

Antecedent Configurations of Organizational Resilience in Photovoltaic Enterprises under Involutionary Competition Based on fsQCA and NCA

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Abstract

Amidst the impact of cutthroat competition, or neijuan ("involutionary competition"), organizational resilience has emerged as the key to the sustainable development of photovoltaic (PV) enterprises. Using the impact of involutionary competition as an observational lens, this study draws upon the technology-organization-environment (TOE) framework and employs an integrated approach of fuzzy-set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA) to investigate the antecedent configurations of organizational resilience. Key findings include: (1) No single condition is strictly necessary for organizational resilience; rather, organizational resilience is the outcome of the synergistic interplay of digital transformation, technological innovation, strategic deviance, agile responsiveness, and government subsidies. (2) Three distinct configurations lead to high organizational resilience in PV enterprises: the Innovation-Deviance Integration type, the Digitalization-Innovation-Agility Linkage type, and the Subsidy-Innovation Synergy type. (3) The analysis of configurations for non-high organizational resilience reveals that the absence of technological innovation and strategic deviance acts as a critical barrier hindering PV enterprises from cultivating resilience. This study not only broadens the contextual boundaries of organizational resilience research, but also provides important theoretical foundations and practical guidelines for enterprises seeking to break free from the involutionary predicament and build sustainable competitive advantages.

Introduction

Driven by overcapacity, technological homogenization, and vicious price wars, involutionary competition has emerged as a prominent practical problem constraining the high-quality development of the real economy. Furthermore, the comprehensive regulation of involutionary competition has been explicitly incorporated into China's Fifteenth Five-Year Plan, further highlighting the strategic urgency of breaking free from this vicious cycle and promoting corporate sustainability. As a representative sector of the new energy industry, the photovoltaic (PV) industry is currently deeply entrenched in this hyper-competitive predicament. According to preliminary statistics from the China Photovoltaic Industry Association (CPIA), over 40 enterprises have announced delistings, bankruptcies, or mergers and reorganizations since 2024. This fully demonstrates that involutionary competition has evolved from a mere market phenomenon into a structural problem threatening corporate survival and long-term viability. Compounded by the pressures of rapid technological iteration, supply-demand imbalances, and cyclical overcapacity, this phenomenon continues to severely compress the survival space of enterprises¹. Consequently, determining how to build organizational resilience to weather this impact, thereby achieving counter-trend survival and sustainable development, has become an important issue demanding both theoretical breakthroughs and practical solutions.

Organizational resilience, defined as the positive adaptive capacity to confront multifaceted adversities, is an indispensable attribute for enterprises to achieve counter-trend growth². Existing research widely acknowledges its critical role in sustaining long-term development³ and navigating severe crises, such as the September 11 attacks^{4,5}, the global financial crisis^{6,7}, and the COVID-19 pandemic^{2,8-12}, and has systematically investigated the antecedents of organizational resilience through technological, organizational, and environmental lenses. At the technological level, enterprises can construct the "hard power" necessary to weather crises via digital transformation¹³⁻¹⁵ and technological innovation^{9,16,17}. At the organizational level, firms can leverage internal characteristics, such as strategic deviance^{8,18} and agile responsiveness¹⁹⁻²², to cultivate "soft power" for crisis management. Finally, at the environmental level, external factors like government subsidies serve as either a "driving force"^{10,11} or a "constraining force"¹² shaping organizational resilience.

Although existing research on organizational resilience has yielded fruitful results, several notable gaps remain. First, methodologically, previous studies have predominantly focused on the "net effects" of individual factors on organizational resilience, largely neglecting the synergistic effects among multiple variables. Furthermore, there are inconsistent findings regarding the actual impact of certain antecedents¹². Therefore, a systematic analysis of organizational resilience formation from a configurational perspective is urgently needed. Second, contextually, most existing literature centers on sudden exogenous shocks, such as the September 11 attacks, the global financial crisis, and the COVID-19 pandemic, or examines organizational adaptability over long-term economic cycles. Unlike these transient disruptions, involutionary competition is a chronic structural stressor. Consequently, its impact mechanisms on organizational resilience and the underlying governance logic exhibit unique characteristics. Exploring the pathways to build organizational resilience within this specific context thus holds profound theoretical and practical significance.

In light of these gaps, this study positions involutionary competition as its research context and draws upon the technology-organization-environment (TOE) framework. By employing both fuzzy-set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA), we investigate the antecedent configurations of organizational resilience across technological, organizational, and environmental dimensions. Specifically, this study focuses on addressing the following four questions: First, what are the key factors shaping the organizational resilience of PV enterprises amidst involutionary competition? Second, which antecedent configurations drive high organizational resilience in these enterprises? Third, what are the constraining factors that lead to non-high organizational resilience? Fourth, what are the distinctive characteristics and underlying logics of the different configurational pathways?

Theoretical Basis and Literature Review

Theoretical Basis

Involutionary Competition

Involutionary competition refers to a competitive paradigm in industries characterized by enterprise proliferation and capital overinvestment where capacity growth far outpaces market expansion to severely compress corporate profit margins and compel survival-driven firms into inefficient zero-sum games that continuously intensify competition, leaving the overall innovation efficiency and profitability of the industry in a state of stagnation²³. The conceptual origins trace back to 1936, when Goldenweiser employed "involution" to describe a cultural pattern that, once solidified, develops toward internal refinement and complexity without generating new models²⁴. Subsequently, Geertz applied this concept to his study of agriculture in Java, Indonesia, proposing "agricultural

involution" to delineate the phenomenon of diminishing returns resulting from the continuous, intensive input of labor on limited land²⁵. Building upon this foundation, You et al. constructed an involution growth model encompassing diverse elements such as land, labor, and capital, revealing the underlying mechanism wherein the continuous input of a single factor, under given constraints, inevitably leads to diminishing returns after reaching its peak²⁶. Thereafter, the concept of involutionary competition was progressively extended to manufacturing and emerging industries, manifesting as intense price wars, severe product homogenization, low R&D efficiency, and overcapacity²⁷. Consequently, it is evident that involutionary competition does not stem from any isolated antecedent condition; rather, it emerges from the complex causal interplay of multiple factors, including market structure, factor allocation, innovation pathways, and the institutional environment. Traditional single-dimensional explanations focusing on net effects fail to fully capture its generative logic. Therefore, to uncover its formation mechanisms and identify breakthrough trajectories, it is imperative to move beyond linear thinking and systematically investigate the equifinal pathways of organizational resilience from a multi-factor synergistic configurational perspective.

