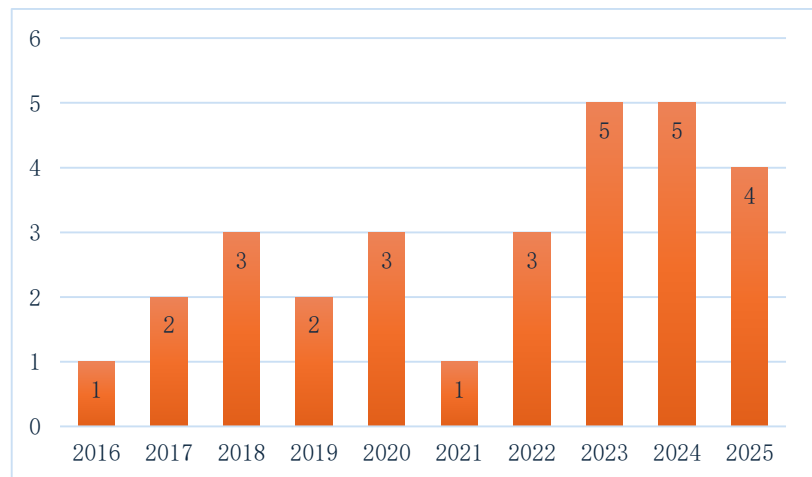
Table 4. Full-Text Screening Criteria.

Type	Criterion	Key definition
Include	SME-focused study	SMEs as clear unit of analysis
Include	Technological innovation capability	Key outcome is technological innovation capability
Include	Org/leadership antecedent	At least one Organisational antecedent or CEO or TMT antecedent
Include	Journal article, English, 2016–2025	Peer-reviewed, in English, published 2016–2025
Exclude	Not SME-focused	No separable SME evidence
Exclude	No tech innovation outcome	Outcome not related to technological innovation
Exclude	No org/leadership antecedent	No Organisational antecedent or CEO or TMT antecedent
Exclude	Non-article, non-English, or wrong year	Not a journal article, not English, or outside range

3. Results

3.1. Study profile and evidence map

Publications on TIC in manufacturing SMEs increased gradually over the review period (**Figure 2**). From 2016 to 2020, annual output remained modest, rarely exceeding three articles per year. From 2021 onward, output rose more clearly, with 2023 and 2024 each contributing five included studies. Interest in TIC appears to have grown alongside digital transformation and environmental volatility, particularly in emerging economies (Albis Salas et al., 2023; Alharthi, 2025; Mazzucchelli et al., 2021; Xia et al., 2024).

**Figure 2.** Temporal Distribution of Publications (2016–2025).

Research is geographically concentrated (**Figure 3**). China and India together account for more than one-third of included studies, reflecting the central role of these economies in global manufacturing and SME innovation research (Hudnurkar et al., 2023; Jiang and Wang, 2024; He and Sun, 2025; Kim et al., 2018). Other prominent contributors include Italy, Korea, and the United Kingdom. Additional studies come from Europe, Saudi Arabia, Iran, Ireland, Russia, Morocco, Vietnam, Malaysia, Colombia, Denmark, Hungary, Uganda and Tanzania, Indonesia, Sweden, and the United Arab Emirates (Parida et al., 2016; Ali et al., 2020; Selivanovskikh, 2023;

Lassen and Larsen, 2024; Zulkiffli et al., 2024; Kobusingye et al., 2025). Several articles adopt a regional or multi-country perspective.

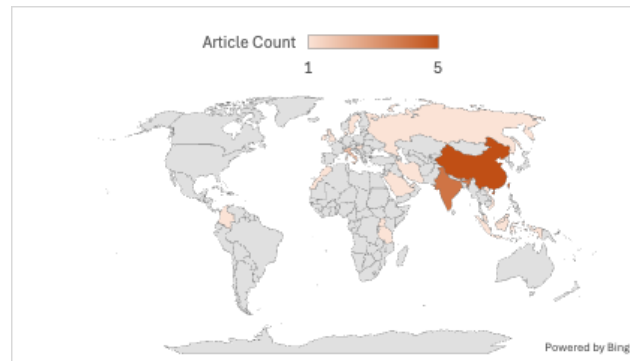


Figure 3. Geographic Distribution of Studies.

Most included studies focus on general manufacturing SMEs without specifying a subsector, accounting for over two-thirds of the sample (**Figure 4**) (Zhang and Hartley, 2018; Mazzucchelli et al., 2021; Albis Salas et al., 2023; Alharthi, 2025; Kim et al., 2018). A smaller subset addresses high-tech manufacturing and advanced technology firms (Parida et al., 2016; Taleb and Pheniqi, 2023). Only a handful examine specific subsectors, including low and medium-low technology manufacturing (Dooley et al., 2017), food and agricultural manufacturing (Kazemi et al., 2024), garment and home appliance manufacturing (He and Sun, 2025), IT, chemical, and pharmaceutical manufacturing (Kim et al., 2018), MSME manufacturing in India (Hudnurkar et al., 2023), and new equipment manufacturing (Xia et al., 2024). Subsectoral differentiation remains limited across the literature.

