POLITECNICO DI TORINO

Collegio di Ingegneria Gestionale e della Produzione

Master of Science Course

in ENGINEERING AND MANAGEMENT

How Digital Transformation Shapes Export Resilience
——Case Insights from China's Manufacturing Sector
under Global Trade Fragmentation

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2025.09.16

Abstract

This study explores how Chinese manufacturing enterprises build export resilience through digital transformation. It examines the interaction between external factors such as global trade fragmentation, market uncertainty, and technological change and internal capability reconfiguration. This study aims to fill a gap by proposing and applying the Policy-Technology-Organization (PTO) triple helix framework in the context of state-led policy. First, this paper reviews existing research on digital transformation and export resilience.It finds that most Western literature focuses on market-driven and technology-determinist views and pays less attention to mechanisms under state-led policies. Therefore, the study aims to contextualise the process of resilience formation in Chinese manufacturing firms.

This study selects Haier, Sany, and Zoomlion as typical case companies.The research adopts a multi-case study approach with an interpretivist and constructivist paradigm, including mechanism comparison, cross-case pattern matching, and corporate reports analysis, industry white papers, and policy documents. Drawing on the framework of policy trigger–technological penetration–organisational restructuring–resilience output, the study classifies three types of export resilience: absorptive, recovery, and transformative. It also compares their performance in market diversification, crisis recovery cycles, as well as resilience outcomes.

The result shows that export resilience is shaped by the interaction of external institutional cues and internal dynamic capability reconfiguration. Different forms and implications of resilience are produced by differences in organizational alignment, the degree of technology penetration, and the effectiveness of policy translation. The study theoretically expands the dynamic capabilities view by emphasizing the significance of institutional embeddedness and firms' positioning within global networks. This study shows recommendations on how to align digital strategies with export resilience goals in a practical perspective. At the end it also identifies limitations in sample coverage, data granularity, and methodology, and recommends further research on cross-country comparisons, quantitative modeling, and the restructuring of global value chains.

Keywords: Digital transformation; Export resilience; Institutional embeddedness; Chinese manufacturing

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1. Introduction

1.1 Background

China has undergone a significant change from an agricultural society to the world's second largest economy after initiating economic reforms in 1978. This rapid growth was exerted in continuity of export-oriented industrialization which was sustained in an annual average GDP growth rate of more than 9% in between 1980 and 2010. Export-oriented development strategies inserted China deeply into international production networks, and raised some 800 million out of poverty, while making China a key factor in global trade. As Figure 1.1 shown, over the past decades China's GDP scale and its share of the global economy have expanded significantly and that China accounted for about 18% of global GDP and 12% of global trade volumes by 2023.

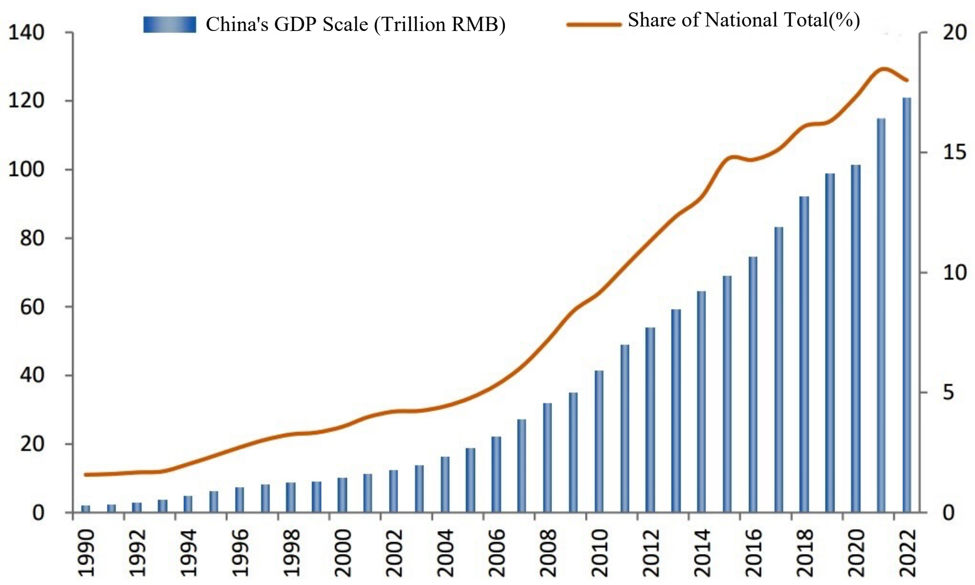

Figure 1.1 China's GDP scale and share of national total

Source: National Bureau of Statistics of China; World Bank; International Monetary Fund (IMF); Zeping Macro Research

However, China's economy has become particularly vulnerable to global disruptions by relying on the very factors that underpinned its rise. In recent years, events exemplified by the US–China trade war since 2018 which were rising economic policy uncertainty (EPU), mounting global protectionism, and escalating trade tensions, these have significantly challenged its export-dependent economy.

Beyond bilateral tensions, firms have faced a succession of systemic shocks since 2008: the global financial crisis and its prolonged demand slump, the COVID-19 pandemic and mobility restrictions, freight rate spikes and logistics bottlenecks, and geopolitically induced energy and commodity volatility (e.g., the Russia–Ukraine conflict). In parallel, protectionism and unilateralism have heightened non-tariff barriers. Export-reliant manufacturers maintain competitiveness under uncertainty by prioritizing resilience , rather than relying on efficiency alone, since this cocktail of risks raises variance in orders, delivery, and compliance (WTO, 2020; UNCTAD, 2021; CPC, 2022).

While these shocks have intensified in recent years, signs of vulnerability were already visible in the earlier period. From 2011 to 2016 the growth of China's export fluctuated significantly and this period was marked by rising global uncertainties and increased trade barriers. What's more, traditional manufacturing practices showed limited adaptability to sudden disruptions during this period. Firms address this exposure by building mechanisms to enhance resilience and competitiveness under uncertainty. This structural vulnerability became more visible in recent years. China's share in total U.S. imports dropped from 21.2% in 2018 to just 12.8% by early 2024, signaling structural decoupling tendencies driven by U.S. reshoring and "friend-shoring" strategies (CASS, 2025). These trends reinforce the urgency particularly through digital transformation for Chinese manufacturers to develop greater export resilience.

In response to these evolving challenges China strengthens domestic economic resilience and reduces dependence on international markets by adopting the "dual circulation" strategy. Digital transformation is central to this strategy, involving the widespread integration of digital technologies into economic activities as a key mechanism for enhancing manufacturing resilience. In the last ten years, China has built digitalization at a pace and scale unmatched by any other country in the world, leading in 5G, AI, cloud, and big data. By 2022 China had built more than 2.3 million 5G base stations, forming the world's largest 5G network, greatly facilitating connection and information communication. The digital economy generated almost 40% of China's GDP, indicating digital technologies were integral to current economic growth in China.

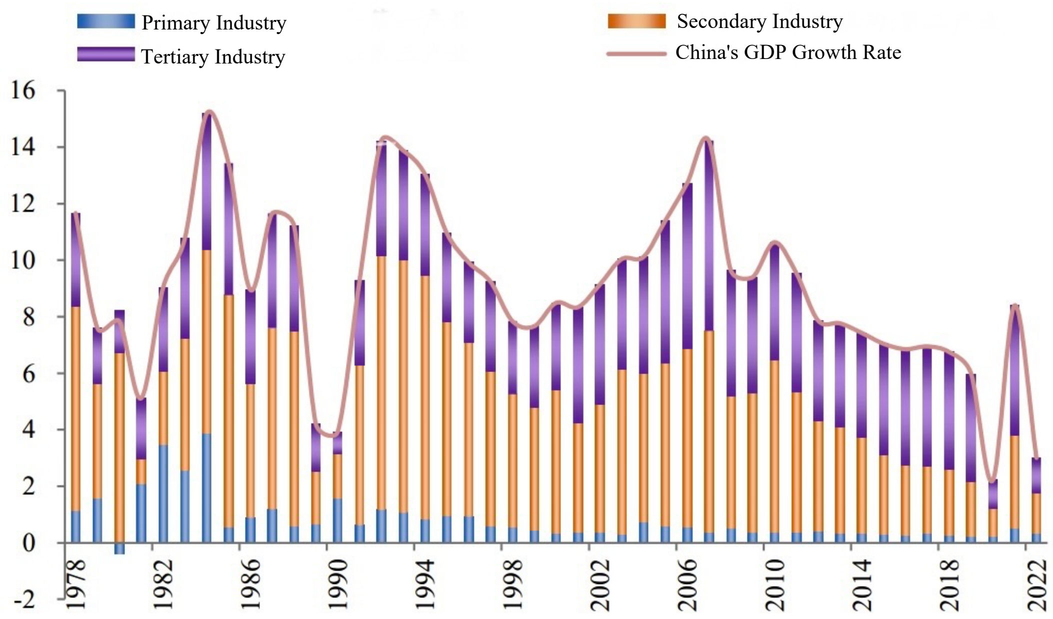

Figure 1.2 Contributions to China's GDP Growth by Sector (1978–2022)
Source: Wind, Zeping Macro Research.

As illustrated in Figure 1.2, the secondary sector, dominated by manufacturing, construction, and utilities, has historically been the most important driver of China's GDP growth, especially at the peak of export-oriented industrialization. Foremost among them is manufacturing, as the linchpin of China's industrial sector, both in terms of size and employment, and in its role as a focal point in China's economic integration and globalization.

Manufacture, meanwhile, is also a key frontier of technological upgrade in recent years. In this industry, which represents the core of China's export-driven economy, digital transformation has already started to profoundly change operational routines. AI-powered analytics, automation, and cloud logistics, have improved productivity, decreased operating costs, and streamlined supply chain operations. For example, now advanced data analytics enable real-time monitoring and immediate reactions to supply chain breakdowns. At the same time, AI-driven automation has been shown to enhance productivity by up to 20% in leading high-tech manufacturing firms, particularly where intelligent systems and digital twins are integrated into production processes (Deloitte, 2024; PwC, 2023).

Moreover, e-commerce has fundamentally transformed China's export channels and force manufacturers to access international markets successfully. China's cross-border e-commerce exports reached 1.55 trillion yuan (approximately $230 billion) in 2022 due to the endeavors of Platforms such as Alibaba and JD.com etc. This growth enabled Chinese manufacturers to directly link with foreign consumers through digital channels. This digital commerce ecosystem renders export channels multiple and provides essential buffers from disruption due to geopolitical tensions and trade restrictions.

1.2 Research Significance

Despite these advancements, existing literature primarily explores digital Despite these trends, existing literature only partly analyzes digital transformation in developed economies of innovation firm-driven environments. These models cannot be used to describe the complexities of state-led market ecosystems like China, whose digitalization is significantly state-level strategy and government-led infrastructure development. A vast research gap exists in terms of the role played by digital transformation in affecting export resilience in policy-led markets and conditions of rising economic uncertainty. Specifically, there are two fields that require further investigation. First, there is limited understanding regarding how government-funded digital platforms and infrastructure, such as national industrial internet platforms supporting firm-level adaptive capacities.

Second, we are not enough know how manufacturing firms design and apply resilience strategies under policy direction, regulatory uncertainty, and fragmented global supply chains. This limits our understanding of digital transformation as a process of improving operations, as well as a socio-technical process shaped by institutional contexts.

To plug these gaps, this study aims at the manner in which digital transformation intersects with export resilience within the Chinese manufacturing sector. This study aims specifically at how mechanisms impacting the intersections of technology adoption, organizational adjustment, and policy intervention take shape. Utilizing an interpretivist, multi-case study approach, it examines how companies build resilience via digital practices amidst accelerated global economic uncertainty. This research emphasizes that digital transformation is as much a process of operational improvement as it is a socio-technical process rooted in policy. By describing these mechanisms, it aims to contribute to theoretical understanding regarding export resilience in state-directed market economies and offer practical insights to policymakers and producers in other emerging economies facing such difficulties.

1.3 Research Objectives and Questions

The aim of this research is to provide a contextualised understanding that how chinese manufacturing firms develop export resilience through digital transformation, and to explain the underlying processes. and the first objective is to identify and conceptualise the mechanism pathways that connect policy triggers, technological capabilities, and organisational adaptation in the resilience-building process.

Another goal is to examine how large-scale state-led initiatives shape firms' strategic and technological choices by translating into operational practices and long-term strategic plans. The study also analyses how firms build distinct forms of resilience by reconfiguring organisational structures, decision-making systems, and human-resource allocation in response to crises.

The final objective is to identify how these differences lead variations in digital transformation approaches, policy conversion efficiency, and export resilience performance by comparing different firms. Through such objectives, the study seeks to develop both a theoretical model suitable for policy-intensive emerging economies as well as practical recommendations for policymakers and managers seeking to realign digital strategies with resilience goals.

And the research is guided by four questions: RQ1: What mechanisms do Chinese manufacturing firms use to build export resilience under policy-driven digital transformation?RQ2: How do state-led digital infrastructure and policies shape firms' digital transformation paths?RQ3: How do firms reorganize their structures and processes in response to major external shocks?RQ4: How do ownership structure and industry positioning condition the relationship between digital transformation and export resilience?

1.4 Structure

The structure of this thesis is organised as follows. Chapter1 introduces the research topic by situating China's manufacturing sector as the primary context for exploring how digital transformation affects export resilience. It outlines the background and motivation behind the study, presents the core research questions and objectives, and explains the theoretical and practical relevance of investigating this issue under the dynamics of global trade fragmentation and state-led industrial digitalisation.

Chapter 2 reviews the literature on digital transformation and export resilience, and these focus on three general areas: theoretical perspectives on manufacturing resilience, digital technology in international supply chains, and the way state industrial policies interact with firm-level plans in emerging economies. Review for this chapter also sets the research gaps and presents the conceptual framework of analysis thereafter.

Chapter 3 outlines the research method. It explains the theoretical foundations of the study, presents the multiple-case study approach, and sets out the data sources and the methods of analysis. Special emphasis is placed on the use of NVivo to code policy document qualitatively, keyword frequency, and categorizing recruitment data in terms of capabilities. Quantitative processing and visualisation tasks, such as data extraction, key word identification, frequency distribution computations,, trend charts, and radar charts, were conducted using Python for reproducibility and accuracy in data handling. The chapter also outlines the rationale for the selection of the three case companies: Haier, Sany, and Zoomlion.

Chapter 4 shows the findings and analysis. It first applies the "policy–technology–organisation" triple-helix framework to examine each case through four analytical stages: policy triggers, technological penetration, organisational restructuring, and resilience outputs. It then conducts cross-case comparisons in terms of technological penetration, policy conversion efficiency, and organisational adaptation. Furthermore, it will evaluates export resilience performance by acrossing three representative cases(absorptive, recovery, and transformative).

Chapter 5 concludes the thesis by summarising the findings in relation to the research questions, discussing the theoretical contributions and policy implications, reflecting on the study's limitations, and also about future research directions with particular attention to the applicability of the framework in different industrial and institutional contexts.

1.5 Technical Roadmap

Based on the above research objectives and structure, the technical roadmap of this study is illustrated in Figure 1.3 to clarify the logical sequence and methodological integration of the entire research process:

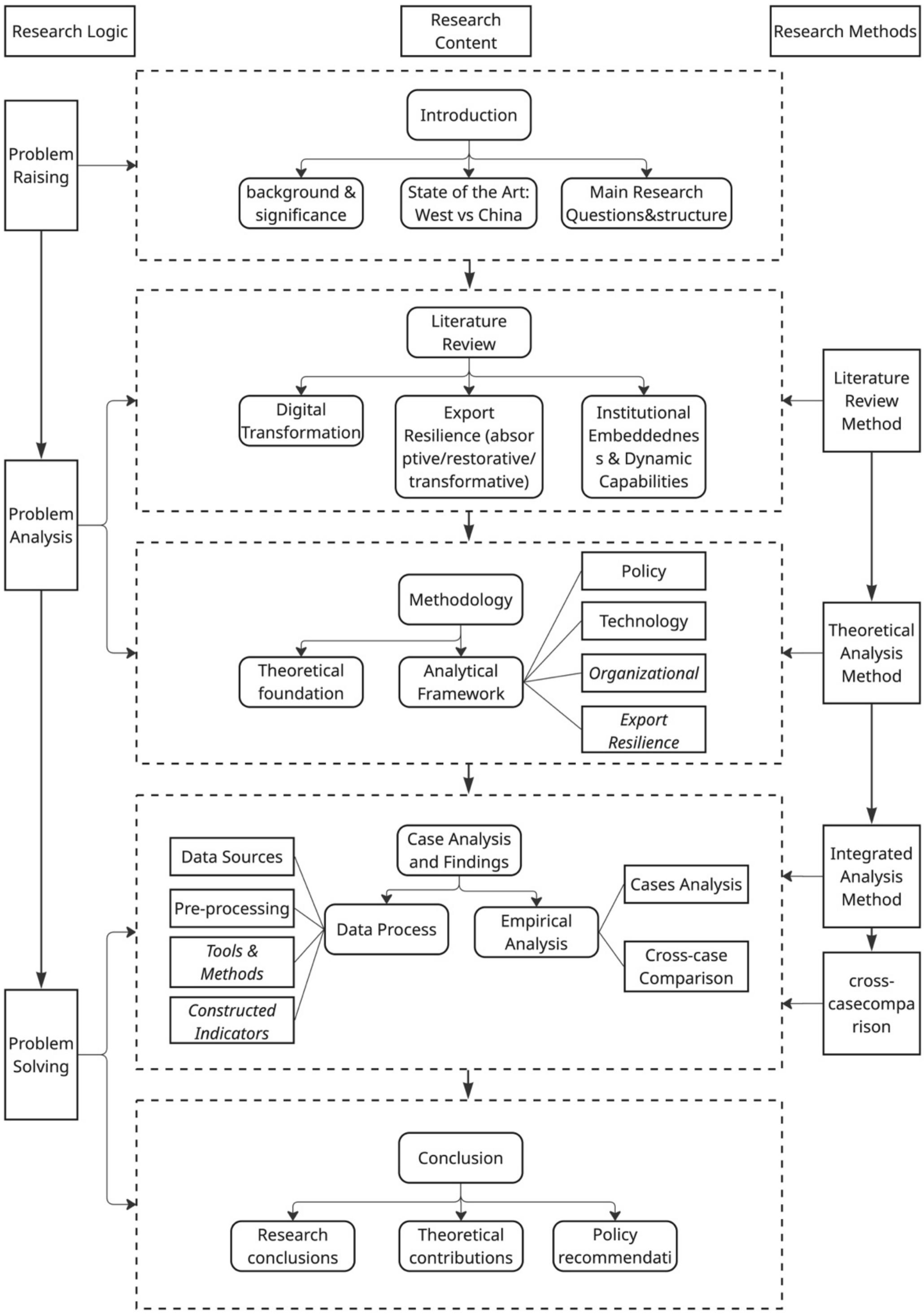

Figure 1.3 Technical Roadmap

2. Literature Review

2.1 Research on Digital Transformation

2.1.1 Conceptualizing Digital Transformation

In Western literature, digital transformation is commonly framed as the strategic integration of digital technologies across the firm to achieve competitive advantage and value creation. Bharadwaj et al. (2013) reconceptualize IT and business strategy as a fused “digital business strategy,” i.e., an organizational strategy that leverages digital resources to create differential value. This perspective emphasizes that digital technologies encompassing information, computing, communication, and connectivity can reconfigure products, processes, and capabilities across networked relationships. In the same spirit, Ebert and Duarte (2018) cast digital transformation (DX) as the adoption of disruptive technologies to raise productivity, create value, and enhance customer or social welfare.

At a definitional level, it is useful todistinguish digitization/digitalization from digital transformation. Early accounts describe digitization as expressing and transmitting information through digital codes and infrastructures such as cloud, AI, big data (Negroponte, 1995). DX, by contrast, touches the core of the business: new business models, redesigned processes, and organizational renewal rather than mere conversion of analog data. Recent surveys converge on a similar arc: research has progressed from technology application toward innovation integration, then to organizational reconfiguration, and ultimately to system-level change beyond the firm boundary (Wei et al., 2021). In that progression, some authors emphasize focused applications in specific business domains (Lee, 2015). DX brings new actors, structures, and values, producing a composite innovation effect (Hinings et al., 2018). It is thus a process in which prior business models are displaced and new value-creation logics emerge (Vial, 2019). In the Chinese discourse, this is often described as a cross-system rather than an intra-system shift (Xiao, 2020).

Western research underscores the disruptive and recombinable properties of digital technologies. Karimi et al. (2015) note that disruption forces ongoing adaptation that closer to continuous creative destruction than to a one-off upgrade. Building on the materiality of digital technology, (Yoo et al.,2012) identify programmability and data homogenization as foundations for layered modular architectures and flexible recombination of processes, products, and business models. Related work points out that DX is not only about installing tools but also about the organizational and social arrangements through which technology is enacted (Reis et al., 2018).