TOE Theory

Originally proposed by Tornatzky and Fleischer in 1990, the technology-organization-environment (TOE) framework was initially employed to investigate the antecedents of technological innovation, classifying them into technological, organizational, and environmental dimensions²⁸. Specifically, the technological dimension encompasses the technical systems and attributes mastered by a firm; the organizational dimension focuses on internal governance mechanisms and resource endowments; and the environmental dimension examines the external context in which the firm is embedded. Due to its comprehensiveness, robust explanatory power, and operational flexibility, the application of the TOE framework has transcended the boundaries of traditional innovation research. It has evolved into a holistic analytical framework widely adopted for delineating the antecedents of diverse organizational behaviors and strategic outcomes²⁹⁻³¹. Concurrently, existing literature has extensively investigated the diverse factors influencing organizational resilience, which can be inherently aggregated into technological, organizational, and environmental levels. Consequently, the TOE framework demonstrates exceptional theoretical fit and adaptability for examining the organizational resilience of PV enterprises.

Literature Review

Digital Transformation and Organizational Resilience

Digital transformation constitutes a dynamic process wherein enterprises leverage technologies such as big data and cloud computing to drive process reengineering and paradigm shifts in value creation¹³. Amidst involutionary competition, digital transformation fortifies organizational resilience across three critical dimensions. First, at the process reengineering level, digitalization dismantles internal information silos to drastically slash operational friction while simultaneously enabling intelligent manufacturing to construct a formidable cost advantage amidst brutal price wars. Second, at the resource allocation level, digitalization optimizes resource orchestration by lowering agency costs, enhancing information transparency, and alleviating financing constraints¹⁵, thereby mitigating the severe capital strain induced by involution. Third, at the green development level, digitalization propels the greening of operational processes and the enhancement of total factor productivity, empowering enterprises to accumulate competitive momentum even within highly compressed profit margins¹³. This nexus between digital transformation and organizational resilience has been extensively validated by recent empirical research, with Li and Wang as well as Xu et al. confirming the positive impact through regression analysis, while Zhang et al. corroborated these findings using structural equation modeling and fuzzy-set qualitative comparative analysis¹³⁻¹⁵.

Technological Innovation and Organizational Resilience

Through continuous technological innovation and knowledge accumulation, enterprises can construct a differentiated capability foundation amidst the homogenization pressures induced by involutionary competition³². From a market expansion perspective, technological innovation facilitates the development of novel product and service domains, thereby reducing reliance on a single market and mitigating the erosion of profit margins caused by external disturbances¹⁶. From a capability accumulation perspective, sustained investment in technological innovation contributes to the sedimentation of knowledge assets and the reinforcement of dynamic capabilities. This enables enterprises to flexibly orchestrate existing resources and respond rapidly to environmental shifts even under resource constraints precipitated by external shocks, ultimately transforming potential threats into developmental opportunities⁹. Consistently, Jia et al. utilized the COVID-19 pandemic as an observational window and found that enterprises with superior technological innovation capabilities exhibited greater performance resilience during the crisis⁹. Similarly, Zhang et al. drew upon a sample of manufacturing enterprises to reveal that technological innovation exerts a significant positive impact on organizational resilience¹⁶. Furthermore, Do et al. employed regression analysis to demonstrate that technological innovation effectively enhances the organizational resilience of small and medium-sized enterprises¹⁷.

Agile Responsiveness and Organizational Resilience

Agile responsiveness denotes an enterprise's capability to perceive, identify, and instantaneously react to external environmental shifts³³, empowering firms to rapidly discern external threats and potential opportunities amidst involutionary competition and transform passive coping mechanisms into proactive defensive postures. From a perception perspective, agile responsiveness furnishes enterprises with enhanced early warning capabilities, enabling them to initiate resource reallocation and strategic adjustments before product market downturn signals fully materialize and thereby secure a temporal advantage in strategic deployment over competitors. From an execution perspective, agile responsiveness allows enterprises to swiftly translate external signals into concrete actions. This facilitates the timely adjustment of capacity deployment and product configurations amidst the frequent fluctuations in market prices and demand structures inherent in involutionary competition, thus preventing inventory backlogs and profit attrition induced by delayed decision-making and sustaining stable operational conditions under continuous competitive pressure^{19,20}. Independent studies by AlQahtani et al. as well as Yağmur and Myrvang

have utilized structural equation modeling to collectively corroborate that agile responsiveness significantly augments organizational resilience capabilities during crisis scenarios^{21,22}.

Strategic Deviance and Organizational Resilience

Strategic deviance empowers enterprises to construct inimitable niche barriers through differentiated competitive positioning, effectively mitigating profit erosion and viability threats amidst involutionary homogenization. From an operational stability perspective, strategic deviance cultivates a diversified resource base and market footprint to reduce reliance on any single operational dimension. This enables enterprises to sustain stable revenue streams and operating conditions amidst industry fluctuations and intensified price competition³⁴. From a competitive protection perspective, strategic deviance acts as an effective buffering mechanism against external shocks. It allows enterprises to avoid direct confrontation with rivals along identical dimensions, thereby preserving vital space for survival and growth amidst fierce competition³⁵. Kong et al. utilized event study methodology and regression analysis to confirm that strategic deviance significantly enhanced organizational resilience during the COVID-19 pandemic⁸.

Government Subsidies and Organizational Resilience

As a vital component of the external environment, government subsidies exert a contentious impact on organizational resilience. Regarding positive mechanisms, their utility manifests primarily across resource and signaling dimensions. From a resource perspective, direct financial support immediately alleviates liquidity distress to enable enterprises to sustain essential technological iteration investments amidst compressed profit margins and avoid the forced contraction of core capability building induced by capital constraints³⁶. From a signaling perspective, the certification effect of subsidies projects policy endorsement to external investors to facilitate the broadening of financing channels and the alleviation of financial constraints³⁷. Conversely, government subsidies may stimulate inefficient expansion within industries already facing overcapacity to exacerbate homogeneous competition and further erode organizational resilience. Wei et al. demonstrated that subsidies can induce overinvestment and resource misallocation, observing that heavily subsidized enterprises experienced steeper stock price declines and more sluggish recoveries during external shocks¹². Consequently, the influence of government subsidies on organizational resilience transcends isolated linear relationships, indicating that their actual efficacy inherently depends upon synergistic coordination with multiple configurational conditions.

In summary, drawing upon the TOE framework, this study integrates five critical elements: technological innovation, digital transformation, agile responsiveness, strategic deviance, and government subsidies. By employing a combined approach of fsQCA and NCA, this research explores how multi-level factors interact through synergistic interplay and configurational matching mechanisms to jointly drive the construction of organizational resilience in PV enterprises, thereby providing multiple pathways and practical references for these firms to break through the predicament of involutionary competition and achieve high-quality development. The detailed framework is illustrated in Figure 1.