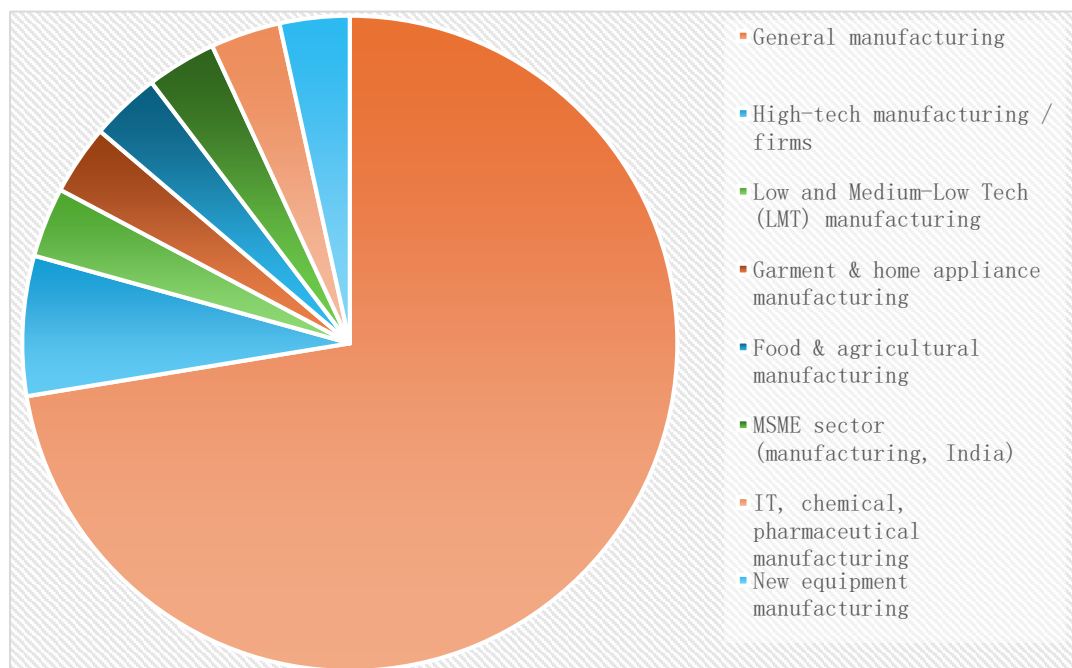


Figure 4. Distribution by Industry and Subsector.

Quantitative designs dominate the reviewed literature. Twenty-one of 29 studies use survey-based or secondary data approaches, typically analysed through structural equation modelling, regression, or related techniques (Kiron and Kannan, 2018; Mazzucchelli et al., 2021; Singh et al., 2022). Six studies use qualitative methods such as case studies and interviews (Corsi and Prencipe, 2019; Lassen and Larsen, 2024; Troise et al., 2022). Two studies adopt mixed-methods designs (Ali et al., 2020; Kazemi et al., 2024) (**Figure 5**). Quantitative approaches still dominate, although interest in more contextually grounded qualitative work is increasing.

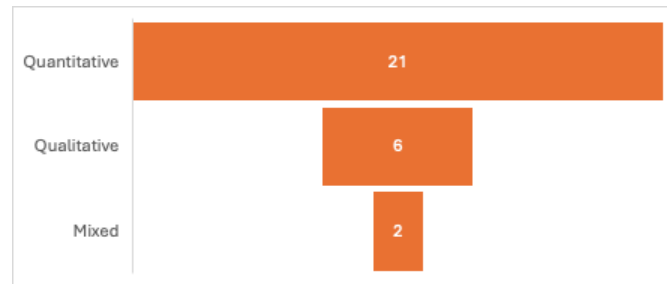


Figure 5. Distribution of Research Methods.

Dynamic Capabilities Theory (DCT) is the most frequently adopted theoretical framework, informing 11 articles either alone or in combination with other perspectives (Mazzucchelli et al., 2021; Taleb and Pheniqi, 2023; Xia et al., 2024). The Resource-Based View (RBV) underpins eight studies (He and Sun, 2025; Kiron and Kannan, 2018; Zhang and Hartley, 2018). The remaining articles draw on a range of other theories, including organisational capability and ambidexterity, corporate governance, upper echelons, open innovation, stakeholder theory, institutional theory, social capital, knowledge management, and decision science (Ali et al., 2020; Singh et al., 2022; Kim et al., 2018). Several studies combine multiple frameworks to reflect the multi-level nature of TIC in SMEs (**Figure 6**).

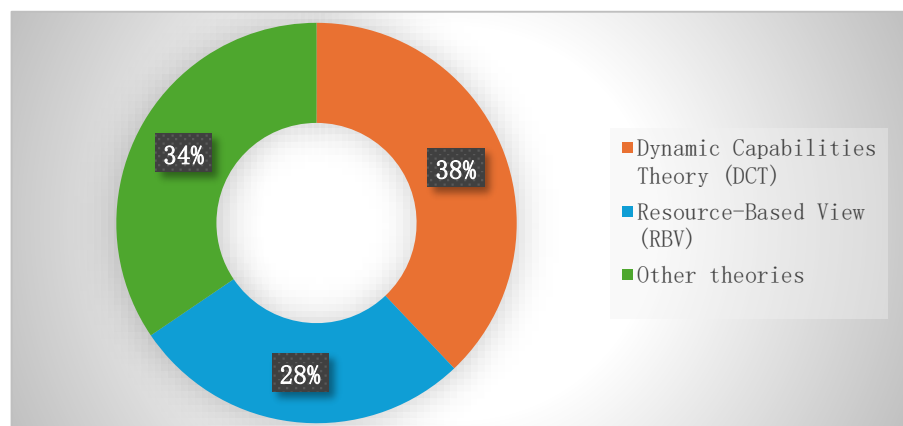


Figure 6. Theoretical Foundations in Reviewed Studies.