Chinese scholarship extends this conversation by stressing techno-institutional co-evolution. In policy documents such as the 14th Five-Year Plan, digital transformation is positioned as a driver of change in production, lifestyle, and governance, affirming that DX is not a purely firm-internal strategy but part of a broader institutional transition. (Zhang and Wu .,2021) argue that technological upgrading such as industrial internet, smart manufacturing) co-evolves with policy support, standards, and ecosystem development. (Zhu and Lin.,2021) synthesize antecedents, types, and outcomes, distinguishing internal enablers (digital strategy, technology deployment, resource and capability baselines) from external drivers (market demand shifts, user behavior, competitive dynamics). A complementary line conceptualizes the basic connotations of DX in terms of digital technologies deployed, the scope of transformation, and the intended outcomes: firms reorganize products and services, processes, organizational structures, business and partner models through information, computing, communication, and connectivity, with the goal of redesigning business activities for superior value capture (Wu et al., 2021). In operational terms, the substance of DX lies in leveraging the volume and velocity of data to confront uncertainty and lift productivity (Li & Liang, 2020), and in advancing the digitalization of production factors and processes, rather than merely digitizing records. In the manufacturing context, DX has become a central pathway for renewing traditional growth engines and advancing high-quality development (Yuan et al., 2021).

What follows is a sharper articulation of who, with what, and toward which outcomes. The firm remains the central actor such as initiator, executor, and beneficiary, are responsible for reviewing business models, structures, and routines, and deciding how to mobilize digital technologies in each domain. Digital technologies are the instruments enabling more precise market sensing, operational optimization, and enhanced customer experience (Yoo, 2012). The outcome is comprehensive renewal: not only new products or services, but also re-designed processes, reconfigured structures, and shifts in culture that together rebuild competitive advantage and support sustainable growth. Strategy and capability must keep pace with tool adoption. Evidence from digital and servitization transitions suggests that digital strategy and digital innovation capabilities are decisive; mere tool introduction is at best a preliminary step (Zaki, 2019). Leadership and workforce capabilities matter as well: organizations with digitally skilled leaders and employees, and with firm-level digital ecosystems and systems, progress more smoothly along the transformation path (Yao et al., 2022). Recent Chinese definitions converge on process reconfiguration, which is the use of digital technology to reshape business processes so that employees and users can see new patterns and routines. (Zhang & Li, 2022).

So this study adopts a techno-institutional co-evolution position: digital change is simultaneous change in the technological basis and organizational and institutional context of a firm, then produces new capabilities and forms of value creation. The Western view such as Bharadwaj et al and Ebert & Duarte, which is competitive value and firm strategy through digital innovation. The Chinese approach such as Zhang & Wu, Zhu & Lin and policy reports, which covers system-level coordination such as policy support, infrastructure, standards, and ecosystems and synchronizes with firm-level transformation. The two traditions recognize the change potential of digital technologies; explicit institutional leadership is given in the Chinese structure.

Table 2.1 Comparison the Western and Chinese frameworks of digital transformation

Aspect	Western	Chinese
Definition	IT–Business Alignment; Digital Technology Impact	Technology–Policy Integration; Tech–Institution Co-evolution
Scope & Focus	Firm-centered	Ecosystem-oriented
Key Enablers	Market-driven and firm-led.	Driven by state–market coordination.
Outcomes Emphasized	Competitive performance Market metrics	Dual growth goals Firm & policy impact
Change Process	Internal transformation; cultural shifts	internal and external both change;Adaptive co-evolution

Overall, understanding digital transformation as a techno-institutional co-evolution acknowledges that in contexts like China, digital change is not an isolated business strategy choice but part of a larger institutional transition. This perspective will inform our analysis of how such transformation contributes to export resilience.

2.1.2 Impact Trajectories of Digital Transformation

Having defined digital transformation, we next review how it is theorized to affect firm performance and resilience. The literature converges on two broad trajectories—an efficiency logic and an innovation logic, while recent work suggests that their realization depends on a layered set of enablers and constraints inside and outside the firm. In the background is a gradual research shift from technology application toward innovation integration, organizational reconfiguration, and even cross-system change beyond the firm boundary (Wei et al., 2021).

In the logic of efficiency, DX optimizes processes and information flows, it can reduces transaction and coordination costs and increases asset utilization. Digitalization initiatives enhance the speed of response, decrease information asymmetry, and enhance transparency (Vial, 2019). Empirical evidence in Chinese businesses reveals DX can decrease operating and labor costs, these can improve productivity and asset efficiency (He & Liu, 2019). In supply chains, connectivity and real-time information enable anticipating, rerouting, and inventory rebalancing, this also shows the classic adage: connectivity enhances resilience (Sheffi & Rice, 2005). In reality firms with responsive digital supply chains and remote command always had more stable operations in major disruption, illustrating how "leaner, quicker, more flexible" firms better absorb and rebound from shocks.

The innovation logic emphasizes new value creation. Digitalization opens avenues for business-model renewal, market expansion, and service transformation (Caputo et al., 2021). Modular architectures, programmability, and data homogenization support rapid recombination of products and processes (Yoo et al., 2010, 2012), while digital platforms extend reach to previously inaccessible customers and geographies. In China, platform-based export channels helped manufacturers diversify destinations when traditional trade routes were disrupted; higher levels of industrial digitalization are associated with greater ability to develop new products and markets and with stronger post-shock export recovery (Huang, 2023). This logic links DX to a more entrepreneurial, opportunity-seeking posture that not only replaces lost revenue but opens new growth paths.

Firms can benefit from improvements in efficiency, innovation, or even both based on network, resource, and cognitive conditions. At the cognitive level, leadership support and digital leadership always have a key role. Evidence shows that leaders possessing digital technology expertise and actively driving change can set direction and mobilize followers, reporting tangible results in business model renewal. (Kreutzer et al., 2017; Mihardjo et al., 2018, 2019). Team cognition matters too: shared knowledge of digital strategy, threats, and uncertainties improves coordination and decision-making speed across transformation, raising the chances of successful adoption (Hadjielias, 2021).

On the resource side, dynamic capabilities(sensing, learning, and reconfiguring) are central to executing DX (Matarazzo et al., 2021). From a resource-based view, digital technology capability itself is a critical asset (Eller et al., 2020). Implementation friction is expected: enterprises have hardware–software incompatibility and integration issues between digital production technologies and conventional processes (Favoretto et al., 2021). Shortages in capability and data literacy, especially in small and medium-sized businesses, slow progress unless complemented with external technical support (Chen et al., 2021). Customer-facing digital literacy at the leadership level increases value co-creation, customer insight, and business-model innovation (Witschel et al., 2019).

At the network level, embeddedness within industry and supply chains enables resource orchestration and collective change (Camarinha-Matos et al., 2019; Vendrell-Herrero et al., 2018). Too embedded or too dense networks could bring along very high maintenance expenses and managerial diversion, dissolving transformation momentum (Song & Chen, 2021). Correspondingly tying levels of breadth and intensity is therefore part of the DX design challenge.

External factors, such as the rapid spread of digital technologies and shifts in consumer behavior (e.g., increased internet usage and co-creation), have driven change, although the need for managerial inspiration and internal strategic renewal has also been important. (Warner & Wäger, 2019). According to case studies, if DX is seen as a basic strategic activity that entails balancing exploration and exploitation and leveling resources, results will be better. Last but not least, the regulatory environment is a two-pronged moderator: while infrastructure, standards, and supporting regulations can foster increased efficiency and innovation, regulatory barriers, data sovereignty restrictions, or conflicting objectives (e.g., automation versus job protection) may inhibit or guide DX through selective or phased adoption (Luo et al., 2023).

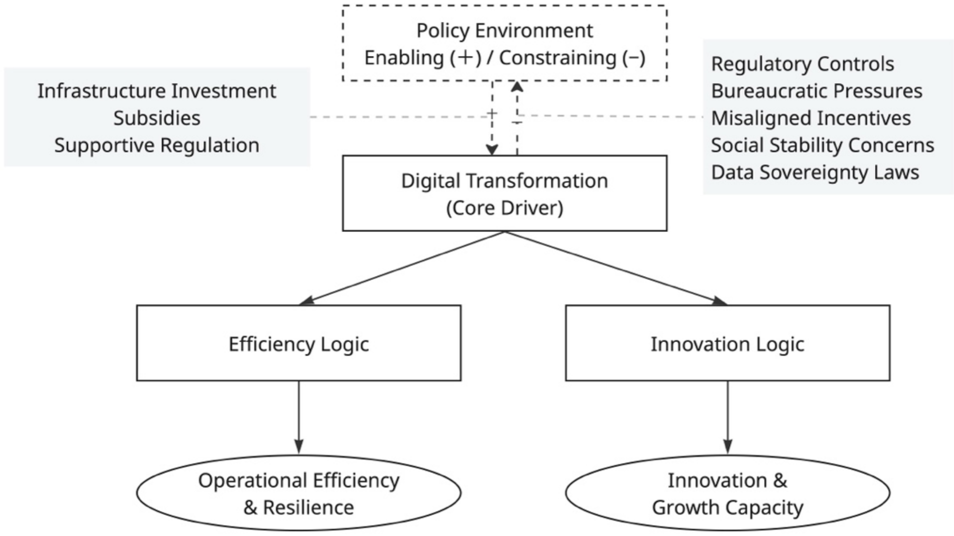

Figure 2.1 Pathways to Digital Transformation (DX)

Together, Figure 2.1 conceptualizes DX's impact as two principal logics: efficiency and innovation, which is enabled by cognition, resources, and networks, and conditioned by the policy environment. This layered reading helps explain why similar digital investments yield different performance and resilience outcomes across firms and contexts.

2.1.3 Measuring Digital Transformation

Since DX combines technological, organizational, and institutional attributes, evolves over time, and exhibits path dependence. Measuring digital transformation (DX) is complicated; Consequently, no single indicator can capture it precisely. Existing firm-level work typically operationalizes DX through inputs and practices. Common proxies include IT intensity (e.g., the share of IT expenditure in sales, counts of digital tools or platforms, the proportion of IT/data personnel, the share of online sales) as well as multidimensional "maturity" scorecards and manager surveys organized around customer, technology, operations, strategy, and organization (Nwankpa & Roumani, 2016). These approaches facilitate cross-firm comparisons but reveal little about the depth of digital embedding or the extent of business process re-engineering; they also entail subjective calibration across industries. Although many studies link DX to efficiency, agility, and innovation (Vial, 2019), measurement often regresses to "having" rather than "using," failing to reflect whether digital resources are effectively integrated.

In the Chinese context, measurement faces additional constraints from policy and disclosure. Subsidies, pilots, and “cloud/platform migration” initiatives can inflate investment-based indicators without necessarily producing durable capabilities, so naively treating spending as capability risks construct bias. Moreover, listed firms disclose IT outlays and system coverage with uneven granularity, limiting comparability. To widen coverage, recent work mines annual reports and MD&A text, constructing firm-level DX indices from the frequency of terms such as “digitalization,” “industrial internet,” “intelligent,” “automation,” and “platformization” (e.g., Wu et al., 2021; Zheng & Gu, 2021). Textual proxies extend time series and sample breadth, but are vulnerable to promotional language and semantic ambiguity, and therefore require cross-validation against objective disclosures. At macro and regional levels, index systems are also widely used, they are from information-sector value added and iGDP (Machlup, 1962; McKinsey, 2014) to multi-indicator frameworks depicting regional digitalization, spatial clustering, and links to high-quality manufacturing growth (Fan & Wu, 2020; Tian et al., 2023). These furnish useful background for cross-level comparisons, though careful translation to the firm micro level remains necessary.

At the company level, there are three common work paths. "input/factor" indicators captures information assets, information labor, and system use, including IT expense shares, electronic network and information expenditures, counts of computer users on a given day or in IT jobs, and revenues obtained through internet or e-commerce channels. These indicators are straightforward and easy to understand, but these rely on survey metrics or self-reporting. So sampling and reporting biases are common. An "event/policy" path identifies the incidence of DX by assigning 0–1 readings from corporate announcements or from participation in "integration of informatisation and industrialization" pilots (Tan Zhidong et al., 2022). An "text/narrative" path analyzes listed companies' year reports: one sub-path builds dictionaries for "cornerstone technologies" (AI, big data, cloud, blockchain) and for "practical applications." these weights or normalizes keyword frequencies and generates a DX index.

We can see that international and domestic literatures strike different compromises between comparability and feasibility. Input/checklist approaches are simple to implement and generalize but potentially sacrifice integration quality and the rhythm of change; event/policy indicators are transparent but only capture whether or not DX occurred; text/narrative proxies increase the sample frontier but introduce linguistic noise; composite indices are able to capture multi-dimensional progress but are sensitive to weights, industry heterogeneity, and data availability. Against policy guidance and disclosure practice in China, using annual-report words analysis—supplemented by veriifable disclosures to measure relative levels of "technological embedding, institutional alignment, and ecosystem connection", an available pragmatic and auditable alternative. While such proxies are, however, predominantly reflective of "what is disclosed" rather than directly looking through the depth of datafication of internal procedure or decision capability in real-time. Any later chapter conclusion is therefore framed tentatively in terms of these measurement limitations.

2.2 Research on Export Resilience

2.2.1 Conceptualizing Export Resilience

Export resilience describes how firms, industries, or regions withstand, recover from, and adapt to shocks in external markets. Scholars first developed the idea in ecology and later carried it into economics and economic geography. Holling (1973) frames resilience as a system's ability to maintain function under disturbance and, in later work, distinguishes“engineering” resilience (how fast a system returns to a prior equilibrium) from “ecological” resilience (how much disturbance a system can absorb before it flips to another regime) (Walker, 2006). Regional economists advance the concept by shifting from a static, single-equilibrium lens to an evolutionary one that emphasizes non-equilibrium dynamics, path dependence, and diversity; in this view, resilience unfolds as an ongoing process shaped by pre-shock structures and capabilities (Martin, 2012; Fingleton, 2012; Martin & Sunley, 2015; Martin et al., 2016).

Applying this lens to examine trade, export resilience refers to how exporting firms endure initial shocks (demand drops, supply chain failure, policy shifts) and recover or redesign export performance. Scholars define resilience by intersecting resistance and recovery and coupling with transformational renewal in most cases(Hu et al., 2020; Zhu & Ye, 2024). Empirical work operationalizes this idea by measuring rebound following failed trade, resistance to disruption and subsequent recovery (Mena et al., 2022), or reconfiguration of export channels during shocks (Wang et al., 2021). China's academic community adheres to these three principles, linking export resilience and resistance, recovery, structural upgrading, and short-term continuity achieved through long-term restructuring. (He et al., 2019; Zong et al., 2021).

We define two boundaries. one is: robust systems absorb shocks without changing whereas resilient systems do change in the longer term. another one is: elasticity is quantified in price/quantity reaction over time, but resilience plots cross-period performance trajectories and capacity development.

Current work expands export resilience into three layers: anticipatory, ecosystem, and institutional resilience. Firms build anticipatory resilience by creating buffers and options such as scenario planning, inventory flexibility, export market diversification, and early-warning analytics so that they reduce loss and lengthen recovery time when shocks take place ("resilience dividend"). for example in the US–China trade war, firms buffered impacts by pre-diversifying customers ahead of tariffs. Exporters build systemic resilience by joining networks of resilient suppliers, policies, and logistics; otherwise, even flexible enterprises will suffer when suppliers go out of business or ports close. We observe ecosystem resilience when logistics firms go around about through backup ports, when firms change suppliers, or when industry associations coordinate information and policy relief. Clustered economies with deeply integrated linkages and back-up institutions in China rebound from system-wide shocks faster, and cities with more sophisticated digital infrastructure and diversified industrially-based bases have lower export volatility in times of global crises (Chen et al., 2022).

All determinants in GVC and trade literature attest to this multi-layered approach. Firms restructure exposure by choosing their GVC position: greater upstream embedding may heighten input-shock exposure (lower resilience) but accelerate recovery by establishing substitute input and market channels (Jiang, 2021). Exporters build resilience by diversification especially across markets and not only across products (Liu & Qi, 2021), but some studies warn against diminishing returns or negative effects when diversification multiplies correlated external-demand risks or puts pressure on managerial attention (Xu & Liu, 2023; He et al., 2019). Regions improve medium-term upgrading and recovery by pursuing related diversification, though in the short run relatedness might improve exposure to local demand shocks and make it difficult to improve quality (He & Chen, 2019). Firms improve resilience further by making investments in innovation that improves productivity and quality and by developing dynamic capabilities that allow for sensing, agility, and reconfiguration (Akpan et al., 2022).

Results are also shaped by policy and connectivity. Signing trade agreements to mitigate risks and enhance product quality (Wei et al., 2023), expanding multimodal transport corridors like the China–Europe Railway Express to reinforce network effects (Sun & Chen, 2023). Firms improve financing slack and diversification by building brands, while board composition (e.g., a higher share of female directors) can moderate those effects (Wei, 2023). In China's context, exporters often co-produce resilience with the state; we therefore treat institutional resilience as part of the conceptual domain.

We classify export resilience on three horizons aligned with the firm-level typology of Chapter 4:

• Absorptive(Immediate): Firms mitigate performance deterioration by mounting buffers and flexible capacity, diversifying markets, and generating redundancy in ecosystems. Empirically, we track smaller deviations around the pre-shock baseline, less volatility (std/CoV) of export share or value, and check whether 2020 crosses the 2019 baseline for COVID-19.

• Adaptive (Short-term): Firms regains the pre-shock trend by re-shuffling across markets, products, and channels and by re-wiring networks. We measure time-to-recovery and observable redeployment (e.g., ramp-ups in cross-border e-commerce).

• Transformative (Long-term): Firms use the shock to reshape strategy by quality upgrading, greenifying to address new compliance regimes, or insourcing offshored production and service bases. We record structural reconfiguring in terms of changes in market/product mix, capability investments (green, digital), certification, and persistent gains over pre-shock levels.

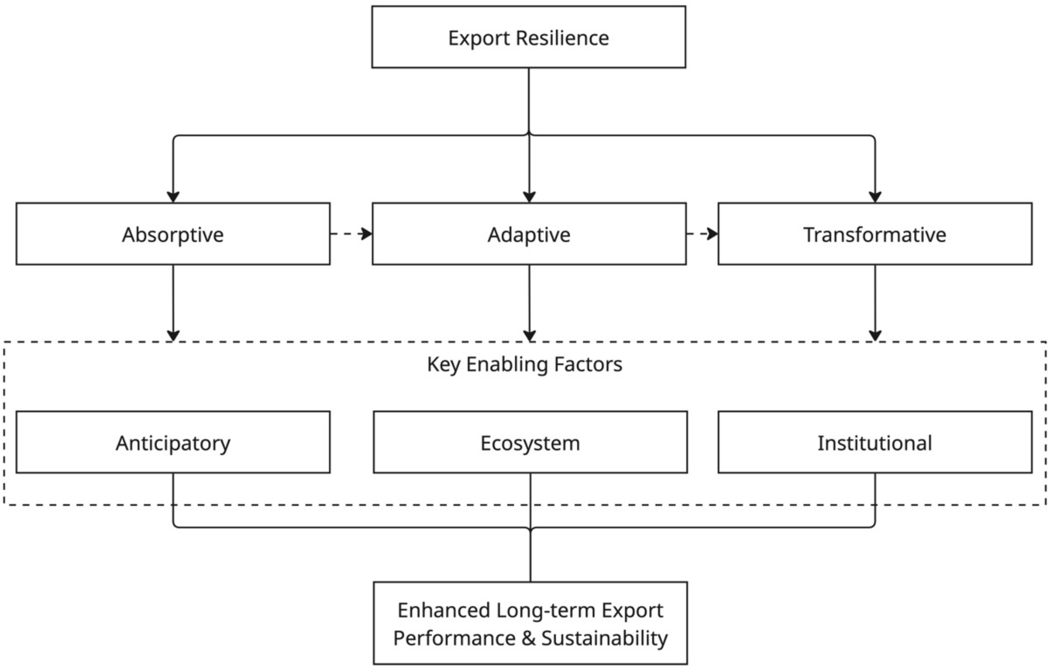

Figure 2.2 Export Resilience Conceptual Framework

Figure 2.2 summarizes the framework. Shocks hit export performance; firms respond along absorptive–adaptive–transformative pathways; and firm capabilities (diversification, dynamic capabilities, digital supply-chain visibility), ecosystem properties (supplier/logistics redundancy, cluster institutions), and policy context (trade facilitation, standards, finance) mediate outcomes. This conceptualization bridges the literature and prepares the operational indicators and firm comparisons in Chapter 4.

2.2.2 Determinants of Export Resilience

Export Resilience is the result of determinants that operate at different levels. We group them into (i) firm-level capabilities and strategies, (ii) value chain and cluster location in networks, and (iii) the macro–institutional context. This sequence enables us to map determinants onto the three horizons of resilience in Chapter 4 on absorptive, adaptive, and transformative.

Firm-level capabilities and strategies. Firms build resilience by mobilizing dynamic and innovation capabilities, financial slack, and export experience. Organizations respond more effectively under hostile conditions when they reallocate resources, redesign products, and adjust channels through dynamic capabilities and innovation strength (Gorynia et al., 2024). By creating sensing and agility practices, producers increase even greater resilience; the results are consistent with organizational elasticity and dynamic capabilities in manufacturing settings (Akpan et al., 2022).Export experience matters because companies that establish global channels (i.e., foreign offices or a diversified customer base) rely on social capital and knowledge when under shock.

Export diversification helps firms manage risk but isn't always straightforward. Because companies trade technology and diversify risk across products and markets, diversification has worked in most studies (Xu & Zhang, 2019). Market diversification always does better than product diversification for resilience because firms shift demand between places without paying sunk costs to reform product lines (Liu & Qi, 2021). Diversification can, nonetheless, unravel: if industries are correlated, shocks can spill over across related activities, and managerial attention can become diluted, decreasing short-run resilience (He & Chen, 2019; Xu & Liu, 2023).briefly, diversification can dilute concentration but, if portfolios are truly uncorrelated, increases absorptive capacity to a point and speeds up recovery.