Research Design

Research Methodology

This study employs a combined methodology of fuzzy-set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA) to investigate the antecedent configurations of organizational resilience in PV enterprises. The specific rationales are as follows: (1) By utilizing combinations of conditions as the fundamental unit of analysis, fsQCA can effectively capture the synergistic effects among multiple antecedent variables³⁸, making it highly suitable for analyzing the complex driving pathways of organizational resilience amidst involutionary competition. (2) fsQCA exhibits a significant advantage in processing continuous variables, and since all variables in this study rely on continuously measured data, they perfectly satisfy the data prerequisites of fsQCA. (3) fsQCA is not strictly constrained by sample size limitations³⁹, and the 58 cases selected for this study constitute a typical medium-N sample, which is highly appropriate for fsQCA analysis. (4) Although fsQCA is capable of identifying necessary conditions, it can only evaluate whether a condition variable is necessary for the outcome from a qualitative perspective, whereas NCA not only identifies necessary conditions but also determines the specific degree to which an antecedent condition must be present to become a necessary condition through bottleneck analysis³⁹⁻⁴¹. Therefore, this study adopts the configurational analysis of fsQCA as the primary framework and integrates NCA for necessity testing, thereby enhancing the precision of the research findings.

Sample Selection and Data Sources

This study selects PV enterprises as the research sample. The specific data acquisition and screening processes, along with the data sources, are detailed as follows. First, drawing upon the research of Wang et al., 83 A-share listed enterprises were manually screened and selected as the initial sample from the "PV" and "Solar Energy" sectors within the "Industry Chain Platform" of the Wind database. The selection criterion required that the combined proportion of PV-related revenue, such as "PV business," "PV products," and "PV modules," within their core business revenue composition reaches 30% or more⁴². Second, from 2021 to 2022, PV module prices remained at high levels, triggering a massive influx of capital into the PV industry. The production capacity from these early investments began to be released in 2023, leading to severe oversupply in the PV market and the bankruptcy of numerous enterprises. This period is thus characterized as the ongoing "most intense involutionary competition in history." Consequently, this study utilizes data from 2023 to 2024 to measure organizational resilience under the shock of involutionary competition. Furthermore, considering that the cultivation of organizational resilience necessitates a certain time span, the condition variables are lagged by one period. Specifically, the mean values of the outcome variable from 2023 to 2024 are matched with the mean values of the condition variables from 2022 to 2023. Third, to ensure data reliability, listed companies designated as ST or *ST, as well as those with missing data for the condition or outcome variables, were excluded, ultimately yielding a valid sample of 58 enterprises. Finally, all data required

for this research were acquired from the China Stock Market and Accounting Research (CSMAR) database, the Wind database, the Chinese Research Data Services Platform (CNRDS), and the annual reports of the listed companies.

Measurements and Calibration

Outcome Variable

Organizational resilience. Currently, academia primarily adopts two approaches to measure organizational resilience. The first is the direct measurement approach, whose core rationale is to design corresponding scale items for direct assessment based on the conceptual connotations and inherent attributes of organizational resilience. For instance, drawing upon the BS65000:2014 guidance published by BSI, Pescaroli et al. developed a four-point Likert scale ranging from 0 to 3 to evaluate organizational resilience⁴³. The second approach is indirect measurement, which operationalizes a firm's resilience level through its performance during crisis scenarios. For example, utilizing the global COVID-19 pandemic as an observational window, Ma et al. adopted the average return on assets (ROA) during the pandemic as a proxy variable for organizational resilience⁴⁴. Amidst an involutionary competition landscape characterized by severe overcapacity, frequent price wars, and widespread corporate bankruptcies, ROA accurately reflects an enterprise's capability to absorb external shocks and sustain normal operational continuity. Therefore, drawing upon the methodology of Ma et al., this study conceptualizes organizational resilience as the outcome of stable corporate operations under crisis conditions⁴⁴ and utilizes the mean value of the quarterly ROA from 2023 to 2024 as the proxy variable for organizational resilience.

Condition Variables

Digital transformation. Drawing upon the methodology of Hu et al., this study extracts characteristic keywords related to digital transformation from the annual reports of listed companies⁴⁵. First, a digital transformation feature dictionary was constructed, categorizing the characteristic keywords into five major dimensions: artificial intelligence technology, blockchain technology, cloud computing technology, big data technology, and digital technology application. This process yielded a total of 76 characteristic keywords, with the specific keywords for each dimension detailed in Table 1. Second, Python web scraping technology was employed to obtain the text of the annual reports of the listed companies. The frequency of each characteristic keyword appearing in the annual reports was matched and tallied. The keyword frequencies under each dimension were aggregated respectively, and the frequencies across the five dimensions were then summed to derive the total keyword frequency for corporate digital transformation. Finally, the natural logarithm of the total frequency plus one was calculated to construct the proxy variable for the degree of enterprise digital transformation.

Technology category	Keywords
Artificial intelligence	Artificial Intelligence, Business Intelligence, Image Understanding, Intelligent Data Analysis, Intelligent Robot, Machine Learning, Deep Learning, Semantic Search, etc.
Blockchain	Blockchain, Digital Currency, Distributed Computing, Differential Privacy Technology, Smart Financial Contracts.
Cloud computing	Cloud Computing, Stream Computing, Graph Computing, In-Memory Computing, Green Computing, Cognitive Computing, Converged Infrastructure, Internet of Things, etc.
Big data	Big Data, Data Mining, Text Mining, Data Visualization, Heterogeneous Data, Credit Reporting, Augmented Reality, Mixed Reality, Virtual Reality.
Applications of digital technology	Mobile Internet, Industrial Internet, Mobile Connectivity, Internet Healthcare, E-commerce, Mobile Payment, Third-Party Payment, NFC Payment, Smart Energy, B2B, B2C, C2B, etc.

Table 1. The keyword lexicon of digital transformation.

Technological innovation. The level of enterprise technological innovation is measured by taking the natural logarithm of one plus the number of independently filed invention patents in the current year.