Table 5 classifies how TIC and related constructs are measured across the reviewed studies. Explicit measurement of TIC as the primary dependent variable is observed in only a limited subset (Type A), including Alharthi (2025), Kim et al. (2018), Kiron and Kannan (2018), Mazzucchelli et al. (2021), Taleb and Pheniqi

(2023), and Xia et al. (2024). A larger proportion (Type B) operationalises related but non-TIC constructs, such as digital innovation capability, eco-innovation, or general innovation capability (He and Sun, 2025; Jiang and Wang, 2024; Ko et al., 2022; Selivanovskikh, 2023). Some articles (Type C) use innovation outputs or performance proxies (Albis Salas et al., 2023; Corsi and Prencipe, 2019). Others (Types D and E) either embed TIC within broader constructs or omit explicit operationalisation (Dooley et al., 2017; Ali et al., 2020; Nanda et al., 2020; Hudnurkar et al., 2023; van Hoang and Hien, 2024).

Environmental uncertainty is also measured inconsistently across studies. Some use established multi-dimensional scales capturing market, technological, and competitive uncertainty (Taleb and Pheniqi, 2023; Kim et al., 2018). Others rely on single-item proxies or secondary data indicators (Mazzucchelli et al., 2021; Sahoo, 2019). A subset discusses uncertainty conceptually without direct empirical measurement (Dooley et al., 2017; Singh et al., 2022). These differences indicate that construct definition and measurement are still not consistent across the field.

Table 5. TIC Measurement Typology in Reviewed Studies.

TIC evidence type	Description (concise definition)	Studies
Type A: Explicit TIC as dependent variable (DV)	TIC is explicitly labelled and measured as the focal dependent variable using multi-item scales or composite indices.	Alharthi (2025); Kim et al. (2018); Kiron and Kannan (2018); Mazzucchelli et al. (2021); Taleb and Pheniqi (2023); Xia et al. (2024)
Type B: Related innovation capability constructs (non-TIC)	Innovation-related capabilities are measured (e.g., innovation capability, eco-innovation, digital innovation capability), but not explicitly framed as TIC.	He and Sun (2025); Jiang and Wang (2024); Zhang and Hartley (2018); Zulkiffli et al. (2024); Selivanovskikh (2023); Ko et al. (2022); Kobusingye et al. (2025); Lassen and Larsen (2024); Panjaitan et al. (2022); Oh et al. (2025); Sahoo (2019)
Type C: Innovation outputs or performance proxies	Innovation is operationalised via outputs or performance indicators (e.g., product/process innovation, productivity), rather than capability constructs.	Albis Salas et al. (2023); Corsi and Prencipe (2019)
Type D: NA (no explicit TIC or innovation capability DV)	TIC is not measured; technological innovation capability is absent or embedded within other constructs (e.g., DCs, agility, sustainability).	Ali et al. (2020); Liu et al. (2017); Nanda et al. (2020); Parida et al. (2016); Singh et al. (2022); Troise et al. (2022); van Hoang and Hien (2024)
Type E: None (innovation capability not a focal outcome)	Innovation capability is discussed conceptually but not operationalised as a dependent variable.	Dooley et al. (2017); Hudnurkar et al. (2023); Kazemi et al. (2024)

Note: Type D includes studies where innovation capability is embedded within broader constructs (e.g., DCs, agility) as part of a multi-dimensional outcome. Type E includes studies that discuss innovation capability conceptually but do not operationalise it empirically.

3.2. Organisational and CEO or TMT antecedents of TIC

Both organisational factors and CEO or TMT characteristics are reported in the reviewed studies as antecedents of TIC in manufacturing SMEs, particularly under uncertainty. At the organisational level, recurrent antecedents include organisational flexibility, decentralised decision-making, learning-oriented culture, resource allocation, and external knowledge-related conditions (Mazzucchelli et al., 2021; Kim et al., 2018). Structural effects vary across studies. In some cases, flexible arrangements are associated with stronger innovation outcomes. In others, moderate formalisation and clearer governance are described as supporting innovation indirectly through compliance and risk management under regulatory or resource constraints

(Corsi and Prencipe, 2019). Technology investment, dynamic resource reallocation, strategic collaboration, and bricolage also recur as reported drivers of TIC-related outcomes (Kazemi et al., 2024; He and Sun, 2025).

Learning-oriented culture is frequently linked to TIC, often in conjunction with absorptive capacity and external knowledge integration mechanisms. Several studies report that cultural emphasis alone is insufficient when knowledge absorption and recombination mechanisms are weak, particularly in knowledge-intensive settings (Selivanovskikh, 2023). Human capital development and social capital through internal and external networks are also reported as relevant organisational conditions, although the reported effects vary across sectors and contexts (Hudnurkar et al., 2023).