Although with smaller buffers, SMEs occasionally adapt more quickly through product switching or going online. Large enterprises, nevertheless, tend to maintain exports by relying on reserves, multi-plant presence, and negotiating power. Although the channel is still under-researched, digital finance (e.g., supply-chain finance platforms) has the potential to solve the liquidity issues of SMEs.Also noteworthy are brand power and governance: companies that develop their brands enhance financing slack and facilitate diversification, and board composition (e.g., greater proportion of female directors) can mitigate the relationship between brand and resilience (Wei, 2023).

Firms increasingly drive resilience by increasing digital readiness. Digitally sophisticated exporters more adequately meet disruptions by transforming into digital channels, anticipating using data analysis, and governing using cloud-based systems. Contemporary studies link business digital change with higher export resilience 2008–2020 through efficiency and cost variables (Zhang et al., 2023), replicating the efficiency and innovation logics that we elucidated in §2.1.

Network Position: Position in global value chains (GVCs) is two-sided. Increased upstream embedding increases exposure to input shocks(also known as the "bullwhip" effect), thus resilience decreases in a downturn; however, the same embedding can speed up comeback when demand recovers because firms utilize substitute inputs and markets via installed networks (Jiang & Liu, 2021; Ma, 2021). we can know that GVC engagement reduces absorptive performance but can increase adaptive performance.

Regional and sectoral agglomeration further affect resilience. Urban spaces and industrial districts through industrial clustering to contribute economic resilience (Wang & Zhao, 2021; Liu Rui & Zhang Weijing, 2021). Producer-services agglomeration effect on resilience shows a U-shaped, and diversified agglomeration has an inverted-U effect: diversified clusters consolidate supply chains and accelerate short-term restart of logistics and specialized clusters facilitate structural adjustment and long-term sustained gains (Li Lanbing & Liu Rui, 2021). These explain why intensive supplier and service networks reduce time-to-recovery and why specialized capacities facilitate transformative upgrading.

Macro–institutional environment. Policy, infrastructure, and diversification at the national and regional levels lay the groundwork for resilience. Countries buffer sectoral collapses when they diversify export capacity across a number of industries and trading partners so that some can offset others in the event of a shock. Logistics and digital infrastructure matter: robust ports, corridors, and e-customs redirect goods; digital trade zones and platforms sustain transactions when physical channels collapse. China's China–Europe Railway Express strengthened firm resilience primarily through enhancing inward trade-network effects (Sun & Chen, 2023).Trade agreements raise resilience by reducing export risk and improving product quality (Wei et al., 2023). On the other hand, policy uncertainty increases transaction costs and risk, which weakens firm resilience (Zhu & Ye, 2024).

With effects that may be more pronounced in less developed areas, regional innovation capacity boosts productivity and quality and supports export recovery (Chen, 2022).At the same time, studies report that related diversification bolsters medium-term recovery and structural upgrading but can depress short-run resilience by increasing exposure to local demand shocks and slowing quality improvements (He & Chen, 2019). These findings remind us to separate short- and long-run horizons.

SMEs and network fragility. Macroeconomic data obscures the role of SMEs but in fact they support export supply chains a lot. By pooling on platforms, forging cooperatives, and taking up niche demand when anchors fail, smaller firms co-create system resilience in the absence of buffers. Input shortages for major exporters when multiple small suppliers fail; network vulnerability gets transmitted into macro volatility.

Synthesis and mapping. These determinants map cleanly to our three horizons. Diversification, buffers, and digital visibility raise absorptive performance by limiting initial loss. Agile redeployment through platforms, supplier substitution, and logistics rerouting shortens adaptive time-to-recovery. Innovation, upgrading (e.g., green compliance), localization of overseas service/production, and supportive policy regimes enable transformative gains beyond the pre-shock baseline. Because some levers trade off, for example, GVC depth reduces resistance but improves recovery, empirical work must separate phases and report both volatility and rebound metrics.

Overall, export resilience is the result of the interaction between firm competences (diversification, dynamic capability, finance, digitalization), network position (GVC embedding, agglomeration), and macro–institutional conditions (diversification, infrastructure, policy stability and support). The previous literature emphasized diversification and size; more recent evidence brings digital readiness, network connectedness, and institutional design more to the forefront. These determinants we will carry forward to operationalization and to the firm cases in Chapter 4.

2.2.3 Operationalizing Export Resilience

Turning “resilience” from a concept into something observable is difficult: it is latent, multi-dimensional, and path-dependent, so it cannot be measured directly. As a result, the literature typically proxies resilience with the trajectory of outcome variables before and after a shock, and then separates resistance (a smaller drop during the shock) from recovery (a faster return to baseline). Early international approaches use sensitivity/impact indices and shock-cycle analysis (Martin, 2012; Martin et al., 2016) to gauge the depth of impact and the slope of recovery for a region or industry. In the Chinese context, many studies take the 2008–2009 global financial crisis as an exogenous shock and compute deviations and recovery with 2008 as a common baseline (e.g., Jiang & Liu, 2021; Liu & Qi, 2021). Common single-indicator measures include a baseline deviation rate:

$$\text{Resilience}_{i,t} = \frac{\text{Export}_{i,t} - \text{Export}_{i,2008}}{\text{Export}_{i,2008}}$$

where a larger value indicates stronger resistance/recovery; or the difference between each year's export growth rate and the baseline year's growth rate (He Zhanfei & Chen Tao, 2019; Jie Chuming, 2022). Building on this, some papers explicitly decompose resilience, using "whether the series fell below baseline," "the size of the drop," and "time to return to baseline" to capture resistance and recovery (Chen Anping, 2022), and, drawing on shock-cycle models, estimate separate resilience coefficients for the recession and recovery phases (Zhang Yuesheng, 2022; Xu Yuan & Zhang Linling, 2019; Xu Yuan & Deng Huyan, 2020). In parallel with single-trajectory indicators, stability can also be described by volatility (standard deviation/coefficient of variation) and by exporter survival rates (the share of firms that continue exporting after the crisis).

In addition to single indicators, another line of research is the index-system approach: theoretically extending resilience conceptually into three directions: resistance, recovery, and structural upgrading/transformative capacity, and constructing a composite index (He Zhanfei et al., 2019), in general, based on customs statistics and local statistical yearbooks, with objective weights like entropy methods. Its virtue is that it brings structural upgrading (e.g., product quality/structure change) into the "transformative" territory of resilience; its vices are high data requirements and sensitivity of cross-industry comparability and definitions. Similar organizational/finance perspectives use low long-horizon volatility of returns or event-study abnormal returns as a proxy for firm resilience (Markman & Venzin, 2014; Albuquerque et al., 2020; see also Hu Haifeng et al., 2020, 2022). These reflect the relationship of "steadfast performance" and resilience but relate to export-specific resilience weakly.

Chinese micro studies also show that firm-level performance measures (e.g., deviation, repair time, rebound slope) might order resilience naturally (Jiang & Liu, 2021; Liu & Qi, 2021; Ma Xiaoqi, 2021). At the same time, the literature also records flaws of outcome-based measures: (i) they easily mix up policy support (e.g., speedy tax rebates, "green channels," privileged financing) with innate ability; (ii) outcomes are sensitive to shock window and baseline choice (whether baseline is 2008 or 2019, and whether shock year is only 2009/2020); and (iii) one number tends to "flatten" multi-dimensional material of resilience, hiding structural adjustment and upgrading paths. Thus, others use some work pools dimensions with composite indices or phase-specific coefficients at the cost of methodological sophistication and heavier data demands.

Given this review and to ensure operability and consistency with our empirical chapter, this study adopts a parsimonious and transparent operationalization: use 2019 as the common baseline and 2020 as the shock year; read firm export-share series (2017–2023); use "whether the series fell below baseline" and overall volatility to capture steady/absorptive resilience; use 2020 to 2023 rebound magnitude and time-to-recovery/repair slope for fast-recovery/restorative resilience; and identify transformative resilience from public, verifiable evidence of structural change (e.g., EU-facing green/low-carbon compliance and product upgrades, overseas localized production/service networks, market/product-mix reconfiguration). We then form an ordinal comparison rather than a complex weighted score, for presentation in Chapter 4's table and radar chart. It is worth stressing that more process-oriented measures (e.g., management response lag, supply-chain reconfiguration frequency, or the "digital narrative density" in managerial texts) are conceptually useful but are not included in this study's metrics; they are left for future work when suitable data become available.

2.3 Linking Digital Transformation to Export Resilience

2.3.1 Direct and Mediated Effects

Understood the relationship between digital transformation (DT) and export resilience as a set of direct mechanisms complemented by organizational and contextual channels. At this point, we can regard real-time visibility is a central lever of supply-chain responsiveness. Routine DT using such as IoT on in-store floors, real-time tracking of shipping, and easy supplier data integration, these can reduce detection–response loops. So that disruption can be contained by rapid rerouting or rescheduling, an argument years emphasized in the literature on resilience (Sheffi, 2005). Recent disruptions' evidence continues this mechanism: firms deploy advanced digital supply-chain systems experienced fewer stockouts and quicker logistics recovery, with export continuity intact.

Platformization constitutes a second pillar insofar as participation in global B2B/B2C marketplaces widens access to buyers and reduces search and communication costs, enabling reallocation across destinations when regional demand weakens (Liu & Nath, 2013). Studies on Chinese manufacturers further indicate that industrial digitalization, including online platforms and digital marketing, has facilitated post-shock rebounds by opening new products and markets (Wei et al., 2022).

A complementary strand concerns efficiency and innovation. Automation, AI-enabled optimization, and digitized processes lower unit costs and raise productivity, with concomitant improvements in export product quality (Xie & Wang, 2022). DT also strengthens innovation incentives and intensity (Zhao & Yang, 2020) and upgrades export quality through innovation capability, product switching, and the use of higher-quality intermediate inputs (Du et al., 2022). Where digital capability is initially low, adjustment costs may crowd out innovation and depress quality; at higher capability levels, the relationship turns positive, with heterogeneity across regions, ownership types, and product segments (Hong et al., 2022). On the sourcing margin, digital development alleviates information asymmetries in overseas procurement, improving the quality and variety of imported intermediates and indirectly upgrading exports (Wang & Yuan, 2022). These firm-level changes translate into stronger export competitiveness via productivity gains, cost reduction, and tighter supply-chain coordination, with effects differing across firm groups (Meng & Dong, 2022).

Whether these benefits materialize depends on organizational uptake. DT contributes to resilience to the extent that it is internalized through dynamic capabilities are supported by training and cross-functional routines; technology alone is insufficient. Context also matters. Economic policy uncertainty raises transaction and compliance costs and weakens the DT–resilience link, whereas digital-economy development mitigates this negative effect by lowering search and coordination frictions (Zhu & Ye, 2024). Data governance such as localization rules, sovereignty requirements, and cybersecurity, all acts in a similar moderating fashion: restrictive regimes erode cross-border coordination benefits, while clear protections allow DT gains to materialize.

2.3.2 Contextual Blind Spots

Whereas the intersection of export resilience and digital transformation creates many empowering narratives, assumptions driving them must be challenged specifically for deal with context. The literature makes free-market assumptions and a relatively static theory of resilience to a great extent, which may not be true everywhere, for example China's policy-deficient environment. So we see two issues: market logic assumptions in the literature that overlook how state and institutional conditions shape outcomes, and static approaches to resilience that overlook institutional and dynamic aspects such as isomorphism and metric bias.

Many studies that extol digital transformation's benefits for resilience are grounded in market-based thinking – the idea that firms independently strategize to maximize profits and that competition and innovation drive adaptation. In this view, resilience is an emergent property of many independent firm decisions. However, in China and some other emerging economies, the state plays a heavy role in shaping firm behavior. As noted earlier, firms may undertake (or avoid) digital initiatives due to government pressure rather than pure market rational. This means that one cannot simply assume that if digital transformation is beneficial, firms will do it and become resilient. Institutional pressures can cause decoupling: firms might ceremonially adopt certain technologies to signal compliance with policy (to gain legitimacy or subsidies) without actually embedding them deeply for competitiveness. Rose Luo's study (2023) on conflicting pressures highlights this decoupling – some Chinese firms invested in digitalization not primarily to improve efficiency, but to satisfy local government mandates, and they tended to choose approaches that would minimize layoffs (sometimes adopting less advanced automation to preserve jobs). The result is a kind of suboptimal digital transformation if viewed from a market perspective, potentially yielding less resilience gain than expected.

Furthermore, the market logic also assumes open international markets. But geopolitics (i.e. tech export bans, trade blocs) in practice also implies that a Chinese firm's digital resilience strategy may be constrained by exogenous politics. For instance, a Chinese telecoms equipment exporter can digitally optimize its supply chain.but exports will be curtailed if foreign governments prohibit it on security grounds. it is a non-market shock that technology cannot absorb. A blind spot would be failing to acknowledge political and institutional shocks. Resilience mechanisms need to also consider political risk (e.g., by manufacturing locally in several countries to guard against sanctions).

Some literature treats resilience as a static trait or outcome – you either are resilient or not in a given event – and fails to consider how resilience develops over time and differs across institutional contexts. A static view might, for example, rank countries by an index of resilience and leave it at that. But resilience should be seen as a dynamic process (as argued by Linnenluecke, 2017): companies learn and improve (or deteriorate) with each shock. The static approach doesn't capture learning effects or the path-dependence of resilience. In China, one could argue that the export sector's resilience today is partly a result of learning from past shocks (Asian financial crisis 1997, global crisis 2008, trade war 2018, etc.), and that the institutional memory in policies has evolved (e.g. creating stabilization funds, digital trade facilitation platforms) which a static snapshot would miss. Studies must be careful to incorporate time, a longitudinal approach can show whether digitally transformed firms gain cumulative resilience benefits (like dynamic capabilities that strengthen with use).

Another static blind spot is treating "resilience" as one general concept without context. In reality, resilience can be multi-form. For instance, Chinese state-owned enterprises (SOEs) might exhibit resilience due to state backing (they seldom fail because the government bails them out), whereas private enterprises rely on agility and innovation. These are different resilience regimes. If one only measures outcome (who survived), you might wrongly conclude SOEs are equally resilient as private firms, without noting the mechanism (state support vs. digital agility). This touches on institutional isomorphism: organizations in China may all claim to pursue digital transformation, leading to homogeneity in reported strategies, but the actual outcomes might differ based on ownership and institutional support. Many private firms might truly innovate, while some SOEs might just invest heavily in tech without organizational change, relying instead on cushion from the state. Research often fails to distinguish these patterns, instead pooling firms together. A recent Chinese study (Huang, 2023) did find that digitalization's effect on export resilience was stronger for private firms than SOEs, presumably because private firms actually need the efficiency or innovation gains to survive, whereas SOEs have other safety nets. This suggests that a one-size-fits-all interpretation would be misleading: context (ownership structure, institutional environment) conditions the DT-resilience link.

Institutional Isomorphism and Overemphasis on Metrics: Institutional theory tells us businesses mimic current norms, "digital transformation" has become a near buzzword imperative in China. Businesses may engage in what (DiMaggio and Powell,1983) call mimetic isomorphism: copying others' digital initiatives simply because it's fashionable or expected by government and investors, not because it fits their strategy. This would create a scenario where numerous companies invest in identical digital solutions such as ERP systems and automated warehouses, and it just achieve a superficial level of transformation. The literature might record the increased IT investments or digital mentions and predict improved resilience, but if the investments were not well-implemented, the actual resilience improvement may be little to none. Yet our standard metrics would wrongly suggest a high level of transformation. In short, metric bias can occur when proxies (like spending) do not align with true capability. This is particularly problematic in a setting with strong institutional pressure that metrics can be gamed. For example, if local governments measure digital adoption in terms of how many cloud systems have been installed, businesses will install cloud systems to tick the metric but possibly use them hardly at all. Academics need to be aware that generic measures will be manipulated by such behavior, painting a more positive picture of digital readiness than really is the case.

Another measurement issue is about resiliencet: measuring resilience by outcome (e.g., how fast exports recovered) might not capture quality of recovery. A company might recover export volume by cutting prices very aggressively (as some companies did to regain market share after COVID). Is that resilient or a desperate action that sacrifices profitability and future viability? In the qualitative context the metric "recovered volume in 6 months" looks good, but the health beneath may be poor. We recommend careful interpretation of measures of resilience, especially where firms may sacrifice long-term health for short-term recovery at the behest of external pressures (e.g., a state-owned exporter may be commanded to continue exports at any expense, even if it means selling at a loss. it achieves numerical resilience but weakens the firm).

In conclusion, digital transformation and resilience occur in a broader setting. Market logic assumptions need to be tempered with institutional facts .particularly in China it not only distort but also reinforce these trends, where the role of the state can reinforce as well as distort them. Static resilience tests have missing evolutionary and contextual nuances, e.g., how companies of different types end up experiencing and doing resilience, and in what ways measurement can be deceptive if it is not read in context. Recognizing these blind spots could opens the way for a more subtle research approach, one responsive to the interplay between technology, organization, and policy, rather than treating each singly or hypothesizing one effect in many different contexts.

2.4 Research Gaps

Having reviewed the literature, the existing literature on digital transformation (DT) and export resilience (ER) reveals several substantive gaps that constrain theoretical refinement and empirical applicability, particularly in policy-intensive manufacturing contexts such as China.

Many studies thus far establish that digital transformation is positively correlated with resilience outcomest, but they often stop at high-level explanations (e.g. “digital firms cope better”). There is a paucity of in-depth research into the mechanisms and processes through which resilience is generated. Specifically, the interaction of policy, technology, and organizational change in producing resilience is underexplored. Studies like Gao et al. (2024) and Huang (2023) provide statistical evidence of positive impact, and maybe test one mediator (like innovation capacity or cost efficiency), but a comprehensive causal narrative is missing. How exactly do policy initiatives (say a government digital subsidy program) translate into a resilient outcome? Is it because the subsidy allows deeper tech adoption, which then enables faster reconfiguration in a crisis? Or is it because the program also fosters networks among firms (ecosystem effects) which provide mutual support? We don't fully know. There's a gap in qualitative and longitudinal studies that follow firms through the process: from embarking on digital transformation, interacting with policy, implementing changes, and then experiencing a shock and responding. Capturing that story would illuminate co-evolution (e.g., did the firm's organizational structure evolve to fit new tech and policy demands? Did that new structure prove resilient?). In short, the micro-foundations of how resilience emerges from the techno-institutional transformation remain a black box in much literature.

The second gap is conceptual and concerns the applicability of existing frameworks to China. Much resilience and digital transformation theory originates in Western contexts. As we've discussed, China's environment has unique features: strong state involvement, policy-driven digitalization, a mix of state and private ownership, and massive scale. There is a need to develop frameworks that are sensitive to these contextual factors. For instance, Western frameworks might assume firms undertake digital transformation primarily for competitive advantage, whereas in China it could be partially for compliance or accessing incentives. A context-sensitive framework would incorporate the role of government policies as an integral part of the model (not just an external factor). For example, Zhang & Wu (2021) (techno-institutional co-evolution perspective) and Zhu & Lin (2021) (comprehensive DT framework) highlight that one must consider external environment changes together with internal change. However, these ideas haven't been fully integrated into resilience studies.

The last gap is the lack of qualitative, rich descriptions and alignment with the dynamic capabilities theory. Digital transformation is taken to enhance a firm's dynamic capabilities: sensing, seizing, reconfiguring (Teece, 2007), which are considered the foundation of strategic resilience. Yet, there is scant empirical work that directly links digital expenditures with, for example, sensing capability (e.g., being able to detect changes in customer demand beforehand). We do have indirect evidence (e.g., Im et al. 2021 investigating narrative cues), but more direct observation needs to be done.

So in order to understand the dynamics between policy environments, technology adoption, and organizational transformation, we must see them from a comprehensive analytical lens. Follow-up studies do not have to see them as distinct or additive variables but rather investigate their co-evolutionary processes: how policy stimuli influence technology adoption, how technology triggers structural adjustments, and how these mutualisms enhance (or detract from) export resilience to exogenous shocks. In China, institution and state influence penetrate deeply into corporate strategy choice, necessitating the multi-actor, multi-level framework to break through linear causality and give us new understanding about the multiple paths towards resilience. Closing this knowledge gap is the overall purpose of this study.

Based on above, this study tries to address four interrelated research questions:RQ1: What mechanisms do Chinese manufacturing firms use to build export resilience under policy-driven digital transformation?RQ2: How do state-led digital infrastructure and policies shape firms' digital transformation paths?RQ3: How do firms reorganize their structures and processes in response to major external shocks?RQ4: How do ownership structure and industry positioning condition the relationship between digital transformation and export resilience?

3. Methodology

3.1 Theoretical foundation

3.1.1 Institutional Theory and State-Driven Digitalization

Institutional theory explains how organizations conform to external pressures to gain legitimacy and secure resources within their institutional environment (DiMaggio & Powell, 1983). For China's manufacturing the state plays a dominant role in guiding industrial priorities, and coercive isomorphism is especially important. National strategies such as Made in China 2025 and the Industrial Internet Development Action Plan set formal and informal requirements for companies to adopt advanced digital technologies, follow technical standards, and participate in government-supported initiatives (Zhu et al., 2020). This alignment can help firms access subsidies, gain preferential procurement, and join pilot projects, thus strengthening both operational capacity and market legitimacy (Li et al., 2022).