Strategic deviance. Drawing upon the approaches of Tang et al. and Kang et al., this study constructs an indicator of enterprise strategic deviance from the perspective of resource allocation^{46,47}. The specific process is as follows. First, six indicators are selected to capture the strategic input characteristics of an enterprise: advertising and promotion investment (selling expenses / operating revenue), R&D investment (net intangible assets / operating revenue), capital intensity (fixed assets / number of employees), fixed asset renewal degree (net value of fixed assets / original value of fixed assets), administrative overhead (administrative expenses / operating revenue), and financial leverage ((short-term borrowings + long-term borrowings + bonds payable) / book value of equity). Second, for each of the aforementioned indicators, the mean and standard deviation are calculated by year and by industry. The original values for each enterprise are then standardized to obtain the firm's deviation in each individual dimension relative to the industry mean for the corresponding year. Finally, the arithmetic mean of these six standardized deviations is calculated to serve as the comprehensive indicator measuring enterprise strategic deviance.

Agile responsiveness. In modern enterprises, particularly listed companies, major decisions typically require discussion and approval at board of directors meetings⁴⁸. Therefore, the frequency of board meetings indirectly reflects the intensity with which an enterprise initiates decisions and formulates responses to external changes. Drawing upon the methodologies of Zhang et al. and Li and Wang, this study measures the degree of enterprise agile responsiveness using the number of board meetings held in the current period^{49,50}. A higher number of meetings indicates a greater degree of enterprise agile responsiveness to external changes.

Government subsidies. Drawing upon the research of Tang et al.⁵¹, the level of government subsidies is measured by the ratio of the government subsidies recognized in current profit or loss to the operating revenue for the current year⁵¹. Furthermore, considering the substantial difference in numerical magnitude between government subsidies and enterprise operating revenue, this ratio is multiplied by 100.

Calibration

Given that the condition and outcome variables selected in this study are all continuous, data calibration is performed prior to the causal analysis using the fsQCA method to convert them into fuzzy-set membership scores. During the calibration process, following the approach of Huang et al., the 75th, 50th, and 25th percentiles are set as the anchor points for full membership, the crossover point, and full non-membership, respectively⁵². Furthermore, to avoid dropping cases with a membership score of exactly 0.5, a constant of 0.001 is added to them based on the recommendation of Fiss⁵³. The data calibration details and descriptive statistics are presented in Table 2.

Variables	Calibration			Descriptives			
	0.75	0.5	0.25	Mean	SD	Min	Max
Organizational resilience	0.026	0.005	-0.014	0.003	0.034	-0.103	0.076
Digital transformation	2.072	1.472	0.896	1.567	0.957	0.000	4.075
Technological innovation	3.756	2.819	1.748	2.877	1.445	0.000	6.532
Strategic deviance	0.882	0.611	0.465	0.713	0.388	0.272	2.306
Agile responsiveness	13.375	11.500	9.500	11.664	3.970	4.500	23.500
Government subsidies	0.955	0.693	0.426	1.013	1.088	0.037	5.455

Table 2. Calibration and descriptive statistics.

Research Results

Necessity Analysis

NCA and fsQCA adhere to distinct criteria and rationales when analyzing necessary conditions. In the NCA approach, a necessary condition specifies the exact level of an antecedent condition required to achieve a particular level of an outcome, thereby revealing the specific degree of necessity of the antecedent for the outcome. In contrast, fsQCA evaluates whether an antecedent condition constitutes a necessary condition for an outcome solely from the perspective of set-theoretic relations; it focuses entirely on the qualitative presence or absence of necessity, without addressing its exact degree. Integrating both methods enables a more precise analysis of variations in the necessary degrees of antecedent conditions^{54,55}. Therefore, drawing upon the methodological approaches of Du et al. and Zhang et al., this study initially employs the NCA method to assess necessity, followed by fsQCA for verification and structural judgment^{54,55}. This integrated approach ensures a comprehensive evaluation of the necessity of antecedent conditions driving organizational resilience in PV enterprises amidst an environment of involutionary competition.

NCA Necessity Analysis

This study employs two estimation techniques within the NCA method using R software, namely ceiling regression (CR) and ceiling envelopment (CE), to conduct necessity tests for individual conditions. As presented in Table 3, all antecedent conditions fail to simultaneously meet the criteria of an effect size (d) greater than 0.1 and a p-value of less than 0.05. This demonstrates that digital transformation, technological innovation, strategic deviance, agile responsiveness, and government subsidies cannot independently constitute necessary conditions for organizational resilience^{54,55}.

Antecedent Condition	Approach	Accuracy	Ceiling zone	Scope	Effect Size(d)	p Value
Digital transformation	CR	94.800%	0.011	0.999	0.011	0.121
	CE	100.000%	0.005	0.999	0.005	0.093
Technological innovation	CR	87.900%	0.099	1.000	0.099	0.071
	CE	100.000%	0.009	1.000	0.009	0.045
Strategic deviance	CR	82.800%	0.018	0.999	0.018	0.410
	CE	100.000%	0.001	0.999	0.001	0.483
Agile responsiveness	CR	100.000%	0.000	1.000	0.000	0.926
	CE	100.000%	0.000	1.000	0.000	0.904
Government subsidies	CR	87.900%	0.013	0.999	0.013	0.455
	CE	100.000%	0.006	0.999	0.006	0.110

Table 3. NCA necessity analysis results. CR refers to ceiling regression, and CE refers to ceiling envelopment. CR is suitable for continuous variables, which aligns with the data characteristics of this study; CE is well suited for variables with fewer than five categories. This study employs both methods

simultaneously to ensure a comprehensive comparison of result robustness. The p-values in NCA are obtained through permutation tests with 10,000 resamples.

The bottleneck level refers to the requisite threshold of an antecedent condition within its maximum observed range to achieve a specific level of the outcome. As presented in Table 4, achieving a 70% level of organizational resilience necessitates a 1.1% level of strategic deviance, whereas digital transformation, technological innovation, agile responsiveness, and government subsidies exhibit no bottleneck effects. Furthermore, to achieve a 100% level of organizational resilience, the required bottleneck levels for the respective antecedent conditions are 92.6% for digital transformation, 93.7% for technological innovation, 10.5% for strategic deviance, 0.6% for agile responsiveness, and 8.9% for government subsidies.

Organizational resilience	Digital transformation	Technological innovation	Strategic deviance	Agile responsiveness	Government subsidies
0	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN
20	NN	NN	NN	NN	NN
30	NN	NN	NN	NN	NN
40	NN	NN	NN	NN	NN
50	NN	NN	NN	NN	NN
60	NN	NN	NN	NN	NN
70	NN	NN	1.100	NN	NN
80	NN	5.000	4.200	NN	2.900
90	NN	49.300	7.400	NN	5.900
100	92.600	93.700	10.500	0.600	8.900

Table 4. NCA bottleneck level analysis results. NN means unnecessary.

fsQCA Necessity Analysis

This study also uses the fsQCA method to test the necessity of each individual condition. The results are shown in Table 5. The consistency levels of all condition variables do not reach the critical value of 0.9, indicating that no single condition variable can independently constitute a necessary condition for high or non-high organizational resilience. This further confirms that organizational resilience is not determined by any single isolated factor but is the result of the synergistic interaction and coupling of multiple conditions at the technological, organizational, and environmental levels^{54,55}.