At the leadership level, CEO or TMT characteristics are also repeatedly associated with TIC. Innovation orientation and strategic cognition are commonly reported as positive antecedents, particularly under uncertainty (He and Sun, 2025; Taleb and Pheniqi, 2023). Risk propensity shows mixed findings across studies. Some report beneficial effects at moderate levels, whereas others associate excessive risk appetite with strategic misalignment and inefficient resource use (Singh et al., 2022; Kiron and Kannan, 2018). CEO or TMT backgrounds, including industry tenure, technical expertise, and entrepreneurial experience, are also reported as relevant to the identification and exploitation of innovation opportunities, although these relationships are described as context dependent (Ko et al., 2022; Liu et al., 2017).

Taken together, the reviewed studies indicate that antecedents of TIC are distributed across both organisational and leadership levels, with reported patterns varying by uncertainty type, sector, and internal capability context. **Table 6** summarises these patterns using the evidence mapping categories for environmental uncertainty.

3.3. Dynamic capabilities as linking mechanisms

Among the 29 reviewed studies, 18 explicitly conceptualise or empirically examine DCs. The remaining studies treat DCs more tangentially or focus on related constructs such as organisational agility or absorptive capacity (Ali et al., 2020; Nanda et al., 2020). Inclusion in the RQ2 subset required that a study define and measure at least one core DC dimension, namely sensing, seizing, or reconfiguring, or operationalise a close functional equivalent such as innovation ambidexterity or knowledge integration, and link it directly to TIC outcomes under uncertainty (Ko et al., 2022; Kim et al., 2018).

In the reviewed manufacturing SME studies, DCs are most commonly defined as the capacity to sense environmental changes, seize emerging opportunities, and reconfigure organisational assets in pursuit of innovation (Mazzucchelli et al., 2021; Teece, 2018). Several studies report construct boundary issues between DCs and innovation outcomes. Some treat reconfiguration as a dynamic capability, whereas others use similar routines as indicators of realised innovation capability (Troise et al., 2022; Xia et al., 2024).

Table 6. Evidence Matrix: Antecedents Under Environmental Uncertainty (EU evidence mapping codes). Panel A. Organisational antecedents, Panel B. CEO or TMT Antecedents

Organisational antecedent	Uncertainty type (EU code)	TIC outcome pattern	Representative studies
Structure and governance (decentralisation, flexibility, integration)	EU1; EU2	Reported positive association between decentralised or flexible structures and TIC, while rigid formalisation is described as limiting responsiveness.	Kim et al. (2018); Kiron and Kannan (2018); Mazzucchelli et al. (2021); Taleb and Pheniqi (2023)
Governance alignment and coordination	EU3; EU4	Governance alignment and coordination are described as enabling TIC indirectly through coordination and risk control, with empirical support varying by study design.	Corsi and Prencipe (2019); Zulkiffli et al. (2024)
Resource configuration and investment	EU1; EU2	Reported positive association between technology investment or resource configuration and TIC-related outcomes.	Alharthi (2025); Xia et al. (2024); Mazzucchelli et al. (2021)
Resource orchestration and reallocation	EU5	Resource orchestration and reallocation are reported as associated with sustaining TIC in resource-constrained settings.	He and Sun (2025); Ko et al. (2022); Panjaitan et al. (2022)
Learning orientation and innovation culture	EU4; EU2	Learning orientation and innovation culture are reported as associated with TIC via absorptive capacity and knowledge recombination, with limited comparability across measures.	Sahoo (2019); Mazzucchelli et al. (2021); Lassen and Larsen (2024)
Human and social capital	EU1; EU3	Human and social capital are reported as contingently associated with TIC, often depending on absorptive capacity and relationship quality.	Kim et al. (2018); Ko et al. (2022); Hudnurkar et al. (2023)
Innovation orientation	EU1; EU2	Reported positive association between CEO innovation orientation and TIC in studies situated in EU1 and EU2 contexts.	Kim et al. (2018); Taleb and Pheniqi (2023); Mazzucchelli et al. (2021)
Strategic cognition	EU2; EU3	Strategic cognition is discussed as supporting sensing and adaptive innovation responses, with evidence typically presented as direct associations.	Alharthi (2025); He and Sun (2025)
Risk propensity	EU1; EU2	Mixed direction across studies; risk propensity is reported as beneficial at moderate levels but detrimental when excessive.	Kiron and Kannan (2018); Singh et al. (2022); Parida et al. (2016)
Industry and entrepreneurial experience	EU4	Mixed and context dependent associations with TIC outcomes reported in studies using broad turbulence framing.	Ko et al. (2022); Hudnurkar et al. (2023); Zhang and Hartley (2018)
Technical background and boundary spanning	EU2; EU3	Technical background and boundary spanning are discussed as enabling access to external knowledge and improving technology-related decision quality, with limited formal testing of contingency.	Xia et al. (2024); Kazemi et al. (2024); Singh et al. (2022)

Note. EU codes are evidence mapping categories: EU1 market and competitive turbulence; EU2 technological turbulence; EU3 institutional and regulatory pressure; EU4 general environmental turbulence; EU5 high uncertainty environments. Unless explicitly stated in the original study, uncertainty is treated as a context label rather than a formally tested moderator.