Alongside coercive pressures, mimetic isomorphism shapes digital transformation pathways under conditions of uncertainty. When the benefits or technical routes of digitalization are unclear, firms tend to emulate peers or industry leaders, often those publicly recognized by the state as "model enterprises" (Liu et al., 2021). This imitation reduces perceived risk and accelerates the diffusion of digital practices, that contributing to industry-wide convergence in technological adoption (Huang & Li, 2023).

Institutional effects are diverse. state-owned firms tend to be more strongly institutionally embedded with more direct compliance with the policy mandate, while privately owned firms may choose selective compliance alongside independent policy-free innovation strategies (Peng et al., 2008). This affects the speed and extent to which policy signals translate into technical and organizational change. This study refers to this effect as policy conversion efficiency.

3.1.2 Dynamic Capability Theory and Digital Resilience

Originating from the resource-based view (RBV) and firm capability theory (Wu, 2010), the dynamic capability view (DCV) explains how firms sustain competitive advantages in turbulent environments (Teece, Pisano, & Shuen, 1997; Teece, 2007, 2012). Dynamic capabilities are defined as "the ability of a firm to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece, 2012) and are commonly classified into three dimensions: sensing, seizing (or agility), and reconfiguration (Chowdhury & Quaddus, 2017; Eslami et al., 2021).

Digital transformation enables the improvement of these competencies. Digital sensing involves using technologies like real-time analytics, IoT sensors, and artificial intelligence to identify supply chain disruptions or changes in demand before traditional channels do. This enables a quicker and more accurate response. (Ciampi et al., 2021; Fosso Wamba et al., 2020).Digital agility refers to the ability to adjust operations or strategies rapidly and flexibly,for instance, switching to e-commerce channels or alternative suppliers has facilitated by IT-enabled and modular processes (Eslami et al., 2021). Digital reconfiguration is the capacity to rearrange or reallocate resources, for instance, retooling lines or reassigning staff, supported by digital systems like CAD/CAM and cloud-based collaboration platforms (Warner & Wäger, 2019).

The two main components of resilience are recoverability, or the capacity to adapt and resume operations following disruptions, and disruption absorption, or the capacity to mitigate the immediate effects of shocks (Burt & Soda, 2021; Ardolino et al., 2024). DCV offers the theoretical underpinnings of the technology and organization mechanisms in the "policy–technology–organization" spiral approach used in this study. This helps to explain how digitalization facilitates organizational restructuring and technical penetration to maintain export performance in the face of external shocks.

3.1.3 Policy-Enabled Capability Framework

This paper proposes a policy-enabled capability model based on institutional theory and dynamic capability approaches to explain the interaction between state-owned enterprises and export resilience building. The state is not just coercive pressure, but an positive force enabling digital transformation in China's manufacturing.

Two broad mechanisms support this role. First one is the government provides digital public goods such as industrial internet platforms, national data infrastructure, and open technical standards created in the regular way through public–private partnerships and accessible to a wide base of businesses (Zhang et al., 2022). another one is that policy incentives such as subsidies, tax relief, and pilot project funding persuade firms to adopt these assets and speed up their digitalization transformations. It is consistent with evidence that public policy support can soundly boost their digital take-up and resilience advantages (Mikalef et al., 2021).

Two complementary frameworks are combined to provide the conceptual foundation for this model. It is based on the input–process–output (IPO) model of Vial (2019), which views digital transformation as a chain in which organizational changes (process) brought about by digital technologies (input) result in improved performance and resilience (output).On the other hand, it adapts the Triple-Helix model initially proposed by Etzkowitz and Leydesdorff (2000), which proposes the recursive relationships between government, industry, and academia as drivers of innovation. This study reformulates the model into a policy–technology–organization helix in the context of Chinese manufacturing that better reflects the institutional realities.

This framework captures a techno-institutional co-evolution process whereby policy interventions enhance firms' digital sensing, agility, and reconfigurability, and successful firms legitimate and entrench policy directions through improved performance and crisis resilience. This aligns with research that government-backed digital infrastructure firms' ability to absorb disruption and recover from shock by improving data availability, platform interoperability, and supply chain coordination (Ardolino et al., 2024).

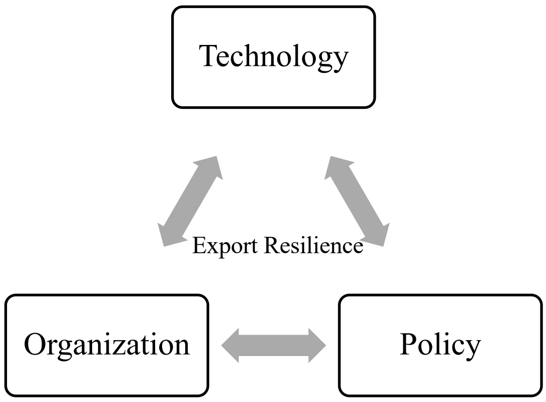

Figure 3.1 The policy-technology-organization triple-helix framework

The effectiveness of this process depends on a firm’s policy conversion efficiency,its ability to integrate external policy support with internal resources and strategies (Burt & Soda, 2021). Differences in ownership and industry positioning influence this integration: state-owned enterprises often display deeper institutional embeddedness, while private firms may combine selective policy alignment with greater autonomy (Warner & Wäger, 2019).

In the policy–technology–organization spiral guiding this research, the policy-enabled capability framework bridges institutional theory, capability theory, and innovation system perspectives. It provides the analytical lens for examining how state-led digital infrastructure shapes firms’ transformation pathways (RQ2) and how these pathways contribute to export resilience (RQ1), particularly through the interaction of policy triggers, technological penetration, and organizational restructuring.

The new literature on china platform-embedded SMEs shows how policy-supported ecosystems can augment data-driven dynamic capabilities and sustainable performance, which is consistent with this conceptualization (Ciampi et al., 2021; Fosso Wamba et al., 2020).

3.2 Research Design

3.2.1 Case Selection

This study employs an exploratory multiple-case study approach with an interpretivist research structure. The approach is suitable to study complex, context-specific processes such as the interaction between digital transformation and export resilience in Chinese manufacturing where controlled experimentation cannot be undertaken. Based on the theoretical sampling rationale (Eisenhardt, 1989; Yin, 2014), the cases were selected that they maximized variation across dimensions pertaining to the research questions with a perspective to maximizing the chance for analytical generalisation.

Three leading Chinese manufacturing firms are selected: Haier Group, Sany, and Zoomlion. Choosing factors includes industry applicability, digitalization maturity, structure of ownership, and globalization etc. Haier operates in the home appliance and IoT sector with mixed ownership and is renowned for mass and early application of industrial internet platforms. Sany is a state-owned construction machinery maker and has heavily invested in proprietary intelligent manufacturing and IoT capabilities. Zoomlion is a state-affiliated builder of construction and farm equipment. And it has integrated digital and green manufacturing solutions into national industrial policy platforms.

Table 3.1 Key descriptive characteristics of the selected cases

Case Firm	Haier	Sany	Zoomlion
Year Established	1984	1994	1992

Industry Sector	Home appliances & IoT	Construction machinery	Construction & agricultural machinery
Ownership Type	Mixed ownership	Private	State-aligned
Key Digital Platforms / Initiatives	COSMOPlat	WitSight; intelligent manufacturing lines	ZValley; AI-enabled agricultural machinery

By design, the aim is not to achieve statistical representativeness but to provides an opportunity to examine diverse organisational trajectories, enabling the identification of potential mechanisms and the contextual factors that may shape their transferability. The multi-case design enables within-case process tracing and cross-case comparison, thereby enabling the identification of converging patterns and divergence in digital capability and resilience-building strategies' development.

3.2.2 Data Collection

This study integrates multiple data sources to triangulate qualitative and quantitative evidence across 2017–2023. This period encompasses the pre-pandemic baseline, COVID-19 disruption, and subsequent recovery phase that overlapped with policy ramping-up under China's 14th Five-Year Plan for Intelligent Manufacturing Development (2021–2025). The year 2017 reflects the consolidation of former industrial digitalization policies like Made in China 2025 and the Industrial Internet Action Plan, while 2023 reflects the latest observable tendencies in digital capacity building and export performance. For the most recent year, certain indicators are incorporated with a descriptive emphasis, reflecting the natural variation in public data availability across sources.

Secondary sources of data were firm archival documents such as annual reports, CSR reports, investor presentations, formal press releases, and product launches. These reports provide longitudinal proof of companies' strategic agendas, streams of technology adoption, and export market outcomes.

Sectoral dynamics were addressed through industry-level data. Specialist reports (household appliances, construction machinery, and agriculture equipment), official trade data, sound news analysis, and market statistics provided by industry associations and customs data from the second tier.

Internal capability construction were got by using structured job postings data collection (2019–2023) from sites(e.g., we can do our best to obtain) like Boss Zhilian, Liepin, and boss etc. We examined digital-associated jobs such as data scientists, cloud architects, industrial internet engineers. And translated job trends as indicators of investment in digital capabilities. For instance, large-scale hiring of "industrial internet platform engineers" could points towards strategic digital transformation.

Internal capability construction was tracked by systematic monitoring of job postings data (2019–2023) from platforms like Boss Zhilian, Liepin, and boss etc. We focused specifically on digital-related positions (e.g., data scientists, cloud architects, industrial internet engineers), from this to observe and conclude employment trends to be evidence of digital skill investment. for instance, the growth in recruitment for "industrial internet platform engineers" signaled certain endeavor for digital transformation.

Finally, secondary academic literature and case studies were reviewed to cross-validate interpretations and position the findings within established theoretical frameworks.

3.2.3 Analytical Workflow

The analytical process followed an abductive logic, moving iteratively between theoretical constructs and empirical evidence to refine emerging explanations. The workflow has three main stages, each supported by specific software environments, data-processing tools, and methodological integrations.

At the initial stage, it conducts qualitative data preparation and coding. Policy documents and related institutional texts were imported into NVivo 14 for structured thematic coding. The core coding corpus is from the 14th Five-Year Plan for Intelligent Manufacturing Development. Additional policy sources which including sectoral guidance documents issued between 2017 and 2023, materials from official government portals, and selected media reports. These were used as supplementary references to contextualize the policy environment and verify the timing of firm-level responses but were not subjected to the same depth of coding. The initial codebook was deductively derived from the “policy–technology–organization” tri-helix model introduced in Chapter 2 and was complemented by inductive codes emerging from the case materials. NVivo’s node frequency and co-occurrence analyses provided a preliminary indication of thematic emphasis, which subsequently informed the selection of high-relevance keywords for quantitative extraction.

According to this, this study use Python libraries such as pandas, jieba for Chinese word segmentation, and NLTK to do text mining and keyword extraction . we obtained annual reports of the three case firms (2017–2023) from official corporate disclosures and verified against commercial databases like Wind. After pre-processing, the report was stripped of non-informative sections (such as disclaimers, boilerplate headlines, and legal notices) and re-presented in a parseable plain text format. Keywords such as digitalization, export trade, and resilience were tokenized, counted, and tracked over time to identify longitudinal trends. Recruitment data were collected from a licensed commercial recruitment database covering major Chinese job platforms and cross-checked with corporate HR announcements where possible. These data were cleaned (duplicate removal, normalization of job titles, segmentation of descriptions) and classified into predefined capability domains (e.g., industrial internet, AI/IoT engineering, cloud infrastructure, green manufacturing), serving as a proxy for digital human capital accumulation. Although 2022–2023 recruitment coverage was somewhat incomplete due to constraints at the platform level, longitudinal trends since 2017 were still legible for capability trend analysis.

Meanwhile quantitative dataset construction integrated firm-level accounting and operational metrics such as export share, R&D share, foreign revenue structure, and low-carbon conformance measures. These derived from company yearly reports, open statistical archives, and sector studies. in a possiable way the figures are validated against commercial databases (i.e., Wind, CSMAR) to rule out inconsistencies and fill missing values. Recruitment data having already been cleaned and classified were stored in Excel files with standardized naming protocols for variables.

During the final stage, it conducted within-case and cross-case analysis. Each case was examined in isolation by using process tracing, and map causal sequences between digital transformation initiatives and export resilience outcomes. Significant events such as platform launches, uptake milestones for technologies, policy inclusion are combined with external shocks such as the COVID-19 pandemic and the EU's regulation on CBAM. what's more, Comparative and temporal comparisons combined qualitative results from NVivo with quantitative statistics through visual analytics within Microsoft Excel and further charting in Python's matplotlib. These included event–timeline mappings, capability growth curves, and cross-case comparison chart formats. The alignment of recruitment patterns, policy coding outputs, and company-specific milestones made it possible to triangulate among digital capability development trajectories, state policy interventions, and export resilience outcome observations.

4. Case Analysis and Findings

4.1 Analytical Framework and Research Logic

This chapter addresses research questions RQ1–RQ4 by theorizing the mechanism pathways through which Chinese manufacturing enterprises build export resilience during their digital transformation. The study adopts a strategy combining single-case embedded analysis with cross-case comparative synthesis, relying on secondary data to systematically deduce and compare findings. This approach ensures the construction of a coherent logical chain and verifiable theoretical propositions even in the absence of primary empirical data.

First, on a theoretical basis, this study develops the *policy–technology–organization* triple-helix model as the overarching analytical framework. The model draws on the triple-helix interaction theory proposed by Etzkowitz and Leydesdorff (2000), adapted to the context of China's manufacturing sector: state-led industrial and digitalization policies (policy helix), firms' internal digital technology applications and innovation trajectories (technology helix), and the organizational restructuring and operational adjustments induced by technological change (organization helix) interact to jointly shape firms' export resilience. This framework enables the identification of the limitations of single-factor drivers and provides an explanation for the compound outcomes generated by multi-element interactions (Etzkowitz & Leydesdorff, 2000; Teece, 2007; Greenwood et al., 2019).

Second, those research design levels take into consideration each case firm as an aggregate analytical case in which four embedded sub-cases are outlined (Yin, 2018): policy triggers, technology penetration, organizational transformation, and resilience outputs.

Third, at the cross-case analysis stage, the study follows the logic of literal and theoretical replication as proposed by Eisenhardt (1989) to inductively identify patterns. Literal replication is applied to detect common results produced by similar mechanisms across different firms, while theoretical replication is used to analyse the reasons for divergences in mechanism pathways under varying contextual conditions. By conducting a horizontal comparison of the mechanism chains in Haier, Sany Heavy Industry, and Zoomlion, the study extracts theoretical propositions that are both generalizable and context-specific.

What’s more, regarding data processing and quality control, the study adheres to the quality standards for non-empirical case research (Yin, 2018; Miles & Huberman, 1994): all analytical variables are defined based on established theories; case facts and mechanism deductions are supported by traceable secondary sources (policy documents, corporate annual reports, industry analyses, academic case studies, and reputable media); competing explanations are incorporated and examined in the reasoning process; the contextual boundaries of the theoretical propositions are explicitly stated in the conclusions. These measures ensure that, even without primary fieldwork, the research maintains logical rigor, transparency, and academic replicability.

On the basis of this framework, the following sections will analyse Haier, Sany Heavy Industry, and Zoomlion as illustrative cases to unpack the resilience-building processes under different mechanism pathways.

4.2 Paths of Dynamic Capability Building

4.2.1 Haier

4.2.1.1 Policy Triggers

Haier’s alignment with China’s national digitalisation agenda has been a deliberate, multi-stage process rather than a set of isolated responses.A clear turning point came in late 2018 with the release of the Industrial Internet Development Action Plan (2018–2020) by the Ministry of Industry and Information Technology (MIIT). This plan set explicit targets for cross-sector platform building and industrial internet applications. Within weeks, Haier’s COSMOPlat was formally listed among the first “dual-cross” platforms recognized at the national level, an endorsement that brought access to government-driven pilot projects and a stronger voice in standard-setting. The recognition was not symbolic: it effectively placed Haier at the center of China’s industrial internet network, opening doors to collaborations across manufacturing sectors. Earlier policy moves had been less directly tied to Haier’s activities. For example, the Guiding Opinions on “Internet Plus Advanced Manufacturing” issued in 2017 outlined the three-pillar industrial internet architecture (network, platform, security), but COSMOPlat’s launch that same year was not yet framed as a direct policy response. By contrast, later initiatives showed a tighter coupling between policy releases and Haier’s actions. Following the Guiding Opinions on Promoting the Digital Transformation of Manufacturing(April 2020), COSMOPlat rolled out multi-industry digital solutions within two months, echoing the government’s call for sector-wide adoption.

In 2021, the *14th Five-Year Plan and 2035 Vision Outline* elevated digitalisation and low-carbon manufacturing to strategic pillars. Haier responded in March with the COSMOPlat upgrade strategy framed as a “Digital + Green” dual-drive. The momentum continued in December, when the *14th Five-Year Plan for Intelligent Manufacturing Development*catalysed the creation of a “lighthouse factory cluster.” Multiple Haier factories entered the World Economic Forum’s Lighthouse Network, enhancing both the company’s brand as a digital manufacturing leader and its ability to transfer advanced practices across global plants.

In 2022 with MIIT's Action Plan for Industrial Internet Innovation Development (2021–2023), Coupling of policy and technology was speed up.Haier took advantage of this to develop the world's first 5G-connected drum-cylinder module production line in Tianjin, a symbol of integration of ultra-low-latency networks with mass-scale customization. Finally, in 2023, the Notice on Speeding Up Manufacturing Digital Transformation pushed the company to expand COSMOPlat's scenarios to more industries such as healthcare and smart energy, a symbol of ambition to export platform capability into its existing appliance market.

A concise policy–response matrix for Haier is presented in Table 4.1, mapping major national-level industrial digitalization and green manufacturing policies issued between 2017 and 2023 to the company’s corresponding milestone actions.

Table 4.1 Policy–Response Events for Haier (2017–2023)

Year	Policy	Direct Response
Jul-2017	New Gen AI Plan	-
Nov-2017	Industrial Internet Guidelines	-
Nov-2018	Industrial Internet Action Plan	COSMOPlat listed
Dec-2019	Smart Manufacturing Plan Summary	Tianjin connected factory
Apr-2020	Digital Transformation Guidelines	Multi-industry solutions
Sep-2020	Dual Carbon Goals	Zero-carbon connected factory
Mar-2021	14th FYP	Upgrade strategy
Nov-2021	14th FYP Intelligent Manufacturing	Lighthouse factory cluster
Feb-2022	Industrial Internet Innovation Plan	5G + COSMOPlat
Apr-2023	Digital Transformation Notice	Scenario-based solutions

4.2.1.2 Technology Penetration

Building on this policy-anchored foundation, Haier’s core technological trajectory revolves around using COSMOPlat as a central hub to advance smart manufacturing, flexible production, and mass customization across its global production network. The platform enables full-chain digital management from user demand sensing, product design, and manufacturing to logistics and delivery, these allows for the rapid adjustment of orders and production capacity in response to external shocks such as trade frictions or logistics disruptions. In the smart home appliance sector, Haier has incorporated AIoT (Artificial Intelligence + Internet of Things) technologies to achieve data interoperability across product lines and enable remote operations and maintenance, thereby enhancing responsiveness and service quality in its transnational operations. This technological penetration extends beyond manufacturing processes to encompass after-sales services and user co-creation communities, ultimately increasing customer stickiness and market adaptability (Zhang et al., 2022; COSMOPlat White Paper, 2023).

4.2.1.3 Organizational Restructuring

Accompanying the diffusion of technology, Haier has implemented the “Rendanheyi” model, which deeply integrates its Global Business Units (GBUs) with localized operational teams, granting frontline teams direct decision-making authority in relation to users and markets. This decentralized, platform-based organizational structure allows Haier to respond swiftly to heterogeneous market demands and regulatory environments. For example, in Southeast and South Asia, Haier has co-established production bases with local partners to enable the localization of technical standards and the on-site sourcing of supply chains; in Europe and North America, it has relied on General Electric Appliances’ (GEA) local R&D and manufacturing networks to strengthen low-carbon compliance and expand its portfolio of intelligent products. This organizational restructuring pathway balances the strategic coherence of headquarters with the operational flexibility of local units (Zhou, 2021; Haier Smart Home, 2022 Annual Report).

4.2.1.4 Export Resilience

Through the combined effects of policy, technology, and organizational mechanisms, Haier’s export resilience demonstrates multi-dimensional strengths. Its export market structure is highly diversified, covering BRI countries, developed economies in Europe and North America, and emerging markets, with balanced regional revenue shares.

During the COVID-19 pandemic and the tariff war, the company maintained steady export share growth by leveraging overseas localized manufacturing and cross-regional resource reallocation. The establishment of lighthouse factories and green supply chains has enabled Haier to proactively address emerging trade barriers such as the EU Carbon Border Adjustment Mechanism (CBAM). Furthermore, the platform-driven model has facilitated the production of customized and high-end products, enhancing the company’s pricing power and brand premium in international markets. This platform-centered resilience pathway not only reflects the global risk management capacity arising from the integration of policy embeddedness and technological platformization but also provides a theoretically generalizable “platform-driven” model for subsequent cross-case comparisons.