Antecedent Condition	High Resilience		Non-High Resilience	
	Consistency	Coverage	Consistency	Coverage
Digital transformation	0.568	0.571	0.545	0.519
~Digital transformation	0.522	0.547	0.549	0.546
Technological innovation	0.739	0.728	0.395	0.369
~Technological innovation	0.360	0.386	0.709	0.720
Strategic deviance	0.428	0.458	0.636	0.646
~Strategic deviance	0.670	0.660	0.467	0.436
Agile responsiveness	0.460	0.500	0.568	0.584
~Agile responsiveness	0.617	0.601	0.514	0.474
Government subsidies	0.492	0.510	0.599	0.588
~Government subsidies	0.602	0.613	0.501	0.483

Table 5. fsQCA necessity analysis of individual conditions.

Configuration Analysis

Grounded in a set-theoretic perspective, configurational analysis examines the sufficiency level of various configurations, comprising multiple conditions, in generating a specific outcome. Drawing upon the research of Du et al. and Zhang et al., this study establishes the raw consistency threshold, PRI consistency threshold, and frequency threshold at 0.80, 0.70, and 1, respectively^{54,55}. Based on these parameters, the antecedent configurations for both high and non-high organizational resilience are analyzed. Given the absence of a unified consensus in existing literature regarding the directional relationship between the five individual conditions and organizational resilience, the state of these conditions during counterfactual analysis is designated as "present or absent." Regarding the selection of solutions, configurational analysis generates three types: complex, intermediate, and parsimonious solutions. Because complex

solutions strictly exclude logical remainders and encompass all possible empirical combinations, they inherently carry a risk of overfitting. Conversely, parsimonious solutions may lead to information loss due to oversimplification. Consequently, this study defines conditions present in both the intermediate and parsimonious solutions as core conditions, whereas conditions appearing only in the intermediate solution but absent from the parsimonious solution are defined as peripheral conditions. This approach ensures analytical depth while maintaining the parsimony of the results. The outcomes of the configurational analysis are presented in Figure 2 and Table 6.

Antecedent Condition	High Resilience			Non-High Resilience		
	H1	H2	H3	NH1	NH2	NH3
Digital transformation	⊗	●			⊗	●
Technological innovation	●	●	●	⊗	⊗	⊗
Strategic deviance	●		⊗		⊗	⊗
Agile responsiveness	⊗	●	⊗	●	●	
Government subsidies		⊗	●	●		●
Consistency	0.930	0.897	0.873	0.921	0.915	0.901
Raw coverage	0.142	0.200	0.218	0.340	0.130	0.150
Unique coverage	0.065	0.146	0.113	0.189	0.039	0.050
Overall consistency	0.888			0.917		
Overall coverage	0.436			0.428		

Table 6. Configuration analysis of high and non-high organizational resilience in PV enterprises. Note: ● indicates the presence of a core condition; ⊗ indicates the absence of a core condition; ● indicates the presence of a peripheral condition; ⊗ indicates the absence of a peripheral condition. The same applies below.

As shown in Table 6, three antecedent configurations drive high organizational resilience. Their respective consistency levels are 0.930, 0.897, and 0.873, culminating in an overall solution consistency of 0.888. These values uniformly exceed the minimum threshold of 0.75 recommended by Schneider and Wagemann⁵⁶. Furthermore, the overall solution coverage is 0.436, indicating that the identified configurations collectively explain 43.6% of the empirical cases exhibiting high organizational resilience. Additionally, three configurations are identified for non-high organizational resilience, yielding an overall solution consistency of 0.917 and an overall solution coverage of 0.428. According to Miao and Zhao, the overall solution coverage in management QCA research based on secondary data typically exceeds 0.30. Therefore, the overall coverage levels for both the high (0.436) and non-high (0.428) resilience models in this study exceed this standard, meeting the empirical requirements⁴¹. Figure 2 illustrates the scatter plot of case distribution for configurations of high organizational resilience. Specifically, the cases under Configuration H1 are JinkoSolar and Tongwei; the cases under Configuration H2 are Chint Electrics, GoodWe, FIRST Applied Material, Ginlong Technologies, Trina Solar, and CECEP Solar Energy; and the cases under Configuration H3 are Maxwell Technologies, DMEGC Magnetics, Hoshine Silicon, and Exciton Technology.

Configuration Analysis of High Organizational Resilience

(1) Innovation-Deviance Integration Type. Configuration H1 indicates that a combination featuring the core presence of technological innovation and strategic deviance, coupled with the core absence of digital transformation and agile responsiveness, generates high organizational resilience in PV enterprises. This pattern demonstrates that under conditions of insufficient digital transformation and suboptimal agile responsiveness, PV enterprises can rely on technological innovation and strategic deviance to enhance their organizational resilience. Specifically, technological innovation enables enterprises to break through the homogenization of competition. Through sustained R&D investment, firms accumulate technological barriers that deter competitors from imitating and overtaking them in the short term, thereby safeguarding their market bargaining power and profit margins^{9,16,17}. Concurrently, strategic deviance utilizes differentiated resource allocation models to help enterprises establish unique brand recognition and customer loyalty within niche markets. This maintains the stability of revenue sources and mitigates the impact of industry-wide downturns on corporate profitability⁸. Furthermore, the absence of digital transformation and agile responsiveness in this configuration does not impede the formation of high organizational resilience. The knowledge reserves and R&D team experience accumulated through long-term technological innovation can effectively compensate for the perceptual gaps caused by insufficient digitalization. Moreover, the niche market barriers forged by a differentiation strategy effectively weaken the penetrative force of external disruptions, enabling enterprises to maintain robust organizational resilience without the need for frequent responses to market fluctuations.

Typical enterprises under this configuration are JinkoSolar and Tongwei. Taking JinkoSolar as an example, the company accumulated nearly 16.92 billion RMB in R&D investment from 2022 to 2024 and independently filed 444 invention patents, forging inimitable technological barriers through sustained technological innovation. Simultaneously, JinkoSolar positioned itself early in the energy storage sector, carving out a "second growth curve" via integrated solar-plus-storage solutions. This strategic move broke its revenue reliance on the single module business and safeguarded corporate profit margins. Driven precisely by the synergistic interplay of technological innovation and strategic deviance, JinkoSolar achieved counter-trend growth amidst a sharp decline in industry profit margins, with its operating revenue surpassing the 100-billion-yuan mark for the first time in 2023.