Measurement approaches vary considerably across the reviewed studies. Most quantitative studies use multi-item scales for sensing, seizing, and reconfiguring (Kim et al., 2018; Mazzucchelli et al., 2021). Other studies rely on proxies such as R&D intensity, speed of new product development, or frequency of process upgrades (Alharthi, 2025; Ko et al., 2022). Qualitative studies typically identify DCs through interview-based accounts of managerial routines and adaptive responses (Lassen and Larsen, 2024). Some studies also report overlap between DC indicators and TIC indicators, and only a limited number explicitly address discriminant separation between the two constructs (Oh et al., 2025).

Across the reviewed studies, DCs are most commonly positioned as mediators linking organisational or CEO or TMT antecedents to TIC. Learning orientation, CEO strategic cognition, and decentralised governance are reported in some studies as improving TIC through sensing and reconfiguring capacity (Kim et al., 2018; Mazzucchelli et al., 2021). Resource orchestration and external network leveraging are also reported in some cases as linked to TIC through reconfiguring routines (Kazemi et al., 2024; He and Sun, 2025). A smaller subset of studies examines DCs as moderators, reporting that the effect of uncertainty on innovation outcomes varies with DC level (Parida et al., 2016; Taleb and Pheniqi, 2023). **Table 6** summarises how DCs are defined, measured, and positioned across the reviewed evidence.

4. Discussion

4.1. Organisational and leadership antecedents under uncertainty

As reported in the Results, organisational and CEO or TMT antecedents of TIC are distributed across two levels, with decentralised governance, flexible resource configuration, learning-oriented culture, and CEO innovation orientation appearing most frequently across the reviewed studies. The Discussion does not repeat these individual findings. Instead, it examines what the overall pattern of results implies for understanding how antecedents operate under different uncertainty conditions.

The most consistent interpretive pattern across the evidence is that antecedent effects on TIC are contingent rather than universal. The same organisational arrangement or leadership attribute does not produce the same outcome across all environmental conditions. This contingency operates along at least two dimensions. First, the type of uncertainty differentiates which antecedents appear most salient. Technological uncertainty appears to reward organisational arrangements that permit fast reallocation and experimentation, such as decentralisation and flexible resource allocation. Market or regulatory uncertainty, by contrast, appears to increase the relevance of external collaboration and boundary-spanning leadership (Mazzucchelli et al., 2021; Singh et al., 2022). Second, the internal capability context of the firm matters. Learning-oriented culture, for example, is frequently reported in conjunction with absorptive capacity, and the evidence suggests that cultural emphasis without adequate knowledge absorption mechanisms produces weaker outcomes (Selivanovskikh, 2023). Similarly, CEO risk propensity shows mixed results across studies, with moderate levels appearing beneficial but excessive risk appetite associated with strategic misalignment in resource-constrained firms (Singh et al., 2022; Kiron and Kannan, 2018).

A further interpretive observation is that organisational and leadership antecedents appear to operate as mutually reinforcing bundles rather than as isolated factors. Several studies report that flexible structures have greater impact when leadership actively promotes innovation, and that CEO vision and external engagement are more effective in organisations with supportive learning cultures (Mazzucchelli et al., 2021; Ko et al., 2022). This pattern suggests that the relevant unit of analysis for understanding TIC antecedents may be the configuration of organisational and leadership conditions rather than any single variable. However, most reviewed studies examine antecedents in isolation or as additive effects within

regression-based models. Few formally test interaction effects or configurational logic, which limits the empirical basis for this interpretive claim.

4.2. Dynamic capabilities as mechanism, not synonym

The Results section reports that DCs are most commonly positioned as mediators in the reviewed studies, with a smaller subset examining them as moderators. This section does not repeat the specific mediation pathways reported in the Results. Instead, it examines the theoretical implications of how DCs are used as explanatory constructs and identifies a recurrent problem in how they are distinguished from TIC.

The theoretical value of the DC framework in this literature lies in its potential to explain how antecedent conditions are converted into innovation outcomes under uncertainty. Sensing, seizing, and reconfiguring provide a process-level account of how firms translate organisational resources and leadership intentions into adaptive responses when environmental conditions are volatile (Teece, 2018). The reviewed evidence is broadly consistent with this theoretical function, although the strength of support varies across studies. In studies that position DCs as mediators, antecedents such as learning orientation, CEO strategic cognition, and decentralised governance are interpreted as being linked to TIC through the strengthening of sensing and reconfiguring capacity. Studies that position DCs as moderators report that the effect of uncertainty on innovation outcomes depends on DC level. This dual positioning suggests that capability development can function as both a transmission channel and a boundary condition for the antecedent-TIC relationship (Parida et al., 2016; Singh et al., 2022).

However, a central finding of this review is that the conceptual and empirical boundary between DCs and TIC is frequently unclear in the reviewed literature. Several studies use overlapping measurement items for both constructs. Some treat reconfiguration as a dynamic capability, while others code similar routines as indicators of realised innovation capability (Troise et al., 2022; Xia et al., 2024). This measurement overlap creates a specific analytical problem. When the mechanism and the outcome share the same empirical indicators, mediation claims risk tautology. The mechanism becomes indistinct from the outcome, which weakens the explanatory power of dynamic capability theory and complicates theory testing (Oh et al., 2025). Few studies test for discriminant validity between DC and TIC measures, which limits confidence in the empirical separation of these constructs.