A real stress test for Haier’s export resilience came in early 2020, when the COVID-19 pandemic caused lockdowns, transport bottlenecks, and the cancellation of trade events worldwide. These disruptions made it hard for factories, suppliers, and overseas teams to work together in person. Thanks to a 2019 strategic partnership with Liangfengtai (亮风台) on AR smart manufacturing, Haier was able to react quickly. The AR system was first used in the world’s initial “smart + 5G” interconnected factory, it was already supporting more than 50 types of work, from remote equipment repair and on-site assembly guidance to inspection and quality checks, across 15 factories in China and abroad (including Russia, Tianjin, and Qingdao). During the lockdown, Haier extended this system to 39 factories and 123 external suppliers in just two weeks (Liangfengtai, 2020; MIIT, 2020). This allowed engineers to give live instructions, troubleshoot machinery, and keep production lines running even when travel was impossible. At the same time, the COSMOPlat industrial internet platform was adapted into an online channel for overseas customers, using virtual showrooms and AR product demos to keep orders flowing (China Daily, 2020). As a result, Haier not only kept deliveries to key markets like North America and Southeast Asia on track but also achieved a 10.3% increase in overseas revenue in 2020, with online channels contributing over 20% of foreign sales. This case shows how combining platform capabilities with immersive technology and decentralized production helped Haier reduce the shock and hold its market position in a global crisis.

4.2.2 Sany

4.2.2.1 Policy Triggers

Sany Heavy Industry’s digital transformation and export resilience trajectory has been tightly coupled with China’s evolving industrial policies from 2017 to 2023. The earliest relevant shift came in November 2018, when the Industrial Internet Development Action Plan (2018–2020), issued by the Ministry of Industry and Information Technology (MIIT), formally placed cross-industry and cross-domain platforms at the core of manufacturing upgrading (MIIT, 2018). Within one month, Sany launched its Rootcloud platform, which was immediately included in the National List of Pilot Industrial Internet Platforms, marking its entry into China's policy-backed digital infrastructure ecosystem (MIIT, 2018b; People's Daily, 2018). This policy alignment laid the groundwork for subsequent intelligent manufacturing deployments, including the December 2019 designation of its Beijing piling machinery plant as a World Economic Forum Lighthouse Factory, in response to MIIT and NDRC's upgraded intelligent manufacturing agenda (World Economic Forum, 2019; Xinhua, 2019).

In 2020 the pace of policy–response coupling was accelerated. In the wake of MIIT's Guiding Opinions on Supporting the Digitalization of Manufacturing in April 2020 (MIIT, 2020), Sany in September set up a 5G+ industrial internet and digital twin system in its piling machinery factory, incorporating national-level technological priorities into its production (Beijing MIIT, 2020). In the same year China's "Dual Carbon" goals were announced at the UN General Assembly and reaffirmed the strategic importance of low-carbon manufacturing while Sany did not start immediate zero-carbon measures, this signal defined its first actions toward electrification and energy efficiency revamps in subsequent years (UN General Assembly, 2020).

The 14th Five-Year Plan (March 2021) reinforced digitalization, intelligent manufacturing, and green transition as strategic pillars (State Council, 2021). Sany responded in September 2021 by announcing a full value-chain digital transformation roadmap, integrating design, production, and service under a unified data architecture (Sany Heavy Industry, 2021). The release of the 14th Five-Year Plan for Intelligent Manufacturing Development (November 2021) prompted further investment in flexible, automated production systems, culminating in another Lighthouse Factory designation for its piling machinery plant in December 2021 (MIIT, 2021; World Economic Forum, 2021).

In the policy cycle's later phase, the Industrial Internet Innovation and Development Action Plan (2021–2023) issued in February 2022 called for the fusion of 5G and industrial internet technologies (MIIT, 2022). By May 2022, Sany had integrated 5G into Rootcloud to enable predictive maintenance, digital twin simulations, and flexible multi-model production (Beijing MIIT, 2022; Sany Group White Paper, 2022). The most recent policy inflection came with the April 2023 Notice on Accelerating the

Digital Transformation of Manufacturing, which prioritized high-end equipment, green manufacturing, and new energy integration (MIIT & NDRC, 2023). While Sany's formal policy-linked announcements in 2023 were fewer, many of its ongoing electrification projects and low-carbon product launches were aligned with these directives, ensuring that its technological and market expansion strategies remained anchored in the national industrial upgrading agenda (Sany Heavy Industry, 2023).

To complement the narrative analysis, Table 4.2 presents a chronological mapping of key national-level industrial and green manufacturing policies from 2017 to 2023 against Sany Heavy Industry's corresponding strategic responses.

Table 4.2 Policy–Response Events for Sany (2017–2023)

Year	Policy	Direct Response
Jul-2017	New Gen AI Plan	-
Nov-2017	Industrial Internet Guidelines	-
Nov-2018	Industrial Internet Action Plan	Rootcloud listed
Dec-2019	Smart Manufacturing Plan Summary	Lighthouse (Piling)
Apr-2020	Digital Transformation Guidelines	5G + digital twin
Sep-2020	Dual Carbon Goals	-
Mar-2021	14th FYP	Full-chain digitalization
Nov-2021	14th FYP Intelligent Manufacturing	Lighthouse (Piling)
Feb-2022	Industrial Internet Innovation Plan	5G + Rootcloud
Apr-2023	Digital Transformation Notice	-

4.2.2.2 Technology Penetration

Sany's core competitiveness derives from sustained investment in high-end equipment manufacturing technologies and its ability to adapt them to diverse global contexts. Leveraging its industrial internet platform and lighthouse factories, the company has achieved full life-cycle digital management of construction machinery, encompassing remote operations, predictive maintenance, energy consumption monitoring, and intelligent scheduling. This technological penetration has enhanced product reliability under extreme operating conditions and significantly reduced operating costs and downtime risks. In the fields of electrification and green technology, Sany has taken an early lead in developing new-energy construction machinery, including fully electric concrete pumps, excavators, and loaders, combining the use of low-carbon materials with high-efficiency power systems to strengthen competitiveness in high-standard markets such as the EU. Furthermore, its 5G-enabled intelligent manufacturing system and modular production lines allow overseas plants to rapidly replicate core manufacturing processes, thereby ensuring that its global production network retains the capacity for flexible reconfiguration under external shocks (Sany Group White Paper, 2023).

4.2.1.3 Organizational Restructuring

At the firm level, Sany developed a "dual-headquarters" model: headquarters in Changsha supplemented by overseas regional headquarters. The arrangement retains core R&D and manufacturing capabilities domestically while providing great decision-making power to regional markets. Having manufacturing and after-sales services at the local level enhanced market responsiveness significantly. Production hubs and component warehouses established in Germany, Hungary, Indonesia, India, the United States, and Mexico form an in-sync supply–production–marketing cycle that covers most major markets. Such a structure enables Sany to react to regional demand speedily while diversifying dependence on any single supply chain, thereby enhancing geopolitical and tariff-sensitivity risk resilience (OECD, 2022; Sany Heavy Industry, 2022 Annual Report).

4.2.1.4 Export Resilience

Through the synergistic interaction of policy, technology, and organizational mechanisms, Sany Heavy Industry has demonstrated notable strengths in export resilience. Its market portfolio remains highly diversified, with emerging markets consistently accounting for over 60% of total exports, while maintaining stable shares in high-end markets in Europe and North America. Even during downturns in the global construction machinery industry, the company has sustained positive cash flows and stable growth in export revenues. The adoption of electrification and green production technologies has reduced the cost share associated with the EU Carbon Border Adjustment Mechanism (CBAM) to below 3%. Its global service network comprised of 210 overseas parts warehouses and remote operations systems, ensures that equipment operation and customer relations are maintained even under supply chain disruptions. This technology-driven resilience pathway, supported by a global manufacturing and service network, has endowed Sany with strong irreplaceability in responding to international market volatility and offers a theoretically generalizable “technology-led” resilience mechanism for cross-case comparison.

Facing the progressively implemented Carbon Border Adjustment Mechanism (CBAM) and the associated stringent green standards, which posed risks of substantial tariff cost increases and potential market access restrictions, Sany demonstrated a high degree of policy foresight as early as 2021. At the very outset of the EU's CBAM legislative proposal, the company's top management made a rapid board-level decision to launch the "Low-Carbon Export Compliance" (also referred to as "Full Value Chain Low-Carbon Transformation") initiative. A cross-functional task force was established, reporting directly to the Group President's Office, to systematically embed the EU's new regulatory requirements into the entire chain of R&D, procurement, manufacturing, and logistics. As a key early action, in July 2021 the company rolled out the "European Green Channel" program, designating its German plant as a low-carbon export pilot site. This plant was the first to adopt the ISO 14064 greenhouse gas accounting system and to implement energy-saving retrofits in high-consumption processes such as welding and painting.

To address carbon reduction at the source, Sany advanced energy structure optimization in parallel across its European and core domestic export bases, signing long-term green power purchase agreements with local renewable energy suppliers. In 2022, its European plant became the first to achieve 100 % green electricity coverage. The company also introduced traceable low-carbon steel and recyclable materials, substantially reducing the carbon footprint of its manufacturing processes. On the product side, Sany accelerated the development of electric and low-carbon models compliant with the EU's "zero-emission zone" construction requirements, such as electric concrete pump trucks, electric loaders, and hybrid excavators. Low-carbon variants of core export lines like concrete machinery and excavators were launched and successfully passed key green compliance certifications, including the mandatory EU CE mark and the ISO 14067 product carbon footprint certification, ensuring unrestricted market access in Europe.

Supply chain optimization constituted another pillar of Sany's CBAM strategy. The company significantly expanded local sourcing and in-region assembly of key components in Europe, effectively shortening cross-border logistics chains and reducing emissions from transportation. By establishing joint certification systems with European suppliers, Sany ensured the overall green compliance of its supply network while avoiding parts of CBAM's tariff scope. Combined with long-term cooperation agreements with municipal and infrastructure project owners in France and Germany, these measures enabled Sany to secure positions on the supplier lists for several high-standard public works during CBAM's trial phase. Since this systematic and forward-looking deployment, by the time CBAM's trial period began in early 2023, Sany's main export product lines to the EU had all achieved full green certification. Through deep low-carbon transformation across the entire value chain, the company reduced the CBAM-related cost share for these products to below 3 % of total costs. More importantly, Sany successfully converted its green-compliant products into a competitive advantage, achieving steady growth in its market share in Europe's high-end construction machinery segment and winning multiple large-scale project contracts in key markets such as Germany and France. This case clearly illustrates how Sany Heavy Industry, through acute policy insight, comprehensive technological upgrading (spanning energy, materials, and products), and deeply localized supply chain collaboration, turned an emerging green trade barrier into a distinctive competitive edge—strengthening both its market position in strategic regions and its overall "green compliance adaptability" within the global export resilience framework.

4.2.3 Zoomlion

4.2.1.1 Policy Triggers

Zoomlion's trajectory toward export resilience has been firmly anchored in China's evolving green manufacturing and intelligent manufacturing agendas, closely linked to the Belt and Road Initiative (BRI) between 2017 and 2023. The earliest relevant alignment emerged in December 2017, when the Guidelines for the Green Manufacturing System Construction (MIIT, 2017) emphasized eco-design, energy efficiency, and industrial internet integration. Zoomlion's subsequent rollout of its ZValley industrial internet platform in 2018 placed it within the national wave of platform-enabled manufacturing upgrading, aligning with the Industrial Internet Development Action Plan (2018–2020) (MIIT, 2018). This alignment deepened with the company's participation in the Hunan provincial green infrastructure initiative (Hunan SASAC, 2019), enabling early-stage policy–market coupling in both domestic and overseas projects. By 2021, the Industrial Green Development Plan (2021–2025) had formally positioned green transition and carbon reduction as strategic pillars; Zoomlion responded by prioritizing low-carbon product R&D for export markets exposed to tightening environmental regulations such as the EU's Carbon Border Adjustment Mechanism (CBAM) (Zoomlion, 2021 Annual Report; European Commission, 2021).

The pace of policy–response integration accelerated under the 14th Five-Year Plan for Intelligent Manufacturing Development (MIIT, 2021), which called for deep integration of industrial internet, automation, and digital twin systems. Not only did Zoomlion upgrade its Cloud Valley Lighthouse Factory cluster with flexible manufacturing and mixed-model assembly capabilities, but it also embedded AR-based remote maintenance services into its global customer support architecture (Zoomlion, 2022 Annual Report). In 2022, the Industrial Internet Innovation and Development Action Plan (2021–2023) (MIIT, 2022) reinforced the mandate for fusing 5G with industrial internet platforms. By mid-2022, 5G connectivity had been integrated into ZValley OS, enabling predictive maintenance, cross-factory resource scheduling, and simulation-based production optimization. The April 2023 Notice on Accelerating the Digital Transformation of Manufacturing further elevated high-end equipment, green manufacturing, and new energy integration as national priorities—objectives that Zoomlion translated into accelerated electrification programs, AI-enabled agricultural machinery, and autonomous driving platforms for export deployment (Zoomlion, 2023 Annual Report).

Organizationally, Zoomlion has answered such requirements by adopting a "global R&D collaboration + localized manufacturing" strategy. Its assembly centers and R&D centers in Italy, Belarus, and Southeast Asia have localized procurement and certification systems that minimize lead time for CBAM compliance and market access. At the domestic level, headquarters works closely with organizations in policy-making, participating in the trial of the Hunan Green Manufacturing Industry Chain Leader System (Hunan SASAC, 2024), which pools upstream–downstream resources to promote standards setting and expand market coverage. The structural adjustment is instrumental in translating policy incentives into tangible international competitiveness rapidly, an efficiency not enjoyed by all counterparts in the industry.

With this tightly interwoven policy–technology–organization nexus, Zoomlion has achieved a few resilience advantages. Its share in the EU high-end construction machinery market has cumulatively risen, and green-certified items have represented an escalating proportion of exports. Incorporating AR remote service capabilities and a worldwide distributed spare-parts system has maintained order fulfillment rates at high levels during pandemic-era supply chain dislocations. Moreover, domestic manufacturing in strategic locations eliminates CBAM compliance cost without compromising brand visibility in carbon-sensitive markets. Emerging product lines, particularly AI-driven agricultural machinery and autonomous equipment, which are not merely supplementary but have become primary growth engines, positioning Zoomlion's "policy-embedded green transition" pathway as a distinct model in the comparative analysis to follow.

To provide a structured overview of the policy–response dynamics, Table 4.3 lists major national and provincial policy signals between 2017 and 2023 alongside Zoomlion's corresponding strategic and technological actions.

Table 4.3 Policy–Response Events for Zoomlion (2017–2023)

Year	Policy	Direct Response
Jul-2017	New Gen AI Plan	-
Nov-2017	Industrial Internet Guidelines	-
Nov-2018	Industrial Internet Action Plan	Zhongke Cloud Valley launch
Dec-2019	Smart Manufacturing Plan Summary	Smart Industry City construction
Apr-2020	Digital Transformation Guidelines	MOM system launch
Sep-2020	Dual Carbon Goals	-
Mar-2021	14th FYP	Smart Industry City progress
Nov-2021	14th FYP Intelligent Manufacturing	Digital transformation benchmark
Feb-2022	Industrial Internet Innovation Plan	5G + AI construction
Apr-2023	Digital Transformation Notice	"Empowering Ten Thousand Enterprises" project

4.2.2.2 Technology Penetration

On the technological front, Zoomlion leverages its self-developed ZValley industrial internet platform and the Cloud Valley Lighthouse Factory cluster to integrate digital capabilities into the R&D, manufacturing, and service processes of its agricultural, construction, and engineering machinery divisions. Key applications include an AR-based remote operations and maintenance system providing real-time technical support and diagnostics for global customers; intelligent production lines capable of flexible manufacturing and mixed-model assembly; and diversified low-carbon product portfolios tailored to different international market standards, such as AI-enabled agricultural machinery, autonomous driving platforms, and electric-powered construction equipment. This technological penetration enables the firm to meet diverse policy and customer requirements in export markets, reduce operating costs and delivery lead times, and significantly enhance the international competitiveness of its products (ZValley OS Technical Report, 2023).

4.2.1.3 Organizational Restructuring

Under the dual impetus of policy mandates and technological upgrading, Zoomlion has restructured its international operations framework. The company has adopted a “global R&D collaboration + localized manufacturing” model, establishing R&D and assembly centers in Italy, Belarus, and Southeast Asia, along with local procurement and certification systems to accelerate market entry in key export destinations. Domestically, its headquarters has strengthened coordination with policy-making bodies, for instance by participating in the Hunan provincial “green manufacturing industry chain leader system” pilot program, which integrates upstream and downstream resources through a provincial-level industrial chain platform to advance standard-setting and market expansion. This organizational restructuring not only improves resource allocation efficiency but also accelerates the conversion of policy dividends into international market competitiveness (Hunan SASAC, 2024; Zoomlion, 2022 Annual Report).

4.2.1.4 Export Resilience

Through the synergistic interaction of policy, technology, and organizational mechanisms, Zoomlion has achieved multiple advantages in export resilience. Its market share in the EU’s high-end construction machinery segment has grown steadily, accompanied by a continuous rise in the share of green and low-carbon products. The combination of AR remote services and a global spare parts network has allowed the company to maintain high order fulfillment rates during the pandemic and international logistics disruptions. Localized production and green certification in key export markets mitigate CBAM-related compliance costs. Emerging product categories, notably AI-driven agricultural machinery and autonomous equipment, are now drive export growth, with accelerated expansion establishing them as primary revenue catalysts. This pathway, which begins with policy embeddedness, is driven by technological implementation and underpinned by organizational coordination, enabling Zoomlion to convert macro-level policy dividends into international competitive advantages and producing a resilience output model distinct from the other cases. The next section presents a cross-case comparison that systematically examines the differences among the three companies in technological penetration, policy conversion efficiency, and organizational adaptability.

During the 2018–2019 U.S.–China trade frictions(under its Section 301 investigation)imposed substantial tariffs on Chinese construction machinery those were including concrete pump trucks and cranes,that directly raising Zoomlion’s export costs and causing delays or cancellations of certain orders (USTR Section 301 List). Confronted with this sudden external shock, the company rapidly deployed a board-level response plan, implementing a coordinated strategy that integrated supply chain geographic reconfiguration, product compliance upgrading, and market diversification. First is that Zoomlion leveraged KD assembly facilities in Belarus and Southeast Asia to shift production and assembly of U.S.-bound products offshore, thereby reducing tariff exposure from direct exports out of China. While using localized certification to shorten delivery lead times. Second,the company swiftly introduced low-emission versions of truck cranes, concrete machinery, and engineering equipment, Passed relevant safety and environmental certifications in the United States to ensure continued market access. Third, it intensified marketing and bidding efforts in Latin America, the Middle East, and Southeast Asia, with a strong emphasis on securing infrastructure project contracts in Belt and Road emerging markets to spread risk away from a single market. The systematic execution of these measures effectively alleviated tariff-related export pressures and provided a solid foundation for maintaining the company's international operations amid heightened trade barriers (Zoomlion Annual Report, 2021).

4.3 Cross-case Mechanism Comparison

4.3.1 Technological Penetration

Anchored in the measurement logic outlined in 2.1.3 (technological depth, policy responsiveness, and ecosystem embeddedness), this subsection compares the three firms across: (i) the cross-industry adaptability and policy recognition of their industrial-internet platforms, (ii) overseas localized technology application, and (iii) intelligent-manufacturing benchmarking.

Across the dimension of technological penetration, the three companies display notable differences in the cross-industry adaptability of their industrial internet platforms, the localization of technology applications overseas, and their achievements in intelligent manufacturing benchmarking. Haier, leveraging its COSMOPlat (COSMO Platform), holds a leading position in cross-industry deployment. As of September 2024, the platform covers 15 major industries including home appliances, clothing, automobiles, chemicals, molds, and energy, serving more than 160,000 companies. Initially launched in 2017 with a focus on Haier's internal appliance factories, COSMOPlat expanded rapidly after 2020 into sectors such as apparel, automotive, and chemicals, and further deepened multi-industry applications in 2023–2024 through the "Tianzhi Industrial Large Model."

In comparison, Sany Heavy Industry’s ROOTCLOUD platform, although recognized by the MIIT as a national “dual-cross” platform and equipped with cross-industry service capabilities, remains primarily concentrated in equipment manufacturing–related verticals (e.g., machinery, steel, textiles). Public disclosures emphasize capabilities rather than overall client counts, consistent with a more domain-focused breadth. Zoomlion’s ZValley OS platform, by contrast, focuses on vertical integration within its core construction-machinery business and extends into agricultural machinery and smart-agriculture scenarios; it has also obtained “dual-cross” recognition, but its cross-industry expansion remains more selective relative to COSMOPlat.

In overseas localized application of technology, Haier employs its industrial internet capability to promote localized production within its overseas network of factories and establishes a replicable model for the application and transfer of platform-based technology. And Sany Group has established overseas intelligent manufacturing bases in Indonesia, India, the United States, Germany, and so on. It has replicated core Lighthouse Factory technologies such as sorting automation, robotic welding, and digital twin application in multiple places and built a close global after-sales/service and spare parts network, compressing localization cycles. To support intelligent assembly and market customization, Zoomlion has built 11 bases of production and a service/spare parts network of over 200 warehouses across eight countries through its "end-to-end, digital, and localized" direct sales model.

In global intelligent manufacturing benchmarks, Haier has over one World Economic Forum Global Lighthouse Factories (the highest number in China), and there are two heavy machinery Lighthouse Factories at Sany. For Zoomlion World Economic Forum Lighthouse Factory certification has not been achieved. Indicators of Lighthouse Factories are also an indicator of the depth of digital manufacturing and the scope of external recognition of a firm's technical incursion.