(2) Digitalization-Innovation-Agility Linkage Type. Configuration H2 indicates that a combination featuring the core presence of digital transformation and agile responsiveness, coupled with the core absence of government subsidies and the peripheral presence of technological innovation, generates high organizational resilience in photovoltaic (PV) enterprises. This pattern demonstrates that amidst insufficient government subsidies, PV enterprises can build organizational resilience by leveraging the technological foundation provided by technological innovation and digital transformation in conjunction with agile responsiveness. Specifically, technological innovation provides the fundamental basis for breaking through homogenized competition and helps enterprises build core competitiveness. Digital transformation enhances the ability to perceive and respond to market changes by optimizing information processing and resource allocation efficiency¹³⁻¹⁵. Agile responsiveness further shortens the time window between identifying market signals and executing strategic adjustments. This enables enterprises to rapidly adjust their capacity layouts and product structures during industry fluctuations, thereby reducing operational risks associated with inventory backlogs and downward price pressures^{19,20}. The synergistic effect of these three factors forms an endogenous driving mechanism for organizational resilience. This synergy allows enterprises to achieve high organizational resilience through their own capabilities amidst involutionary competition, even in the absence of external government resource support.

Typical enterprises under this configuration are Chint Electric, GoodWe, FIRST Applied Material, Ginlong Technologies, Trina Solar, and CECEP Solar Energy. Taking Chint Electric as an example, the company has consistently upheld technological innovation as the core driving force for its development, independently filing a cumulative total of 923 invention patents from 2022 to 2024. Simultaneously, Chint Electric has continuously deepened its "One Cloud and Two Nets" strategy. Relying on three major platforms namely Chint Cloud, the Industrial Internet of Things, and the Energy Internet of Things, it continuously dismantles data silos among products, equipment, factories, upstream suppliers, and downstream customers. Furthermore, Chint Electric has demonstrated the ability to promptly identify domestic market risks, shifting its strategic focus toward overseas market expansion and product iteration upgrades. Supported by the synergistic interplay of technological innovation, digital transformation, and agile responsiveness, the operating revenue of Chint Electric continuously climbed from 45.974 billion RMB to 64.519 billion RMB between 2022 and 2024, demonstrating strong endogenous organizational resilience even in the presence of relatively insufficient government subsidies.

(3) Subsidy-Innovation Synergy Type. Configuration H3 indicates that a combination featuring the core presence of government subsidies and technological innovation, coupled with the core absence of agile responsiveness and the peripheral absence of strategic deviance, generates high organizational resilience in photovoltaic (PV) enterprises. This pattern demonstrates that even when strategic deviance and agile responsiveness are not prominent, PV enterprises can rely on government subsidies and technological innovation to build organizational resilience. Specifically, government subsidies provide critical external resource support for enterprises. This backing alleviates the financial pressures induced by industry price wars and overcapacity, thereby enabling firms to maintain necessary R&D investments and technological iterations even in an environment with narrowing profit margins³⁶. Concurrently, technological innovation facilitates continuous technological accumulation and product upgrades. This helps enterprises establish implicit technological barriers amid homogenized competition, which improves product performance and cost control capabilities to ultimately enhance market competitiveness and risk resistance. Furthermore, the absence of strategic deviance and agile responsiveness in this configuration does not impede the enhancement of organizational resilience. The patent barriers and technological generation gaps formed through technological innovation can functionally substitute for the competitive protection typically offered by strategic deviance. As a result, enterprises do not need to rely on strategic deviation to build competitive barriers. Additionally, the financial security provided by government subsidies enables firms to maintain a stable operational rhythm despite short-term profitability pressures. This allows them to sustain high organizational resilience amidst involutionary competition without the necessity of frequently responding to market fluctuations.

Typical enterprises under this configuration are Maxwell Technologies, DMEGC Magnetics, Hoshine Silicon, and Exciton Technology. Taking Maxwell Technologies as an example, the company independently filed a total of 261 invention patents between 2022 and 2024 and held a dominant position in the field of heterojunction solar cells. Simultaneously, Maxwell Technologies has long enjoyed national policy support for advanced manufacturing equipment, accumulating approximately 146 million RMB in government subsidies from 2022 to 2024, which effectively alleviated financial pressures during the downward cycle of the industry. Benefiting from the dual support of technological innovation and government subsidies, the operating revenue of Maxwell Technologies achieved continuous growth between 2022 and 2024, demonstrating a high level of resilience under the impact of involutionary competition.

Configuration Analysis of Non-High Organizational Resilience

This study further analyzed three antecedent condition combinations leading to non-high organizational resilience. Configuration NH1 shows that in the absence of technological innovation as a core condition, even if PV enterprises have high levels of agile responsiveness and government subsidies, they still cannot build organizational resilience. Configuration NH2 shows that when technological innovation and strategic deviance are absent as core conditions, and digital transformation is absent as a peripheral condition, even if PV enterprises possess high agile responsiveness, it is difficult for them to build organizational resilience. Configuration NH3 shows that when technological innovation and strategic deviance are absent as core conditions, even if the levels of digital transformation and government subsidies are high, enterprises similarly cannot build organizational resilience. The above results collectively reveal that the absence of technological innovation or strategic deviance is the key reason why PV enterprises find it difficult to cultivate organizational resilience. Furthermore, Configurations NH1 and NH3 further illustrate that even with external government subsidy support, if enterprises neglect the cultivation of their own core capabilities, they still cannot effectively build organizational resilience.

Robustness Test

Following the methodologies of Du et al. and Zhang et al., this study conducted robustness tests by elevating both the raw consistency threshold and the PRI consistency threshold^{54,55}. Specifically, the raw consistency threshold was first increased from 0.80 to 0.85. As presented in Table 7, the resulting configurations remained consistent with the original findings. Subsequently, the PRI consistency threshold was elevated from 0.70 to 0.75. As shown in Table 8, with the exception of a minor variation in Configuration H3 for high organizational resilience, all other configurational pathways remained identical. These outcomes collectively demonstrate that the configurational analysis results of this study possess robust reliability.