The integration of CEO or TMT micro-foundations into DC mechanisms is also underdeveloped. Most studies treat top management influence as exogenous rather than embedded within DC routines (Ko et al., 2022; Mazzucchelli et al., 2021). Although some studies imply interactive reinforcement between organisational routines and CEO-level traits, few formally test multi-level moderation or specify when alignment becomes necessary rather than merely beneficial (Ko et al., 2022; Liu et al., 2017). More rigorous construct operationalisation, discriminant validity testing, and longitudinal research are needed to address these gaps.

Three measurement implications follow from this analysis. First, DCs should be operationalised as adaptive, process-based routines that capture sensing, seizing, and reconfiguring, and they should be kept empirically separate from outcome-based TIC

indicators. Second, discriminant validity testing should become standard practice. Overlap between DC and TIC measures can inflate mediation estimates and obscure whether capability drives the outcome or simply relabels it (Mazzucchelli et al., 2021). Third, studies should report uncertainty type and level explicitly. Uncertainty should be specified theoretically rather than treated as a generic backdrop. This is necessary if findings are to accumulate across studies.

4.3. Geographical concentration and institutional context

The reviewed studies are geographically concentrated. China and India together account for more than one-third of the evidence base, with additional clusters in Korea, Italy, and the United Kingdom. This concentration is not merely a sampling limitation. It raises a substantive question about whether the antecedent, DC, and TIC patterns identified in this review are shaped by the institutional environments in which the majority of the evidence was produced.

Institutional environments differ across the reviewed contexts in ways that are likely to condition how organisational and leadership antecedents relate to TIC through DC mechanisms. In China, state-directed industrial policy, public subsidies for technology upgrading, and dense manufacturing clusters create conditions in which organisational antecedents related to external network access, resource orchestration, and government-supported collaboration may be more salient than in settings with weaker policy infrastructure (He and Sun, 2025; Xia et al., 2024; Jiang and Wang, 2024). In India, the predominance of micro and small enterprises operating under severe resource constraints and fragmented regulatory environments may increase the relative importance of CEO or TMT attributes such as entrepreneurial experience and boundary spanning, and reduce the practical relevance of formal DC routines that presuppose organisational slack (Hudnurkar et al., 2023; Kiron and Kannan, 2018). In European contexts, stronger regulatory frameworks, established innovation support systems, and more formalised governance structures may shift the balance toward institutional and regulatory uncertainty as a primary conditioning factor, with governance alignment and compliance-oriented coordination playing a more prominent role in TIC development (Corsi and Prencipe, 2019; Lassen and Larsen, 2024).

These institutional differences suggest that the antecedent, DC, and TIC relationships synthesised in this review should not be assumed to operate uniformly across national settings. The relative salience of particular antecedents and the functional relevance of particular DC dimensions are likely to vary with the industrial policy regime, the structure of manufacturing clusters, the availability of public innovation support, and the regulatory burden on SMEs. This observation is consistent with Proposition 4, which posits that institutional environments moderate the antecedent, DC, and TIC relationship. However, the current evidence base does not permit formal testing of institutional moderation. Most reviewed studies are conducted within a single national context and do not include cross-country comparative designs. Future research should adopt explicitly comparative frameworks to examine how institutional conditions shape the operation of DC mechanisms and the development of TIC in manufacturing SMEs across different national and regional settings.

4.4. Heterogeneity, evidence limits, and what can be inferred

The reviewed evidence is broadly consistent with an antecedent-mechanism-outcome interpretation, but conceptual and methodological heterogeneity remains the primary barrier to stronger generalisations. The 29 studies span multiple geographic regions, manufacturing subsectors, and analytical designs. TIC is operationalised differently across studies, ranging from explicit multi-item scales to output proxies and qualitative assessments. Environmental uncertainty is measured through validated multi-dimensional scales in some studies and through single-item indicators or contextual description in others. These differences preclude direct effect-size comparison and limit the precision of cross-study synthesis.

Most studies rely on cross-sectional survey designs with self-reported data. Longitudinal and multi-level designs remain rare. Formal mediation or moderation tests are conducted in only a subset of studies, and many papers report non-convergent results or omit formal mechanism testing entirely. The dominance of cross-sectional designs means that the direction of causality between antecedents, DCs, and TIC cannot be established with confidence from the existing evidence.

An integrated framework can be inferred from this synthesis (**Figure 7**). Across the reviewed studies, organisational and CEO or TMT antecedents appear to initiate capability building under different forms of uncertainty. The pattern across studies further suggests that environmental uncertainty functions as both a contextual condition and, in a smaller subset of studies, a moderating influence. The reviewed evidence is also consistent with the interpretation that DCs often operate as an important mechanism through which antecedent conditions may translate into TIC, although this mechanism-level role is supported more directly in the narrower RQ2 subset than in the broader evidence base (Kim et al., 2018; Mazzucchelli et al., 2021). TIC, in turn, is treated in the reviewed studies as the firm's realised capacity to generate and implement product and process innovation under volatile conditions (Alharthi, 2025; Xia et al., 2024). However, a distinction must be drawn between the broad evidence base for antecedents (RQ1) and the narrower subset that explicitly conceptualises or models DCs (RQ2). All reviewed studies address antecedents and uncertainty, but only a subset explicitly defines, measures, or tests DCs as mechanisms or moderators. Many contributions therefore remain theoretically suggestive rather than mechanism-explicit. This gap raises the risk that studies conflate routines and outcomes, which weakens causal interpretation and complicates comparison across measurement approaches (Selivanovskikh, 2023; Oh et al., 2025).