Table 4.4 Cross-case Comparison of Technological Penetration Capabilities

Dimension	Haier	Sany	Zoomlion

Industrial Internet Platform Industry Coverage	COSMOPlat covers 15 industries; 160k enterprises served; MIIT dual-cross platform	ROOTCLOUD on MIIT national lists; multi-industry service ability but equipment-centric	ZValley OS recognized as MIIT dual-cross; cross-scenario ambitions (mfg/agri/smart-city/fintech)
Overseas Localized Technology Application	Platform-enabled localization across global plants (case evidence)	Global footprint with industrial bases outside China; dense after-sales (900+ service sites; 900+ parts warehouses)	11 overseas production bases in 8 countries; ~210 service & spare-parts warehouses；“end-to-end, digitalized, localized”
Number of Lighthouse Factories (2023)	9	2	0

Source: Compiled from company annual reports, platform white papers, the MIIT “dual-cross platform” list, and the World Economic Forum Lighthouse Factory certification announcements.

Overall the platform of haier has the widest industry coverage and the best cross-industry adaptability. Sany Heavy Industry has the highest technological maturity to replicate localized intelligent manufacturing, particularly in the heavy equipment sector, rendering it highly irreplaceable. Zoomlion's vertical industry aggregation and direct sales mode facilitates customer loyalty and demonstrates its potential for green transformation and localized standardization. The size of these Lighthouse Factories further highlights Zoomlion's unique competitive space in market-driven technology adoption, Sany Heavy Industry's scarcity value for special industry, and Haier's technological penetration system benefit (see Table 4.4).

4.3.2 Policy Conversion Efficiency

This section addresses Research Question 2 (RQ2): to what extent, and through which mechanisms, state-led digital infrastructure shapes the digital transformation pathways of firms.

Building on the case narratives in Section 4.2, we first present a panoramic view of major national digitalization and green manufacturing policies issued between 2017 and

2023, alongside the corresponding milestone responses of Haier, Sany, and Zoomlion. Figure 4.1 visualizes this policy–response timeline, making explicit the heterogeneous speed and strategic focus of corporate actions: Haier tended to respond within the same year through platform-based initiatives (e.g., COSMOPlat upgrades); Sany embedded its responses mainly in technology localization and electrification projects; and Zoomlion concentrated on green manufacturing line transformations. This broader policy landscape provides the contextual foundation for the subsequent, more focused analysis.

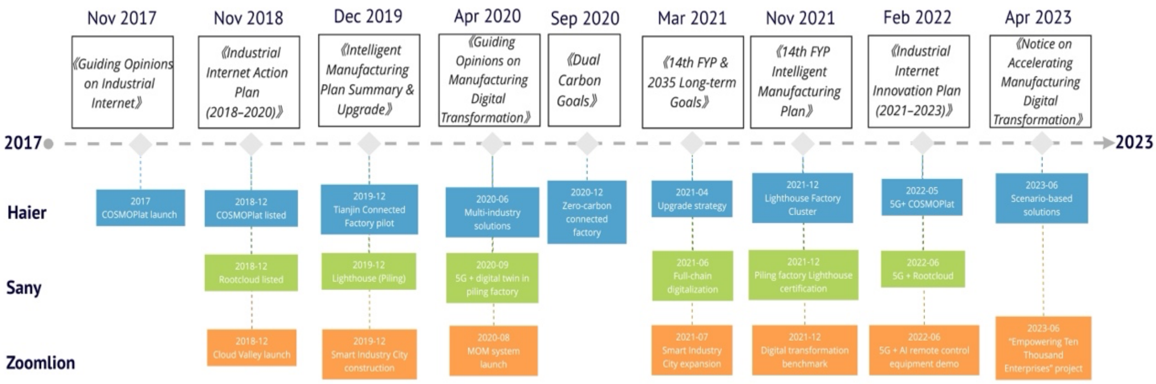

Figure 4.1 Three firms’s policy–response timeline

Against this background, the following analysis applies the three-layer theoretical framework introduced in Chapter 2 and the comparative strategy outlined in Chapter 3, using the policy orientation of the 14th Five-Year Plan for Intelligent Manufacturing Development as a representative case for in-depth examination. It builds on three mechanism categories extracted from NVivo coding(Technological Trajectories, Policy Response Mechanisms, and Organizational Adaptation) ,supplemented by multi-source evidence including keyword frequency data from annual reports, job postings, and industry coverage (see Figure 4.2 and Table 4.5). In the visualization, the area of each rectangle reflects the frequency with which the corresponding node appears in both policy documents and corporate reports, thereby providing a quantitative basis for subsequent comparison.

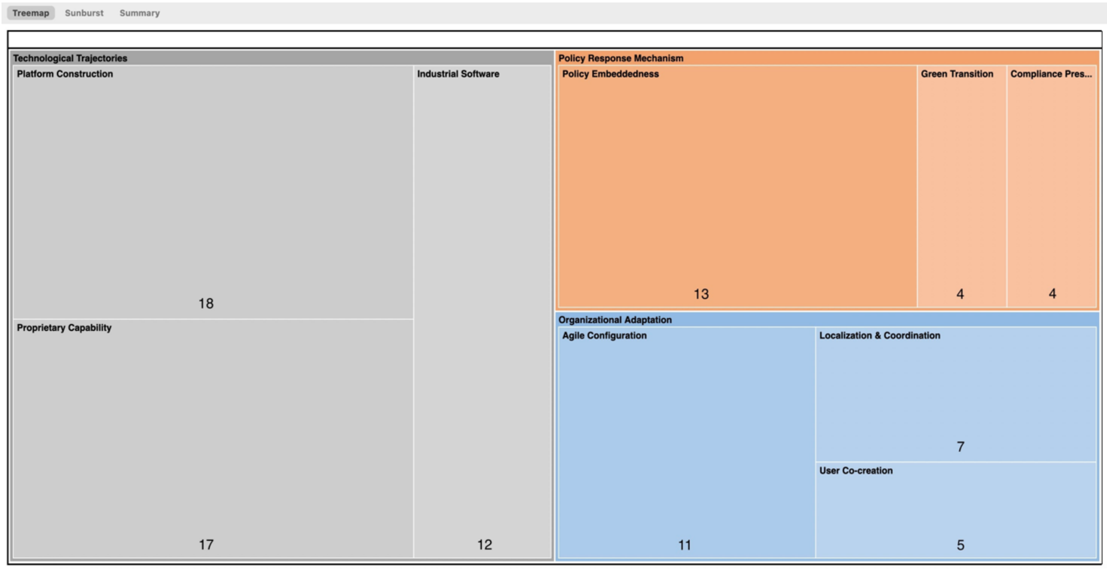

Figure 4.2 Tree map of coding results for the 14th FY

Table 4.5 NVivo coding results for the 14th FY

Organizational Adaptation	23
Agile Configuration	11
Localization & Coordination	7
User Co-creation	5
Policy Response Mechanism	19
Compliance Pressure	4
Green Transition	4
Policy Embeddedness	13
Technological Trajectories	47
Electrification	0
Industrial Software	12
Platform Construction	18
Proprietary Capability	17

Analysis of keyword matches for the three policy-related mechanism categories reveals substantial differences in policy conversion efficiency among Haier, Sany, and Zoomlion. These differences are not only evident in the speed and depth of policy signal absorption but also in the diffusion pathways and strategic emphases of each firm.

Haier's policy conversion displays a clear "platform-driven" orientation. or instance, following the 2017 launch of the New Generation Artificial Intelligence Development

Plan, Haier accelerated COSMOPlat deployment, and in November 2018 the platform was selected among the first batch of MIIT-certified cross-industry industrial internet platforms (MIIT, 2018). In 2020, in response to the national dual-carbon policy, Haier integrated low-carbon modules into COSMOPlat smart factory standards. Its highest-frequency keywords are concentrated in terms such as “platform” (321 occurrences), “smart home” (213), “COSMO” (75), and “COSMOPlat” (20), all of which are closely linked to the industrial internet and user co-creation. This pattern indicates that Haier relies on platform ecosystems and standardized mechanisms as its core modes of policy absorption and diffusion. Haier appears 95 times under the "Policy Embedding" node, higher than Zoomlion (32 times) and second only to Sany Heavy Industry (80 times). Haier uses the COSMOPlat platform to quickly transform policy signals into platform ecosystem rules and supply chain participation standards. This mechanism is particularly visible in the high-frequency application of industrial internet standards and user co-creation (combined keyword frequency exceeding 280), which enables the efficient absorption of institutionalized, standardized policy requirements. However, the relatively low frequency for “green transition” (40) compared to Zoomlion (130) suggests that Haier’s conversion of low-carbon and environmental policy signals relies more on external partners rather than on a fully self-developed closed-loop technological base.

Sany Heavy Industry’s pathway aligns more closely with a “technology localization-led” model. Notably, in November 2018 Sany launched the RootCloud industrial internet platform in alignment with MIIT’s industrial internet guidelines, and in 2021 initiated large-scale electrification of excavators to meet EU Stage V emissions standards. Results in Figure 4-8 show a pronounced dual focus on internationalization and technology, with high-frequency keywords such as “international” (257 occurrences), “overseas” (129), “new energy” (99), “electrification” (96), and “India” (50) forming peaks in both *localization and coordination* (505) and *electrification* (195). Although its “green transition” frequency (17) is lower than Zoomlion’s, the high concentration in electrification (195) and localization (505) enables its policy embeddedness score (80) to translate rapidly into alignment with green transition objectives. The extremely low frequency for “compliance pressure” (1) suggests that the company tends to meet policy requirements proactively through pre-emptive technological upgrades (e.g., EU emissions standards, photovoltaic power supply, full electrification of product lines), thereby avoiding reactive compliance. The core logic of this pathway can be summarised as “technical standards as policy”: by synchronizing proprietary technology development with localized production capacity, Sany pre-emptively locks in market access conditions and mitigates the risk of policy volatility.

Zoomlion follows a “policy-embedded green transition” model. For example, in 2020 it launched the ZValley OS industrial internet platform and in 2021 commissioned the Green Manufacturing Lighthouse Factory in Changsha as part of Hunan Province’s ‘industry chain leader system’ pilot.Its high-frequency keywords such as “R&D” (374 occurrences), “green” (96), “new energy” (65), “carbon” (33), and “carbon emissions” (26),which are directly aligned with green manufacturing and form the backbone of its policy conversion strategy. On both “green transition” (130) and “compliance pressure” (26), Zoomlion scores significantly higher than Haier and Sany, with its policy-related keywords concentrated on green manufacturing, carbon emission reduction, and adaptation to international standards. Leveraging initiatives such as the Hunan provincial “industry chain leader system” pilot and responding to external policy pressures like CBAM, Zoomlion has embedded policy signals directly into production line upgrades and intelligent manufacturing solutions, enabling rapid-cycle implementation of green manufacturing policies. This model demonstrates high sensitivity and responsiveness to policy changes, but relatively limited institutionalized and platform-based conversion outside the green domain.

From a mechanism-structure perspective, Haier, Sany, and Zoomlion's differences in policy conversion efficiency are not an unadulterated strength–weakness continuum along one dimension. Instead, they arise from different combinations of three essential factors: policy embeddedness, green transition, and compliance pressure. Overall Haier achieves a policy absorption advantage through high institutional embeddedness and platform extension. Sany minimizes policy lag risk through timely adoption of technology and domestic production capability. Zoomlion converts policy pressures into direct green manufacturing technology drivers and line conversion.

Table 4.6 Keyword frequency distribution for core policy-related mechanism nodes across the three firms

Main Category	Sub Category	Haier	Sany	Zoomlion
Organizational Adaptation	Agile Configuration	19	46	2
	Localization& Coordination	8	505	140
	User Co-creation	285	0	2
PolicyResponse Mechanism	Compliance Pressure	68	1	26
	Green Transition	40	17	130
	Policy Embeddedness	95	80	32

Technological Trajectories	Electrification	2	195	65
	Industrial Software	11	38	71
	Platform Construction	321	78	28
	Proprietary Capability	21	23	392

Table 4.6 summarises the distribution of high-frequency keywords across the policy-related mechanism nodes for the three firms, further corroborating these differentiated pathways.The differentiated logic of policy conversion demonstrates that even under an identical national policy framework, firms can formulate distinct digitalization pathways based on their resource endowments and strategic positioning. This finding provides a mechanism-level explanatory basis for the organizational mechanism comparison presented in the next section.

4.3.3 Organizational Mechanism Comparison

This section addresses Research Question 3 (RQ3), focusing on how the three companies restructure their organizational mechanisms to achieve resilience transitions in the face of external shocks. Unlike the previous section on "Policy Conversion Efficiency," this analysis does not examine the process of responding to external policy signals but instead centers on the internal capacity-building and structural adjustment pathways within each firm. The analytical benchmarks are threefold: (i) an examination of the 2019–2021 recruitment structure (see Appendix B) and the keyword-based job category charts (Figures 4.3 and 4.4) to reveal differences in organizational adaptability and talent allocation across the firms. Given that recruitment data for 2022–2023 are incomplete (due to non-retrievable records from certain job platforms), the comparative analysis focuses primarily on 2019–2021, supplemented by qualitative updates; (ii) narrative evidence from annual reports and authoritative media coverage documenting organizational reforms, department creation/merger, and management process reengineering; and (iii) analysis of how cross-departmental collaboration and digital platforms permeate organizational processes.

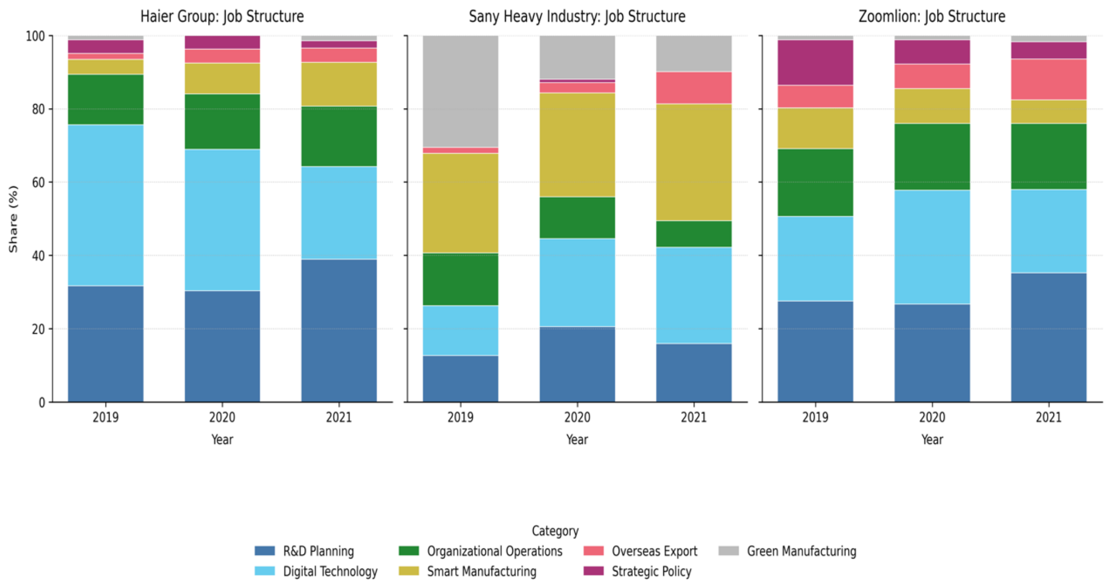

Figure 4.3 Proportion of job categories in annual recruitment

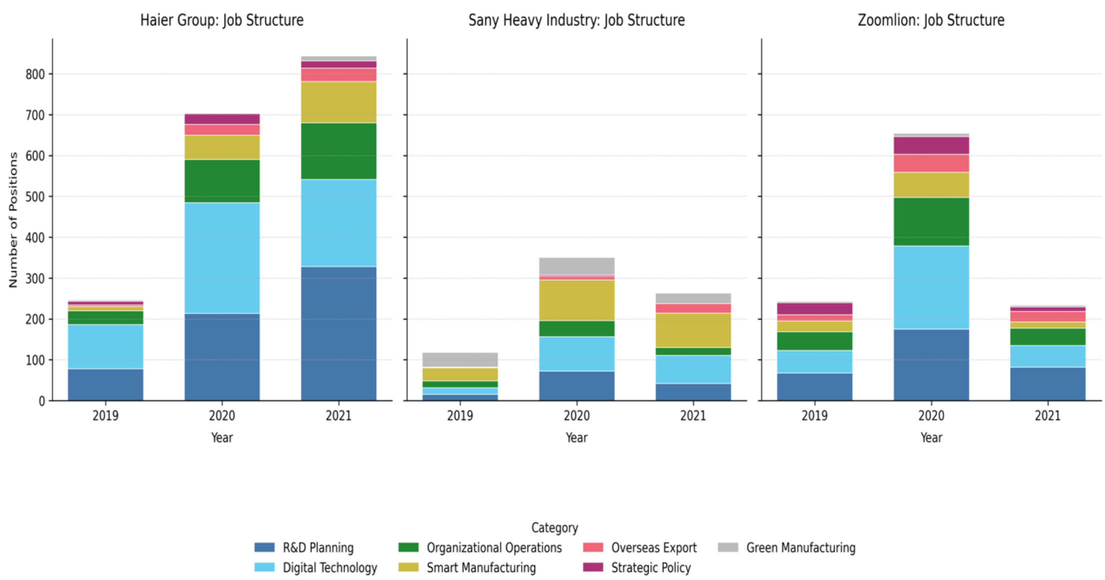

Figure 4.4 Annual recruitment totals by job category

Figure 4.3 (percentage-stacked chart) presents changes in the proportion of each job category relative to annual total recruitment during the observation period, allowing a direct visual comparison of capability priorities at different stages. Figure 4.4 (absolute stacked chart) provides annual totals per category, offering a more accurate view of differences in recruitment investment scale.

(1) Haier Group: Platform-Based Flexible Cross-Department Collaboration Haier's organizational restructuring revolves around the COSMOPlat platform, integrating

R&D, digital technology, and operations roles to form a dual-layer architecture of "platform + micro-enterprises." In 2019–2021, R&D planning and digital technology positions together accounted for over 65% of total recruitment (75.6% in 2019; 63.6% in 2021), reflecting sustained investment in technology and platform operations. Smart manufacturing and organizational operations roles increased notably in 2020–2021 (operations rising from 11.8% in 2019 to 16.5% in 2021), indicating the growing need for process and resource coordination within platform operations. Since abolishing its traditional hierarchy in 2018, Haier has divided into over 4,000 "micro-enterprise units," supported by COSMOPlat as a unified technology and data middleware. The integration of global R&D resources such as the incorporation of Candy and GEA teams into the platform, has reinforced the "user demand to R&D" closed loop, reducing functional silos and accelerating market responsiveness.

(2) Sany Heavy Industry: Manufacturing–Service Functional Integration Sany's organizational adjustments focus on an integrated "manufacturing + services" model, connecting production, operations, and markets in real time via its RootCloud industrial internet platform. From 2019 to 2021, smart manufacturing roles maintained a high share (27.1% in 2019; 32.0% in 2021), digital technology roles remained stable at 20–25%, and organizational operations roles held at around 15%. Overseas export and green manufacturing roles both increased in 2020–2021, aligning with its global localization and low-carbon manufacturing strategies. Following the relocation of headquarters to Beijing in 2018, Sany reorganized its international business division into three major regional commands: Asia-Pacific, Europe–North America, and Africa. In 2021, it established a Lighthouse Factory Division to replicate intelligent manufacturing standards across 13 overseas plants and vertically integrated procurement and production functions, enabling unified supply chain scheduling and reduced cycle times. This has resulted in a three-tiered structure of "headquarters R&D—regional operations centers—localized production bases."

(3) Zoomlion: Policy-Embedded and Cross-Industry Chain Coordination Zoomlion's restructuring pathway emphasizes policy alignment and full-industry-chain coordination, integrating R&D, manufacturing, and market functions through the ZValley industrial internet platform and Cloud Valley Lighthouse Factory cluster. In 2019–2021, R&D planning and digital technology positions together accounted for 45–50% of total recruitment, notably lower than Haier and Sany, indicating a more balanced allocation between technical and non-technical roles (green manufacturing roles reached 12.3% in 2020). Strategic policy roles consistently held a higher share than in the other two firms (12.3% in 2019; 6.6% in 2020), reflecting deep engagement with local governments, industry associations, and international standards bodies. Since

2020, the company has implemented an “end-to-end” direct sales system, eliminating international agency layers, establishing regional headquarters around “aerotropolis” hubs, and splitting major business units such as aerial work machinery and earthmoving machinery into independent divisions. Green manufacturing capabilities have been embedded into divisional workflows, enabling compliance and competitiveness under CBAM and other green trade barriers.

(4) Cross-Case Comparison Each of the three firms has intensified its digital technology and R&D capabilities in recruitment structures, but their paths are different significantly. Haier's de-hierarchized, platform-architecture design enables highly distributed structural designs; Sany's centralized headquarters regime and standardized manufacturing regime build a globally integrated production network on its foundation; Zoomlion combines a divisional structure with green manufacturing to intensify localized responsiveness and compliance capabilities by a direct sales system.

The combined analysis of Figures 4.3 and 4.4 shows that Haier maintains the highest and most stable proportional investment in technology and platform-related roles; Sany exhibits the most pronounced growth in smart manufacturing roles; and Zoomlion displays the most balanced distribution between technical and non-technical categories.