Antecedent Condition	High Resilience			Non-High Resilience		
	H1	H2	H3	NH1	NH2	NH3
Digital transformation	⊗	●			⊗	●
Technological innovation	●	•	●	⊗	⊗	⊗
Strategic deviance	●		⊗		⊗	⊗
Agile responsiveness	⊗	●	⊗	●	●	
Government subsidies		⊗	●	●		●
Consistency	0.930	0.897	0.873	0.921	0.915	0.901
Raw coverage	0.142	0.200	0.218	0.340	0.130	0.150
Unique coverage	0.065	0.146	0.113	0.189	0.039	0.050
Overall consistency	0.888			0.917		
Overall coverage	0.436			0.428		

Table 7. Robustness test results (raised consistency threshold).

Antecedent Condition	High Resilience			Non-High Resilience		
	H1	H2	H3	NH1	NH2	NH3
Digital transformation	⊗	●	⊗		⊗	●
Technological innovation	●	•	●	⊗	⊗	⊗
Strategic deviance	●				⊗	⊗
Agile responsiveness	⊗	●	⊗	●	●	
Government subsidies		⊗	●	●		●
Consistency	0.930	0.897	0.916	0.921	0.915	0.901
Raw coverage	0.142	0.200	0.190	0.340	0.130	0.150
Unique coverage	0.046	0.178	0.094	0.189	0.039	0.050
Overall consistency	0.902			0.917		
Overall coverage	0.417			0.428		

Table 8. Robustness test results (raised PRI consistency threshold).

Conclusions and Discussion

Conclusions

Using the shock of involutionary competition as the research context, and drawing upon the TOE theoretical framework and the governance logic of involutionary competition, this study employs an analytical approach combining fuzzy-set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA) to explore the configurational effects of digital transformation, technological innovation, agile responsiveness, strategic deviance, and government subsidies on organizational resilience. The findings indicate that:

- (1) None of digital transformation, technological innovation, strategic deviance, agile responsiveness, or government subsidies constitutes a single necessary condition for driving organizational resilience. Rather, organizational resilience is the outcome of the synergistic driving effects of technological, organizational, and environmental conditions.
- (2) The antecedent configurations for high organizational resilience can be categorized into three paths: the Innovation-Deviance Integration type (with technological innovation and strategic deviance as core presence conditions), the Digitalization-Innovation-Agility Linkage type (with digital transformation and agile responsiveness as core presence conditions, and technological innovation as a peripheral presence condition), and the Subsidy-Innovation Synergy type (with government subsidies and technological innovation as core presence conditions).
- (3) The analysis of configurations for non-high organizational resilience reveals that the absence of technological innovation and strategic deviance is the key constraining factor in fostering organizational resilience, which conversely confirms the critical role of technological innovation and strategic deviance in an environment of involutionary competition.

Contributions

- (1) Broadens the theoretical perspectives and contextual boundaries of organizational resilience research. This study extends organizational resilience research from the context of sudden crises to structural competitive dilemmas, enriching the theoretical boundaries of the field. Furthermore, it provides a novel analytical framework for understanding the pervasive issue of involutionary competition in the real economy.
- (2) Overcomes the limitations of traditional research focusing on single-factor net effects. By incorporating digital transformation and technological innovation into the technological dimension, strategic deviance and agile responsiveness into the organizational dimension, and government subsidies into the environmental dimension, this study applies configurational thinking to systematically reveal the synergistic and substitutable relationships among these five condition variables. This not only addresses the controversial conclusions in academia regarding the influencing factors of organizational resilience but also provides theoretical foundations and practical references for PV enterprises to select differentiated resilience-building paths under resource constraints.
- (3) Further validates the methodological efficacy of combining fsQCA and NCA in configurational research. From the perspective of necessary conditions, NCA precisely identifies the threshold effects of each condition variable, revealing the specific levels a single condition must reach to support the formation of organizational resilience. Meanwhile, from the perspective of sufficiency, fsQCA reveals the equifinality characteristics among condition combinations, identifying multiple equivalent paths for achieving high organizational resilience. The complementary use of both methods not only enhances the robustness and explanatory power of the research findings but also provides a methodological reference for conducting configurational research in complex causal contexts.

Management and Policy Recommendations

- (1) Foster multi-factor synergistic resilience. Enterprises should construct an internal evaluation system encompassing dimensions such as technological innovation, digital transformation, agile responsiveness, strategic deviance, and the acquisition of government subsidies. By regularly identifying operational weaknesses, enterprises can formulate targeted plans for capability reinforcement and resource allocation. Resources should be optimally configured based on the complementary and synergistic logic of these various capabilities to prevent a lag in any single dimension from constraining overall resilience. Additionally, enterprises should establish dynamic monitoring and early warning mechanisms for organizational resilience, flexibly adjusting the focus of their capability configuration in response to changes in the external competitive environment to ensure a sustained state of high resilience driven by multi-factor synergy.
- (2) Build a collaborative industry ecosystem. Industry associations and alliances should take the lead in establishing classified evaluation standards for organizational resilience and creating an industry-wide information-sharing platform. By regularly publishing industry development reports, they can help enterprises benchmark and identify specific areas for improvement in key dimensions like technological innovation, digital transformation, and agile responsiveness. Furthermore, establishing common technology R&D platforms and diagnostic service systems for digital transformation can significantly reduce the investment costs associated with technological breakthroughs and digital upgrades for PV enterprises. Simultaneously, industry bodies should promote inter-firm collaborative R&D and emergency response linkage mechanisms, regularly organizing specialized training and exchanges on resilience-building best practices to facilitate the diffusion and application of advanced experiences throughout the industry.
- (3) Implement differentiated policy support. Government departments should ensure policy design begins with precise screening, utilizing objective criteria such as R&D investment intensity, patent output levels, and the degree of digital construction to establish differentiated thresholds and support standards for subsidies. This ensures that public resources are directed toward market entities possessing substantial innovation capabilities. Furthermore, a dedicated fund for the resilient development of the PV industry should be established, primarily addressing the funding gaps PV enterprises face in

technological R&D and innovative upgrades. At the same time, the government should implement capacity early warning systems and market competition regulations for the PV industry to guide enterprises away from price wars and toward technological innovation competition. Finally, a mechanism for the dynamic tracking and regular calibration of policy outcomes must be established to ensure ongoing efficacy.

Research Limitations and Future Outlook

- (1) Completeness in the selection of condition variables. Although this paper selects five condition variables based on the TOE framework, it remains difficult to exhaust all potential factors affecting organizational resilience. Future research could introduce condition variables from additional dimensions based on the existing analytical framework to further enrich the completeness of the antecedent configurations for organizational resilience, thereby providing more refined practical guidance for enterprises.
- (2) Limitations regarding the research time span. This paper primarily analyzes the antecedent configurations of organizational resilience in PV enterprises based on cross-sectional data, failing to fully reveal the dynamic evolution of condition variables over time and their temporal impacts on organizational resilience. Organizational resilience itself is a dynamically constructed process, and the impact strength of different condition elements may exhibit significant differences across various stages of the industry cycle. Future research could incorporate time-series QCA (tsQCA) or longitudinal case study methods to track the resilience evolution trajectories of enterprises at different stages of involutionary competition, thereby revealing the dynamic path mechanisms and phased evolutionary patterns of building organizational resilience.