4.5. Digital Transformation as an Emerging Contextual Force in TIC Development

The growth of research on TIC in manufacturing SMEs after 2021 coincides with increasing scholarly and practitioner attention to digital transformation (Albis Salas et al., 2023; Xia et al., 2024). Several included studies situate TIC development within digitalisation-related contexts, and digital transformation emerges as a relevant contextual force in the reviewed evidence, although it is not the primary focus of this review.

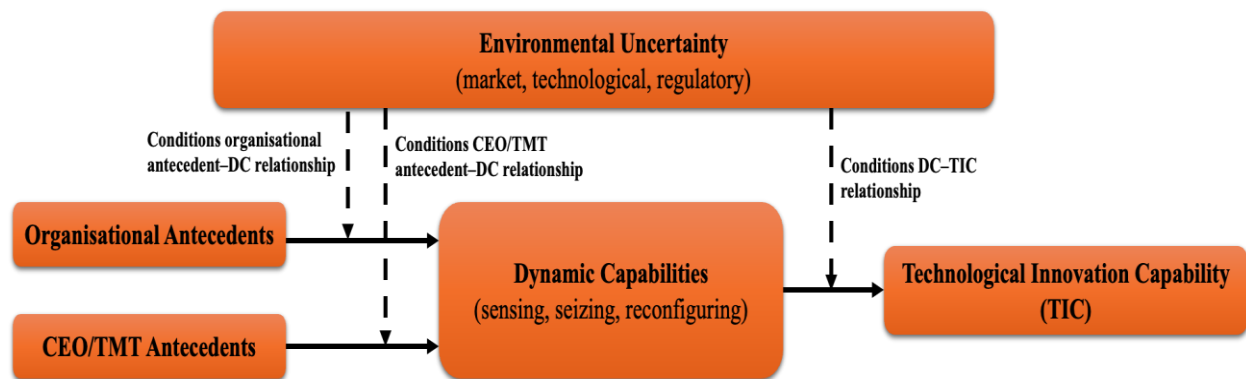


Figure 7. Evidence-informed interpretive framework of TIC development in manufacturing SMEs under uncertainty. Note: This framework is evidence-informed and interpretive. It summarises recurrent patterns in the reviewed literature and should not be read as a uniformly validated causal model. Solid arrows represent recurrent antecedent-mechanism-outcome relationships supported across the reviewed studies. Dashed arrows represent contextual or conditioning relationships for which the evidence is more limited or more inferential.

Digital transformation appears in the reviewed literature in three ways. First, it functions as an intensifier of technological uncertainty. Rapid digitalisation accelerates the pace of technological change in production systems, raising the frequency and urgency of adaptation demands on manufacturing SMEs (Ko et al., 2022; Kobusingye et al., 2025). Second, digitalisation creates new conditions for resource reallocation and knowledge integration. Data-enabled production monitoring, digital communication platforms, and integrated information systems alter how firms sense market signals, coordinate internal responses, and reconfigure operational routines (He and Sun, 2025; van Hoang and Hien, 2024). Third, digital capabilities emerge in some studies as a capability domain adjacent to but not identical with DCs. Studies that examine digital agility, digital competitiveness, or data empowerment describe processes that overlap with sensing and reconfiguring but are operationalised through technology-specific indicators rather than through the general DC framework (Ko et al., 2022; He and Sun, 2025).

The reviewed evidence does not yet justify a strong claim that digital capabilities systematically moderate DC-mediated TIC relationships. The studies that address digitalisation do so with varying levels of specificity, and none formally tests whether digital capabilities alter the strength or direction of DC mediation pathways. However, the evidence does suggest that digitalisation may intensify the need for sensing, data-enabled reconfiguration, and cross-functional coordination in manufacturing SMEs. Future research could examine whether and how digital capabilities interact with DC mechanisms to shape TIC outcomes under different forms of uncertainty. This would require measurement instruments that distinguish digital capabilities from general DC constructs and from TIC indicators, a distinction that the current evidence base does not consistently maintain.

5. Conclusion

Evidence from 29 studies addresses both research questions. Decentralised governance, resource flexibility, learning-oriented culture, and CEO innovation orientation are repeatedly identified as antecedents of TIC in manufacturing SMEs.

Their effectiveness varies, however, with uncertainty type, sector, and firm resource context (Kim et al., 2018; Mazzucchelli et al., 2021; Ko et al., 2022). DCs, particularly sensing, seizing, and reconfiguring, offer a plausible mechanism-level explanation for how these antecedents may translate into innovation outcomes. In some studies, however, the boundary between DCs and TIC remains unclear, which limits the confidence that can be placed in mechanism-level claims (He and Sun, 2025; Troise et al., 2022).

Several limitations apply. The review is restricted to two databases and English-language publications. The 2016 to 2025 time window excludes earlier work. Studies are geographically concentrated in Asia, and subsectoral coverage is uneven. Construct overlap between DCs and TIC, inconsistent operationalisation of uncertainty, and likely publication bias all constrain the scope of generalisation (Mazzucchelli et al., 2021; Oh et al., 2025). The synthesis is interpretive rather than cumulative in a strict statistical sense, and the integrated framework summarised in **Figure 7** reflects patterned tendencies inferred from the reviewed evidence rather than a validated causal model.