Table 4.7 Frequency of recruitment positions in Haier, Sany, and Zoomlion (2019–2023) by keyword-matched category

Dimension	Haier	Sany	Zoomlion
R&D Planning	759	143	344
Digital Technology	690	199	341
Organizational Operations	399	82	210
Smart Manufacturing	231	223	110
Overseas Export	82	39	88
Strategic Policy	69	3	85
Green Manufacturing	21	104	18
Total	2251	793	1196

Table 4.7 (Comparison of the total recruitment position structure of the three case companies from 2019 to 2023, categorized by matching keywords) provides an overview of the raw data analyzed in this section. Considering that the data of some enterprises in 2022-2023 is incomplete, the table only explains the data source in the main text, and the detailed job extraction method is shown in Appendix X.

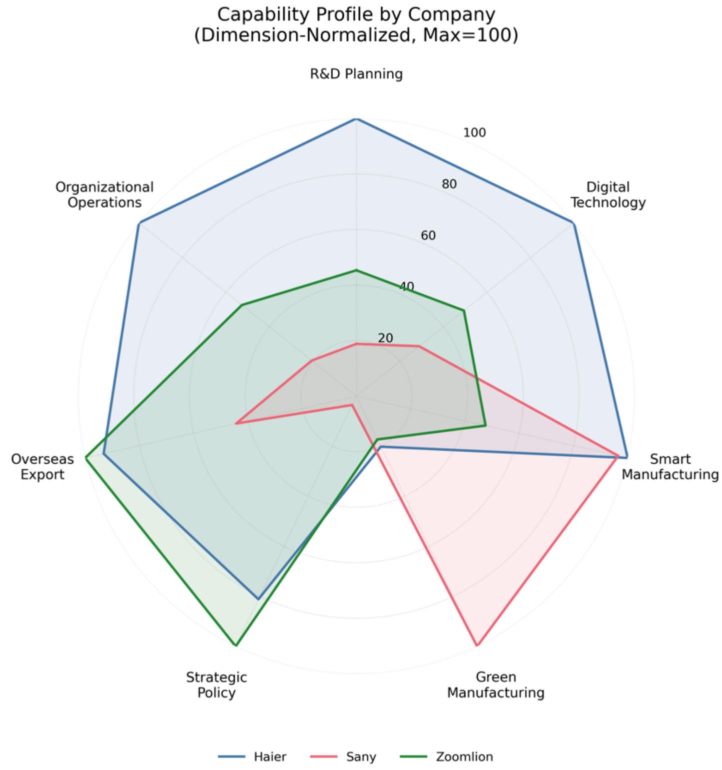

Figure 4.5 Capability Profile by Company

In order to visually present the comparative advantages and structural differences of the three case enterprises in the construction of organizational mechanisms. Figure 4.5 presents a normalized radar chart based on 2019–2021 recruitment data (classified into seven job categories), designed to visualize the relative strengths and structural differences in organizational mechanisms across the three firms. The normalization method sets the maximum value within each job category across the three firms to 100, with the others scaled proportionally, thereby removing the influence of absolute size and emphasizing structural orientation.

The results show marked differences in configuration profiles:Haier reaches maximum values (100) in R&D planning, digital technology, and organizational operations, forming a “technology–operations” dual-peak structure; overseas export and strategic policy roles remain relatively high, reflecting flexible cross-department collaboration enabled by de-hierarchization and platform operations. Sany approaches or reaches maximum values in smart manufacturing and green manufacturing, highlighting the prominence of its manufacturing–services integration and low-carbon strategies; however, its strategic policy and R&D planning shares are lower, suggesting greater reliance on standardized technology and operational efficiency. Zoomlion reaches peaks in strategic policy and overseas export, with green manufacturing at mid-to-high levels; technical roles are evenly distributed without extreme advantages, indicating an emphasis on policy embeddedness and full-chain coordination rather than concentration in a single technical capability.

Comparing with stacked bar charts (Figure 4.2 absolute values; Figure 4.3 percentages), Haier is the highest in absolute recruitment quantity but focuses structurally on technology and platform roles; Sany is middle in volume but concentrates on production and green capabilities; Zoomlion has the lowest recruitment volume but holds incomparable strengths in policy and foreign sides.This trend is supported by previous sections' qualitative findings: differences in ownership structure, industry positioning, and market strategy bring about differing capability configurations, even under similar conditions of digital transformation investment, resulting in different evolutionary paths of organizational adaptation mechanisms.

4.4 Export Resilience Comparison

Building on the preceding mechanism analysis, this section combines objective indicators with typological comparison to systematically evaluate the export resilience of Haier, Sany Heavy Industry, and Zoomlion under scenarios of external shock. The evaluation framework follows the classification of resilience types established in the literature review of Chapter 2, distinguishing *absorptive*, *restorative*, and *transformative* resilience, and validates them using indicators such as export share trends from 2017–2023, speed of recovery, and the depth of strategic adjustments implemented during crisis periods. For comparability, we treat 2019 as the common pre-shock baseline and 2020 as the shock year; “export share” is proxied by the overseas revenue share (overseas revenue / total revenue). In this chapter we implement a parsimonious ordinal comparison aligned with Section 2.2.3 (See Figure 4.6; the year-by-year series are provided in Appendix C.)

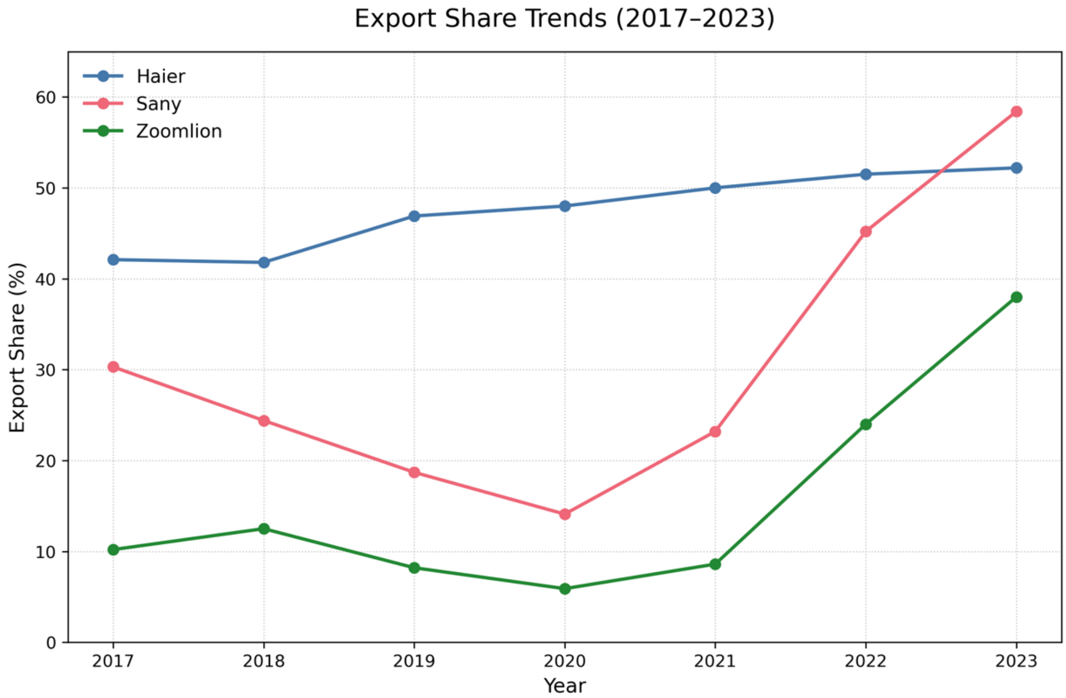

Figure 4.6 Export share trends (2017–2023)

In terms of export share trends, the three companies exhibit differentiated trajectories under varying shock conditions. Haier maintained a generally steady upward trend over seven years, rising from 42.1% in 2017 to 52.2% in 2023; even amidst the logistics disruptions of 2020, the overseas share dipped only modestly to around 48%, then rebounded above 50% in 2021–2023. This stability aligns with Haier's long-standing localized manufacturing footprint (e.g., Pakistan industrial park; Egypt ecological park inaugurated in 2024) and with the COSMOPlat platform used for end-to-end supply-chain orchestration, which is listed by China's MIIT among the "cross-industry, cross-domain" industrial internet platforms.

By contrast Sany experienced the sharp decline between 2017 and 2020 (from 30.3% to 14.1%), but recovered to 45.2% in 2022 and even higher at 58.4% in 2023. it shows a classic "V-shaped" recovery. The rebound is consistent with Sany's global layout and dense after-sales/service network: 16 Chinese industrial bases abroad, 900+ foreign service outlets, and 912 part depots. and with the launch of remote operations (e.g., 5G tele-remote excavators promoted since 2019/2021), which helped revive production and expand market share when the demand returned.

Zoomlion displayed the greatest early volatility, with export share falling from 10.2% in 2017 to 5.9% in 2020, but achieving sustained growth over the following three years to 38.0% in 2023. The improvement coincided with: (i) accelerated overseas capacity and localization (11 overseas production bases across 8 countries and around 210 service and spare-parts warehouses, per company disclosures); and (ii) product upgrading toward intelligent/green offerings and deeper presence in the EU alongside emerging economies.Taken together, these three trajectories in Figure 4.6 provide the factual basis for the ordinal comparison that follows.

Bridge to ranking. Overall, Haier remained stable during the shock year and then trended upward mildly (a steady/absorptive pattern); Sany declined first and then rebounded rapidly with the steepest repair slope (fast recovery); Zoomlion first fell and then rose, accompanied by structural turns toward greening and localization. Accordingly, we provide an ordinal ranking (rather than numerical scoring) based on these observed trajectories(see Table 4.8). The ordering follows three transparent criteria applied to the observed series and verifiable disclosures: (i) stability of export share (volatility and whether 2020 fell below the 2019 baseline); (ii) magnitude and speed of from 2020 to 2023 recovery; and (iii) evidence of structural reconfiguration during/after the shock. Specifically, Haier's absorptive strength stems from risk exposure reduction through diversification and localization prior to shock onset; Sany's restorative advantage lies in its capacity to rapidly recover and even surpass pre-shock performance; and Zoomlion's transformative capacity is evident in converting policy pressures (e.g., EU-facing green requirements, CBAM context) into product upgrading, localization, and market restructuring within relatively short cycles. In absorptive resilience, Sany's sharp 2017–2020 dip (despite clear stabilization after 2021) and Zoomlion's largest volatility/lowest trough place them behind Haier; in restorative resilience, Haier scarcely needed "recovery" in 2020 (having not fallen below the 2019 baseline), while Zoomlion's 2020→2023 rebound, though sizable, proceeded with a slower repair slope than Sany's—hence both trail Sany; in transformative resilience, Haier's path reflects incremental optimization rather than a directional reconfiguration toward EU-facing green/low-carbon upgrades and localization pivots, and Sany's emphasis lies in rapid recovery rather than structural reconfiguration—both therefore rank below Zoomlion. To visualise the relative profiles, Figure 4.7 plots a rank-based radar chart derived from Table 4.8 (ordinal ranks: 3 = highest, 1 = lowest). The radar is a qualitative summary of the ordinal ranking.

Table 4.8 Resilience typing and ranking (3=strongest, 2=medium,1=weakest)

Company	Absorptive Resilience	Restorative Resilience	Transformative Resilience
Haier	3	2	1
Sany	2	3	1

Zoomlion	1	2	3

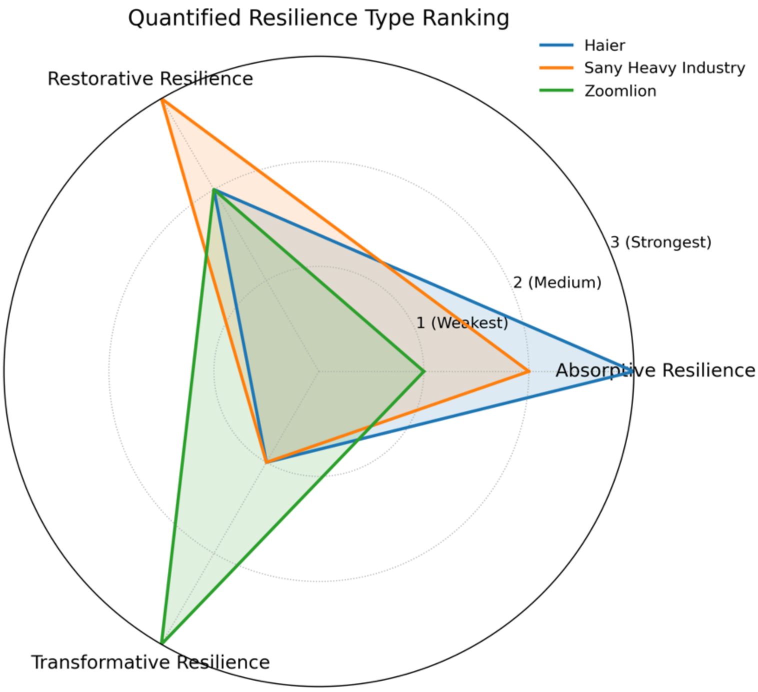

Figure 4.7 Rader chart of ordinal resilience ranking

4.5 Summary

This chapter has systematically analysed the digital transformation pathways and export resilience-building processes of three representative Chinese manufacturing firms—Haier, Sany Heavy Industry, and Zoomlion—within the "policy–technology–organization" triple-helix framework. Through the structured sequence of "policy triggers–technology penetration–organizational restructuring–resilience outputs," Section 4.2 identified three differentiated pathways: the platform-driven model of Haier, which leverages the industrial internet and a globally localized layout to achieve high levels of absorptive and transformative resilience; the technology-led model of Sany, centered on the industrial internet, intelligent manufacturing, and electrification, which strengthens restorative and absorptive resilience; and the policy-embedded model of Zoomlion, which integrates green manufacturing with policy and standards to form a pathway primarily characterized by restorative resilience.

The cross-case mechanism comparison in Section 4.3 revealed clear complementarities and trade-offs among technological penetration, policy conversion efficiency, and organizational adaptability. The platform-driven pathway excels in the synergy between technology and organizational restructuring; the technology-led pathway performs strongly in overcoming key bottlenecks and building technological irreplaceability; and the policy-embedded pathway demonstrates significant advantages in standards adaptation and compliance cost control. These findings directly address RQ1, concerning the heterogeneity of digital transformation mechanism pathways, and RQ2, regarding the role of state-led digital infrastructure in shaping such pathways.

In the export resilience performance comparison of Section 4.4, export share trends and the resilience-type radar chart provided visual validation of the observed mechanism differences. The results indicate that Haier maintains a relatively balanced advantage across all three resilience types, with the highest score in transformative resilience; Sany performs most strongly in restorative resilience, enabling rapid output recovery from short-term shocks; and Zoomlion holds advantages in policy-driven low-carbon compliance and restorative resilience but remains comparatively weaker in absorptive resilience. These performance characteristics suggest that different mechanism combinations not only shape the type of resilience a firm develops but also determine its mode of response and sustainable competitiveness under external shocks. This analysis provides empirical support for RQ3.

Besides, cross-case evidence confirms the explanatory path outlined in RQ4 for ownership structure and positioning industry. Technology-enabled and platform-led paths are more common in firms with strong penetration into global markets and strong market-oriented features, whereas policy-embedded paths are more suitable in firms with strengths in specific policy environments and value chain segments. This distinction implies that effective resilience-generating models depend, not only on the internal capability configuration of a company, but also on the congruence between the external institutional environment and industry characteristics.

5. Conclusion

5.1 Summary of Key Findings

Against the backdrop of global trade fragmentation and tightening international regulatory regimes, this study examines how Chinese manufacturing enterprises build export resilience through digital transformation. Adopting an interpretivist multi-case research design, and applying the "policy–technology–organization" triple-helix analytical framework, it conducts in-depth analyses of three representative firms—Haier, Sany Heavy Industry, and Zoomlion—corresponding respectively to platform-driven, technology-led, and policy-embedded digital transformation pathways. The research focuses on how these differentiated strategic configurations foster resilience in the face of external shocks such as the COVID-19 pandemic, rising trade protectionism, and the European Union's Carbon Border Adjustment Mechanism (CBAM).

First, the findings show that export resilience arises from the interaction between external institutional triggers and internal capability reconfiguration. While earlier research has a tendency to focus on technology adoption or organizational adaptation as one driver of resilience (Dubey et al., 2023; Zhao et al., 2023), this paper identifies that in policy-dense contexts, national digital infrastructure policies and industrial policy designs not only provide institutional incentives and outside resources but also help to shape the direction and pace of dynamic capability development itself. This effect is most evident in the policy-embedded pathway, where compliance requirements are transferred into competitive advantages in green product markets.

Second, cross-case analysis identifies three alternative configurations of digitalization–resilience. The absorptive resilience of Haier's platform-model, based on the COSMOPlat industrial internet ecosystem and global user co-creation mechanisms, facilitates the company to absorb shocks in demand and keep its export growth momentum. Sany's technology-model, which is focusing on intelligent manufacturing, product electrification, and localized global factory configurations. it is restorative in resilience, restoring production and market share within a short period after being disordered. Zoomlion's green transformation strategy through policy is a low-carbon production integrated with the Industrial Internet platform, practicing transformation resilience by reorienting its export product line in value-added directions.

Third, it shows how the three resilience types differ in their performance. The qualitative mechanism analysis is empirically validated by quantitative trends such as export share, entrying emerging markets, compliance capabilities. Between 2017 and 2023, all three companies' reliance on exports grew, but the size and consistency of these gains differed depending on their organizational adaptation and digital strategies.

Overall the findings offer direct answers to the four research questions set before. RQ1 is answered through cross-case mapping of policy stimuli, technology diffusion, and recombination activities of companies. RQ2 is also reflected in national policy agenda effects on the scope and pace of capability building.RQ3 is illuminated by the diverse profiles of the three forms of resilience. RQ4 is indirectly suggested by heterogeneity of strategies observed in a consumer-goods multinational, a capital-intensive equipment producer, and a policy-sensitive heavy machinery producer.

5.2 Theoretical Contributions

This study makes several interrelated theoretical advances in the fields of digital transformation and export resilience.

First, it extends the contextual application of dynamic capabilities theory (Teece, 2007) to policy-driven environments. Existing research typically assumes that firms' abilities to sense, seize, and transform derive primarily from market competition pressures and technological change (Dubey et al., 2023; Bag et al., 2022). In contrast to the Western market-centric assumption, the Chinese context demonstrates that capability evolution can be directly triggered and accelerated by policy agendas and institutional coordination, reflecting the techno-institutional co-evolution perspective outlined in the literature review. In the context of China's state-led manufacturing digitalization, this study finds that the external policy environment is not merely a provider of resources and institutional incentives but also a direct trigger and accelerator of capability development. For example, Zoomlion's green manufacturing capabilities rapidly emerged under the combined impetus of the EU's Carbon Border Adjustment Mechanism (CBAM) and China's "dual carbon" targets. This finding resonates with the perspective of *Dynamic Capabilities for Digital Transformation*, which emphasizes that institutional frameworks can reshape both the direction and the pace of dynamic capability formation, thereby expanding the boundaries of dynamic capabilities theory to non-market-oriented contexts.

Second, the study deepens the understanding of institutional embeddedness in shaping export resilience. Institutional embeddedness theory (Vahlne & Johanson, 2017; Peng et al., 2008) posits that a firm's position within external institutional networks determines its access to resources, information flows, and strategic room for maneuver.

While Western studies often examine embeddedness in relatively stable, market-oriented institutional environments, this research shows that in China's dynamic policy ecosystem, differences in policy translation efficiency become a decisive factor shaping resilience pathways—again underscoring the techno-institutional co-evolution logic identified earlier. This research reveals that differences in policy translation efficiency directly influence resilience pathways: platform-oriented firms (e.g., Haier) leverage institutional embeddedness and platform diffusion to maximize policy dividends; technology-led firms (e.g., Sany) rely on standardization and localized manufacturing to mitigate policy lag risks; policy-driven firms (e.g., Zoomlion) convert compliance pressures into green technology upgrades and high-end market access. This conclusion aligns with empirical evidence from *Economic Policy Uncertainty and Enterprise Export Resilience in China*, which shows that digital capabilities can buffer external shocks and create export advantages in high-policy-uncertainty environments, while this study further uncovers the interaction between institutional embeddedness pathways and digitalization pathways.

Third, the study indicates a "digitalization-driven resilience typology framework" that directly relates absorptive, restorative, and transformative resilience to specific digital transformation pathways. While literature has defined these types of resilience (Christopher & Peck, 2004; Brandon-Jones et al., 2014), few of them have done so systematically for digital transformation mechanisms. By comparing three representative manufacturing firms, this study establishes a robust mapping—platform-driven pathways to absorptive resilience, technology-led pathways to restorative resilience, and policy-embedded pathways to transformative resilience—and validates this linkage using export share trends and organizational mechanism characteristics. This framework is consistent with the argument in Digital Transformation and Supply Chain Resilience that different digitalization logics yield differentiated resilience under crisis conditions, while offering a mechanism-based explanatory foundation.

In addition, the study integrates the "policy–technology–organization" triple-helix into a unified analytical framework, advancing a mechanism-based explanation for export resilience generation in emerging economy contexts. Cross-case comparisons demonstrate that resilience performance is co-shaped by policy translation efficiency, technology penetration depth, and organizational adaptability, with dynamic interaction among these elements rather than independent operation. This result aligns with the OECD Supply Chain Resilience Review's focus on the policy-market-technology coupling, although this study takes further the manner in which this coupling is performed in organizational processes at the firm level.