Declarations

Competing interests

No competing interests.

Ethical approval and Consent to Participate

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Consent to Publish

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Clinical trial number

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Author Contribution

Yujie Luo: Conceptualization, Methodology, Data Curation, and Writing-Review & Editing. Xingyu Wang: Conceptualization, Methodology, Analysis, Software, Validation, Visualization, and Writing-Original Draft. Ting Hao: Supervision, Resources, Validation, Project Administration, and Writing-Review & Editing. All authors reviewed and approved the final manuscript.

Data Availability

The data supporting the findings of this study were obtained from the China Stock Market and Accounting Research (CSMAR) database (<https://data.csmar.com/>), the Wind database (<https://www.wind.com.cn/>), the Chinese Research Data Services Platform (CNRDS) (<https://www.cnrds.com/>), and the annual reports of the listed companies available through CNINFO (<https://www.cninfo.com.cn/>).

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Figures

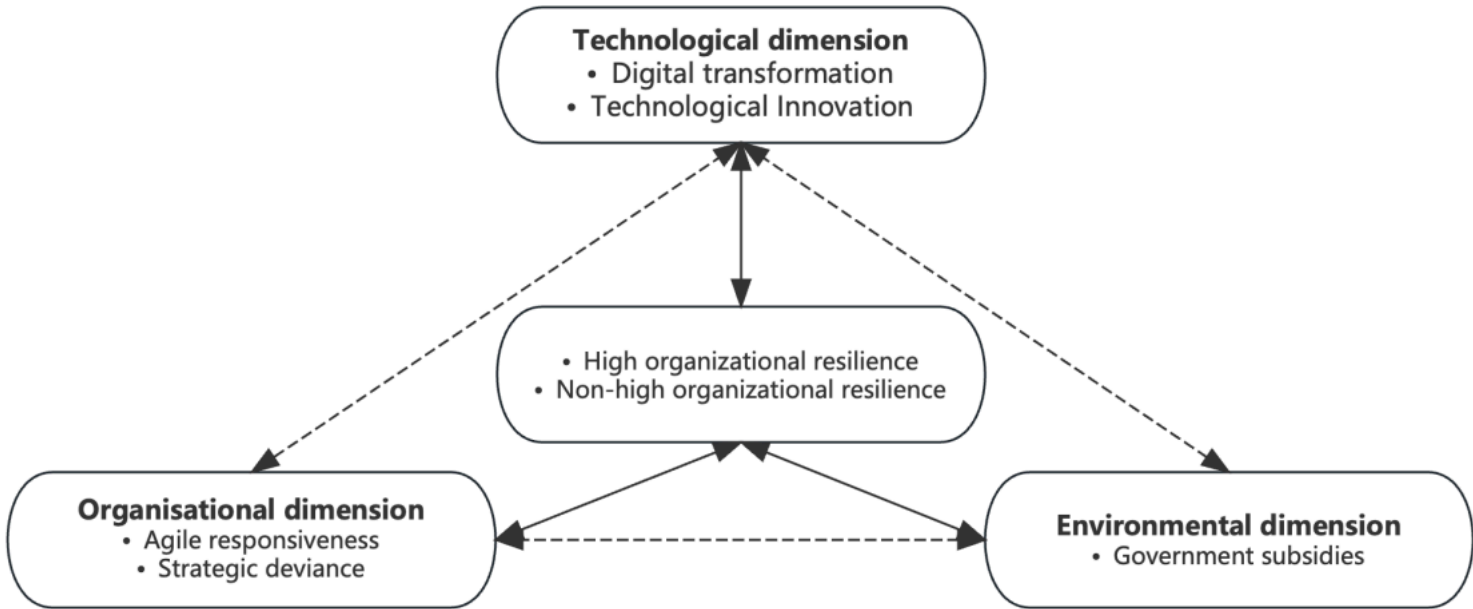


Figure 1

Research framework.

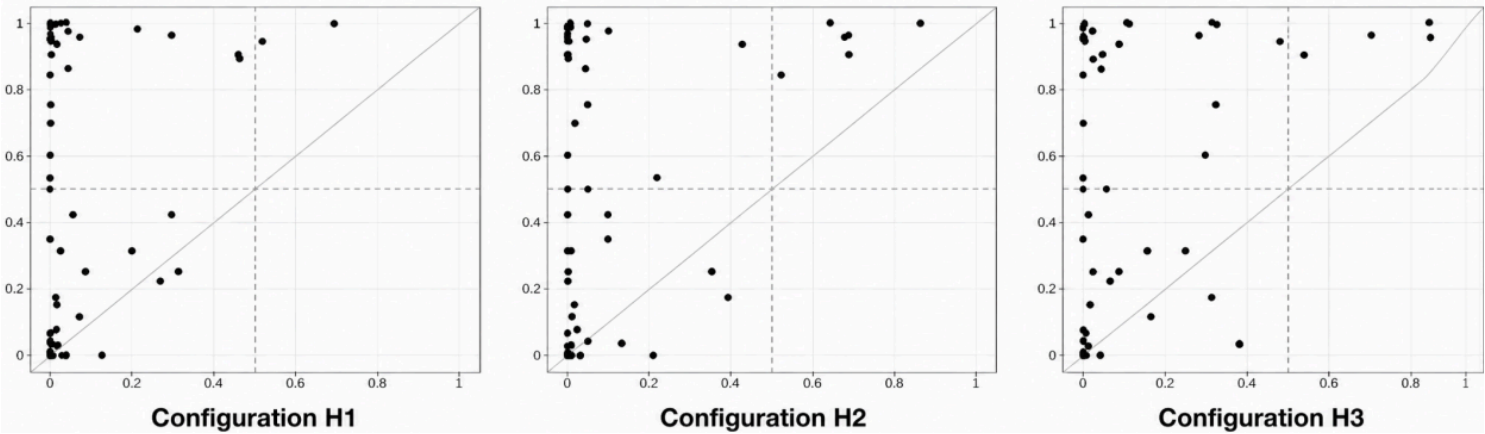


Figure 2
Scatter plot of case distribution for configurations of high organizational resilience.