Future research should address these gaps in three ways. First, TIC and DCs need separate, validated measurement scales to reduce construct overlap. Discriminant validity testing between DC and TIC indicators should become standard practice. Second, studies should adopt differentiated uncertainty typologies rather than treating uncertainty as a single construct. Specifying uncertainty type and level explicitly would allow findings to accumulate across studies with greater precision. Third, CEO or TMT micro-foundations should be incorporated explicitly into mechanism testing rather than treated as exogenous inputs. Longitudinal, mixed-method, and multi-level designs would help clarify causality and contextual contingencies (Ko et al., 2022; Kazemi et al., 2024).

On the basis of the heterogeneous evidence reviewed, this study offers three analytical contributions. First, it adopts a three-level analytical structure that separates antecedent conditions, DC mechanisms, and TIC outcomes, providing a more precise basis for identifying recurring patterns in how organisational and CEO or TMT antecedents relate to TIC across uncertainty contexts in manufacturing SMEs (Johnson and Schaltegger, 2020; Xi et al., 2024). Second, it clarifies a recurring conceptual problem: the boundary between DCs and TIC is frequently blurred in existing research, and this overlap weakens mechanism-level explanation and complicates cross-study comparison. Third, it proposes an evidence-informed interpretive framework that organises the relationships among antecedents, DC mechanisms, and TIC outcomes across different uncertainty conditions. This framework is intended as a basis for more targeted future empirical testing rather than as a confirmed theoretical architecture. Together, these contributions offer directions for more precise theory development and more rigorous empirical work on how manufacturing SMEs build TIC under uncertainty.

Practical implications

The evidence does not support single-factor explanations of TIC outcomes (Kim et al., 2018; Mazzucchelli et al., 2021). Capability outcomes are more often linked to

bundles of organisational routines and leadership behaviours than to any single structural feature or leadership trait. The implications below translate the most consistent patterns from the evidence mapping and DC synthesis into practical guidance. The reviewed studies span multiple geographic regions, including Asia, Europe, Africa, and the Middle East. The recommendations are therefore most relevant to manufacturing SMEs operating under resource constraints and environmental uncertainty, particularly in emerging and transitional economies, but they are not limited to any single region. Where specific patterns appear more salient in particular contexts, this is noted.

The first set of recommendations concerns the configuration of organisational routines. The reviewed evidence suggests that stronger TIC outcomes are more likely when governance flexibility, learning routines, and proactive resource allocation reinforce one another rather than operate in isolation. Decentralisation and cross-functional integration are consistently associated with stronger innovation outcomes in turbulent settings (Kim et al., 2018; Mazzucchelli et al., 2021; Taleb and Pheniqi, 2023). Managers may benefit from clarifying decision rights over process changes, supplier switches, and small technology purchases, and from establishing short-cycle coordination routines anchored to production bottlenecks, customer feedback, and supplier disruptions. Technology investment appears to be more effective when managed as staged experimentation rather than large-scale commitment (Sahoo, 2019; Mazzucchelli et al., 2021). Starting with small pilots that use clear operational metrics, setting decision thresholds before pilots begin, and reallocating resources quickly when evidence does not meet those thresholds may reduce the cost of mistakes in resource-constrained settings. Learning should be treated as a production routine rather than a separate initiative (Taleb and Pheniqi, 2023; Kim et al., 2018). Absorptive capacity and knowledge recombination are recurring pathways in the evidence. Short after-action reviews following large orders, quality incidents, and equipment changes, combined with simple and standardised documentation, can embed learning in daily work. Assigning a small number of boundary-spanning roles to employees who scan technology updates and translate them into options suited to the firm's scale may further support this process.

The second set of recommendations concerns leadership and external engagement. CEO or TMT innovation orientation is frequently associated with stronger TIC under uncertainty (He and Sun, 2025; Taleb and Pheniqi, 2023). However, this does not imply that maximising risk-taking is desirable. Evidence on risk propensity is mixed, and excessive risk appetite can cause strategic misalignment and waste resources, especially in firms with limited slack (Kiron and Kannan, 2018; Singh et al., 2022). A disciplined approach appears preferable. Communicating a clear technology upgrading agenda, setting stop rules for pilots, and defining acceptable loss limits before scaling may help balance innovation ambition with resource constraints. External knowledge access is also important. Boundary spanning with suppliers, customers, universities, and industry associations appears to improve technology decision quality. This may be particularly relevant in production networks where standards, certification, and process knowledge often reside outside the individual firm. Policymakers and intermediaries can support TIC development by reducing coordination and information costs. Technology extension services can provide

diagnostic audits, vendor-neutral advice, and training in production and quality data collection. Cluster programmes can offer shared testing facilities and demonstration lines, lowering the fixed cost of experimentation. Regulators can reduce uncertainty by clarifying transition periods for standards and publishing practical compliance guides that reflect SME constraints.

The third set of recommendations concerns the practical interpretation of dynamic capabilities. For practitioners, DCs are best understood as a guiding lens rather than a direct operational prescription. Firms may benefit from translating the sensing, seizing, and reconfiguring logic into concrete, trackable routines such as environmental scanning, staged experimentation, and disciplined resource reallocation. Where firms lack the capacity to implement all three DC dimensions simultaneously, prioritising one or two dimensions that align with the most pressing source of uncertainty may be a pragmatic starting point.

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