Finally, from a methodological perspective, this research combines nested single-case analysis with cross-case pattern matching to trace the interaction between external shocks, digital transformation pathways, and resilience outputs. Although multiple-case designs are widely applied in organizational management research (Yin, 2018), few empirical studies have linked external institutional triggers to internal capability processes. Drawing on the methodological recommendations in *Developing a Process Model for Digital Transformation*, this study applies such an approach for the first time to the field of export resilience, validating its applicability in manufacturing sectors of emerging economies, and thereby extending the methodological toolkit for studying complex mechanism interactions.

5.3 Policy and Managerial Implications

This study not only deepen the theoretical understanding of the relationship between digital transformation and export resilience but also offer actionable insights for policymakers and corporate managers. In today's global manufacturing landscape which characterized by overlapping uncertainties including geopolitical conflicts, rising trade protectionism, tightening carbon regulations, and supply chain restructuring—forward-looking policy and managerial strategies have become essential to sustaining and enhancing export resilience.

At the policy level, policymakers are required to further promote digital infrastructure and cross-border data governance in order to lay a stable and foreseeable institutional environment for the digital transformation of manufacturing enterprises. The OECD Supply Chain Resilience Review indicates that broad coverage of digital infrastructure and interoperable cross-border data flows are prerequisites for diversification and agility in the supply chain. For this purpose in the context of China, this would not just imply accelerating industrial internet platform, 5G private network, and cloud computing system development, It also means accelerating the signing of digital trade agreements, mutual data security recognition, and coordination of green certification standards with Belt and Road partner countries, thereby minimizing institutional frictions that limit export resilience.

Following this, industrial policy must break free from technology investment subsidy in isolation to "technology–market–organization" synchronized differentials. Deloitte's 2025 Manufacturing Industry Outlook points out that future competitiveness of manufacturing will rely not only on technological innovation, but also on firms' globalization positioning within value chains and organizational adaptability. The triple-helix analysis in this study shows that policy resources are strongest effectively when they are situated based on firms' technological penetration ability and organizational adaptability. It is thus recommended that government programs(e.g., targeted subsidies and tax credits) include conditions assessing international market presence, environmental compliance capability, and organizational reorganization intentions to ensure incentives under policy address the key drivers of resilience improvement.

In addition, policymakers should actively guide and support the low-carbon transformation of manufacturing to address the ongoing escalation of international green trade barriers. *The Future of Industrialization* report underscores that green transformation is becoming a core competitive dimension for industrialization in emerging economies. For export-oriented manufacturers, low-carbon compliance is not merely a defensive response but a passport to high-end markets. Evidence from this study's cases shows that when green manufacturing capabilities are combined with digital capabilities, firms can not only meet CBAM and similar regulatory requirements but also capture brand premiums through green products and transparent carbon footprint reporting. It is therefore recommended that governments establish multi-tiered green manufacturing certification systems and promote cross-border joint R&D in low-carbon production technologies to form compliance standards broadly recognized by international markets.

For corporate managers, the comparative analysis in this research highlights the strategic significance of differentiated digital transformation pathways. Platform-driven firms should deepen the integration of industrial internet ecosystems with user co-creation models, leveraging network effects to enhance market shock absorption. Technology-led firms should focus on standard setting and localized manufacturing to strengthen rapid recovery capabilities, while also using digital tools to improve supply chain visibility and forecasting accuracy. Policy-embedded firms need to proactively convert regulatory pressure into innovation momentum, aligning green technology upgrading with market expansion initiatives. Regardless of pathway, all firms should recognize the combinatorial effects of digital technologies rather than deploying them in isolation. For instance, the coordinated application of cloud computing, artificial intelligence, and big data analytics has been proven across all three cases to be a key driver of resilience enhancement, whereas blockchain's potential in transparency and compliance traceability depends heavily on its deep integration with other technologies.

Finally, firms should actively reposition themselves within global value chains to better leverage the structural advantages of their supply chain networks. Heavy centrality in the network supports access to information and resources during crises, and bridging gaps in structures enables gaining non-redundant information and knowledge across fields. The approach used in this study relies on both case studies and the policy recommendations for supply chain network optimization suggested by the OECD Supply Chain Resilience Assessment. to sustain their innovativeness and competitive resilience in advanced disruptions, companies can decentralize their production and R&D nodes outside of their immediate environment to create a diverse customer and supplier base, and connect these nodes via sophisticated digital platforms to strengthen coordination.

5.4 Study Limitations

Although a number of limitations must be openly stated, this study contributes to a theoretical and practical literature on how digital transformation can increase export resilience in China's manufacturing industry. Such contextual-methodological constraints, which have been set by reference to background conditions, threshold levels of data availability, and study design decisions, also serve to detail promising lines for future inquiry.

Three production archetypes: Haier, Sany Heavy Industry, and Zoomlion. They are the specific empirical targets of our research. Whilst systematic process tracing and cross-case analysis are facilitated by the multi-case strategy, its external validity is necessarily compromised. The processes and paths to developing resilience might be different for small and medium enterprises (SMEs), companies in other industries, or companies with less digital maturity than those represented herein.

The study mostly uses secondary data sources, such as industry white papers, policy documents, annual reports, and credible media coverage. Although triangulation and dependability are guaranteed by this method, data granularity is inherently constrained. Some performance dimensions relied more on qualitative evidence because some of the quantitative indicators suggested in the analytical framework, such as the precise length of crisis recovery periods, specific changes in the geographic composition of exports, and precise proportions of low-carbon compliance costs, could not be obtained in a fully comparable form across the three firms.

The analysis is situated within China's policy environment, where institutional embeddedness is strongly shaped by a state-led digitalization agenda. This differs substantially from market-driven or hybrid governance contexts in other countries. As The Future of Industrialization and OECD Supply Chain Resilience Review note, the dynamic between digital transformation and resilience is varied depending on infrastructure maturity levels, trade integration levels, and regulatory frameworks. It is therefore with trepidation that the findings of these reports will be applied to other contexts, considering institutional diversity.

The 2017–2023 period marks a period of unprecedented volatility in global commerce, during which the COVID-19 pandemic, increasing protectionism, and accelerated low-carbon transformation have created a space of simultaneous shocks. Such concurrent shocks provide a unique stage on which to observe resilience mechanisms but may also mean that the postulated mechanisms are idiosyncratic to the era. Observation over stable and unstable periods longitudinally would allow for testing whether the mechanisms persist and are flexible.

Finally, the research approach will combine policy–technology–organization triple-helix with pattern matching, which could identify mechanisms by not drawing on formal quantitative modeling in identifying causal effects. This is consistent with the mechanism- and interpretivist-centered emphasis of the research but leaves space for follow-on research to operationalize constructs such as policy conversion efficiency, technological penetration depth, and organizational adaptability, and to statistically estimate them from larger samples or mixed-method designs.

5.5 Directions for Future Research

Expanding these constraints, several routes are left open to advance theoretical awareness and empirical coverage in realizing export resilience in the era of digitalization.

To facilitate practical validation of the relevance and adjustment strategies for the policy-technology-organization triple helix mechanism in resource-constrained conditions or industries less affected by policy, the scope of analysis can be extended to small and medium-sized enterprises (SMEs), service-intensive manufacturing sub-sectors, and organizations with lower digital maturity.Following the cross-national strategies outlined in The Future of Industrialization and the OECD Supply Chain Resilience Review, comparate with different ownership structures and foreign companies can also highlight the moderating role of institutional environments.

Developing more fine-grained and longitudinal datasets would enable more precise measurement of resilience performance indicators. While this study relies on robust secondary sources, access to firm-level operational metrics such as detailed post-shock recovery times, disaggregated export destination data, and quantified low-carbon compliance cost ratios, these would support stronger causal inference. Such data could facilitate mixed-method or panel econometric tests of constructs like “policy conversion efficiency” and “technological penetration depth,” which are presented here qualitatively.

More focus can be placed on the connection between digitalization and the reconfiguration of the global value chain (GVC). According to Deloitte's Manufacturing Industry Outlook and Risks and Resilience in Global Trade (OECD, 2023), nearshoring, regional production clusters, and supplier diversification are altering the structural conditions for export resilience.It would be possible to show how differences in GVC structure impact the effectiveness of digital resilience strategies by comparing Chinese manufacturing companies with case comparisons to other significant export economies like Germany, South Korea, and Mexico.

The theoretical model would also beexpanded by tapping into the knowledge of absorptive capacity theory (Zahra & George, 2002), network embeddedness theory (Granovetter, 1985; Zaheer & Bell, 2005), and adaptive governance. Future studies can examine how companies dynamically shape internal digital investments and external network positions to co-produce resilience, though this study demonstrates how a state-led digital infrastructure strategy configures companies' competencies. While simulation or agent-based modeling may test mechanisms for various policy and technological futures, longitudinal qualitative research may monitor how such alignment develops over the course of several external shocks.

Policy studies could also focus on how trade competitiveness and resilience building can be balanced in regulatory design.Green trade measures such as the CBAM may be discussed not only as compliance matters but also as potential drivers of export diversification towards low-carbon niches. This requires integrating findings from international trade law, industrial policy, and technological innovation, in accordance with the OECD Supply Chain Resilience Review and recent scholarship on policy–technology coupling in industrial change.

Acknowledgments

When more and more near the date of thesis conclusion confirmation, I just noticed this date before my 25th birthday for 4 days. 25, this age is in the prime of my life. And it had already been 7 years since I left my hometown. Looking back on the time I completed my undergraduate thesis 3 years ago, I didn't feel much sadness about leaving rather a sense of anticipation and drive for the future. To avoid feeling lost, I desperately sought an internship at a prestigious company. While interning, I also wrote my thesis and studied for the IELTS. Ultimately, I was fortunate to receive 7 offers from top universities. That year, I always believed in hard work and perseverance, wanting to take a gap year to explore what kind of work I truly enjoyed. After my internship, I made my life filled of work. I took a job at a state-owned enterprise, took on part-time teaching, and anxiously prepared my study abroad applications. when I am typing the words "Acknowledgments" on my keyboard now, I suddenly realize time flies that this moment formally marks my farewell to my student years.

Firstly I would like to express my sincere gratitude to my supervisor professor Luigi Benfratello. Thank to his guidance I successfully completed my thesis proposal and writing. Looking back on our conversation in November 2024, he told me to have an open mind. It remains vivid in my mind. Whenever I faced difficulties related to cultural differences or issues in project groups, his advice naturally surfaced. These words have proven far more valuable than the thesis itself. It inspired me to observe and reflect on life with greater depth, becoming a lasting asset in my personal growth. My first class abroad was economics. That course not only marked the beginning of my two-year studying journey, also ignited a profound internal transformation. From initial setbacks and self-doubt to gradual self-reflection like language use, learning adjustments, and deeper understanding of cultural gap. It was through overcoming one challenge after another that I learned to build methodologies and to grow through adversity. I regained the confidence to navigate my study and life.

I am grateful to my parents, my aunt, and my grandparents etc. I understanded what a blessing it is to have family’s support. Over these past years in my life, it is precisely their constant presence as my strongest pillar that has enabled me to keep pushing my limits, to refuse stagnation, and to keep moving forward.

I would also like to thank people I’ve met along my way who from diverse backgrounds. They have constantly expanded my worldview and dissolved former boundaries. The people and events around me have become sources of new knowledge. I’ve learned to keenly notice stuffs that merit repeated reflection in each experience, to store them in

my mind, to chew on them, digest them, and ultimately internalize them into my understanding. Every experience has contributed to my self-betterment. Now I know myself better Objectively. What are my weaknesses? what are my strengths, What kind of person am I? These have propelled me to grow continuously through course projects, life events, and tough challenges.

And finally, I thank all the thorny challenges and stressful-inducing trials of life, both that I have already faced and those still waiting for me. They have shaped the person I am and will continue to keep pushing me forward. I know that right now there are countless versions of “me” are still standing at campus gates: the bright-eyed 18 yo, the wind-blown sleeves of 22 yo, and somewhere in the flowing crowds, I see my 25 yo self taking root. She will pass through all seasons lined with thorns, turning every scar into a new branch, until the barren land blooms with an untamed spring. My life will witness countless golden eras, and I will never stop moving forward.

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Appendices

Appendix.A Keyword Frequency Statistics in Annual reports(2017–2023)

Keyword Frequency Statistics in Zoomlion Annual Reports (2017–2023)

Keyword	2023	2022	2021	2020	2019	2018	2017	Total
研发 (R&D)	94	64	62	44	40	39	31	374
绿色 (Green)	34	21	18	10	6	5	2	96
布局 (Layout)	8	10	14	10	9	9	6	66
新能源 (New Energy)	27	22	11	5	0	0	0	65
一带一路 (Belt and Road)	5	6	6	5	7	8	10	47
智能工厂 (Smart Factory)	15	9	4	4	5	2	4	43
碳 (Carbon)	8	4	21	0	0	0	0	33
大数据 (Big Data)	7	6	2	5	1	1	4	26
碳排放 (Carbon Emission)	9	7	8	1	1	0	0	26
国际化 (Internationalization)	3	5	1	2	6	4	2	23
工业互联网 (Industrial Internet)	3	2	2	5	5	4	1	22
乡村振兴 (Rural Revitalization)	5	4	7	1	1	1	1	20
自主研发 (Independent R&D)	7	6	3	2	0	0	0	18
标准制定 (Standard Formulation)	2	1	2	0	0	2	0	7
智慧工地 (Smart Construction Site)	3	2	0	0	0	0	0	5
十四五 (14th Five-Year Plan)	0	0	3	2	0	0	0	5
新兴市场 (Emerging Markets)	1	0	0	0	1	2	0	4
一体化解决方案 (Integrated Solutions)	1	1	0	0	0	0	0	2
远程运维 (Remote Maintenance)	0	0	0	0	0	0	2	2
绿色施工 (Green Construction)	1	0	0	0	0	0	0	1
智能建造 (Intelligent Construction)	0	1	0	0	0	0	0	1
数字化产线 (Digital Production Line)	0	1	0	0	0	0	0	1
产业链生态 (Industry Chain Ecosystem)	0	0	0	0	0	1	0	1
Total	233	172	164	96	82	78	63	888

Keyword Frequency Statistics in Haier Annual Reports (2017–2023)

Keyword	2017	2018	2019	2020	2021	2022	2023	Total
平台 (Platform)	44	56	53	54	50	31	33	321
智慧家庭 (Smart Home)	15	26	45	46	32	29	20	213
卡奥斯 (COSMOPlat)	0	0	8	22	16	17	12	75
碳 (Carbon)	5	7	3	1	10	22	20	68
绿色 (Green)	0	3	5	3	4	11	14	40
场景方案 (Scenario Solutions)	0	0	4	3	9	7	8	31
共创 (Co-Creation)	4	5	3	1	1	3	3	20
COSMOPlat (COSMOPlat)	9	10	1	0	0	0	0	20
定制化 (Customization)	4	2	3	2	2	1	3	17
智能产品 (Smart Products)	2	0	2	6	0	2	0	12

Keyword	2017	2018	2019	2020	2021	2022	2023	Total
5G (5G)	0	0	4	2	4	0	0	10
自主研发 (Independent R&D)	1	1	0	1	1	2	1	7
灯塔 (Lighthouse)	0	0	3	1	3	0	0	7
本地化 (Localization)	0	0	3	0	2	1	1	7
柔性 (Flexibility)	1	0	0	1	2	2	0	6
流程再造 (Process Reengineering)	0	0	0	1	3	0	1	5
智能场景 (Smart Scenarios)	2	0	0	0	0	1	0	3
自研 (Self-Developed)	0	1	0	0	0	0	1	2
电动 (Electric)	0	0	0	1	0	1	0	2
用户主导 (User-Led)	0	0	0	0	0	1	0	1
双品牌战略 (Dual-Brand Strategy)	0	0	0	1	0	0	0	1
数字孪生 (Digital Twin)	0	0	0	0	1	0	0	1
快速响应 (Quick Response)	0	0	0	0	1	0	0	1
Total	87	111	139	144	141	131	117	870

Keyword Frequency Statistics in Sany Annual Reports (2017–2023)

Keyword	2017	2018	2019	2020	2021	2022	2023	Total
国际 (International)	27	37	33	35	50	51	24	257
海外 (Overseas)	13	15	12	11	22	24	32	129
新能源 (New Energy)	2	12	11	14	14	13	33	99
电动化 (Electrification)	0	1	1	5	36	39	14	96
印度 (India)	8	6	6	7	9	10	4	50
灯塔工厂 (Lighthouse Factory)	0	0	0	10	10	12	9	41
智能制造 (Intelligent Manufacturing)	4	3	4	3	6	10	7	37
协同 (Collaboration)	2	3	2	6	9	8	3	33
基建 (Infrastructure)	2	6	6	4	3	2	4	27
自动化 (Automation)	1	4	1	4	3	4	2	19
本土经营 (Local Operations)	0	0	0	3	4	6	5	18
本地化 (Localization)	3	0	0	2	3	5	5	18
高质量发展 (High-Quality Development)	0	0	3	2	2	2	8	17
一带一路 (Belt and Road)	7	5	5	0	0	0	0	17
工业软件 (Industrial Software)	0	0	6	6	6	3	1	16
矿山 (Mining)	2	6	5	1	1	0	0	15
数字化转型 (Digital Transformation)	1	0	6	3	4	0	0	14
无人驾驶 (Autonomous Driving)	0	4	1	1	3	2	2	13
SCM (SCM)	1	3	3	1	1	0	0	9
绿色 (Green)	0	0	0	0	1	2	4	7
智能检测 (Intelligent Inspection)	0	1	1	1	1	1	1	6
客户云 (Customer Cloud)	0	0	1	2	1	1	1	6
远程遥控 (Remote Control)	0	1	1	2	0	0	1	5
碳中和 (Carbon Neutrality)	0	0	0	1	1	1	2	5
智能化产品 (Intelligent Products)	0	0	0	0	1	1	2	4

Keyword	2017	2018	2019	2020	2021	2022	2023	Total
数据驱动 (Data-Driven)	0	0	0	1	2	1	0	4
十四五 (14th Five-Year Plan)	0	0	0	3	1	0	0	4
MES (MES)	0	1	1	1	1	0	0	4
节能环保 (Energy Conservation & Environmental Protection)	0	1	1	0	0	0	1	3
数字化设计 (Digital Design)	0	0	0	1	1	1	0	3
数字化仿真 (Digital Simulation)	0	0	0	1	1	0	0	2
智慧园区 (Smart Industrial Park)	0	0	0	1	0	0	1	2
光伏发电 (Photovoltaic Power Generation)	0	0	0	0	0	1	1	2
国六 (China VI Emission Standard)	0	0	0	1	0	0	0	1
Total	73	109	104	134	197	201	165	983

Appendix.B Recruitment data classification summary (2017-2023)

Year	R&D & Planning	Digital Technology	Organizational Operations	Smart Manufacturing	Overseas Export	Strategic Policy	Green Manufacturing	Annual Total*
Haier								
2019	78	108	34	10	4	9	3	246
2020	213	271	106	59	27	26	0	702
2021	328	213	139	101	33	17	12	843
2022	73	56	68	46	6	9	5	263
2023	67	42	52	15	12	8	1	197
Total	759	690	399	231	82	69	21	2251
(2022 and 2023 platform data incomplete)								
Sany								
2019	15	16	17	32	2	0	36	118
2020	72	84	40	99	10	3	42	350
2021	42	69	19	84	23	0	26	263
2022	2	2	1	1	1	0	0	7
2023	12	28	5	7	3	0	0	55
Total	143	199	82	223	39	3	104	793
(2022 data from Platform 4 only; 2023 data from Platform 4 and 75 only)								
Zoomlion								
2019	67	56	45	27	15	30	3	243
2020	175	203	119	62	44	43	8	654
2021	82	53	42	15	26	11	4	233
2022	—	—	—	—	—	—	—	—
2023	20	29	4	6	3	1	3	66
Total	344	341	210	110	88	85	18	1196
(2023 data incomplete: only from Platform 13 and 75; 2022 recruitment data missing)								

Appendix.C Export revenue and proportion (2017-2023)

Haier			
Year	Total Rev. (bn CNY)	Overseas Rev. (bn CNY)	Export Share (%)
2017	159.25	67.1	42.10%
2018	183.32	76.7	41.80%
2019	200.76	94.1	46.90%
2020	209.73	100.62	48.00%
2021	227.56	113.73	50.00%
2022	243.51	125.43	51.50%
2023	261.43	136.42	52.20%
Sany			
Year	Total Rev. (bn CNY)	Overseas Rev. (bn CNY)	Export Share (%)
2017	38.34	11.62	30.30%
2018	55.82	13.63	24.40%
2019	75.67	14.17	18.70%
2020	100.05	14.10	14.10%
2021	106.87	24.85	23.20%
2022	80.82	36.57	45.20%
2023	74.02	43.26	58.40%
Zoomlion			
Year	Total Rev. (bn CNY)	Overseas Rev. (bn CNY)	Export Share (%)
2017	23.27	2.37	10.20%
2018	28.70	3.59	12.50%
2019	43.31	3.57	8.20%
2020	65.11	3.83	5.90%
2021	67.13	5.79	8.60%
2022	41.63	9.99	24.00%
2023	47.07	17.91	38.00%