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Spatiotemporal configurations of emergency logistics responsiveness capacity: a panel QCA study of Chinese provinces

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Purpose: Effective emergency logistics responsiveness capacity (ELRC) is critical for mitigating natural disaster impacts, yet the configurational mechanisms through which ELRC emerges and evolves across both time and space remain inadequately understood. This study aims to identify how multiple conditions combine to produce high ELRC in Chinese provinces, and whether these pathways are temporally stable or spatially heterogeneous.

Methodology: Drawing on Configurational Field framework, this study employs panel data Qualitative Comparative Analysis (QCA) to examine provincial ELRC in China from 2017 to 2024. A balanced panel of 29 provinces over eight years (232 observations) is analyzed. Six conditions are calibrated into fuzzy sets: disaster cost, fiscal autonomy, technological infrastructure, digital infrastructure, government attention, and social participation. Consistency is decomposed into pooled, between—unit (temporal), and within—unit (spatial) components to diagnose spatiotemporal heterogeneity.

Findings: Five equifinal pathways to high ELRC are identified, categorized into four models: Routine Administration, Collaborative Governance, Fiscal Substitution, and Technological Autonomy. Notably, non-high ELRC exhibits a convergent pattern, characterized by a "Structural Vulnerability Trap" where the absence of fiscal and technological foundations prevents social participation from compensating. The configurations exhibit temporal resilience over time but pronounced spatial heterogeneity across provinces.

Originality: This study advances the concept of a "Configurational Field" by explaining why certain combinations of conditions are structurally feasible or infeasible across space and time. Methodologically, it provides a rigorous panel QCA application by distinguishing structural boundaries from temporal stability, offering evidence for differentiated disaster governance in large countries.

KEYWORDS

China, Configurational Field, emergency logistics responsiveness capacity, equifinality, panel data QCA, spatiotemporal heterogeneity

1 Introduction

In recent decades, the escalating frequency and intensity of natural disasters have posed formidable challenges to global emergency management systems (1, 2). Emergency logistics, encompassing the rapid mobilization and distribution of relief materials and personnel, constitutes a critical pillar of disaster response. Its effectiveness directly determines the timeliness and adequacy of relief operations, as demonstrated in major events such as the 2004 Indian Ocean Tsunami, the 2010 Haiti Earthquake, the 2011

Tohoku Earthquake and Tsunami, and the 2023 Turkey-Syria Earthquakes (3, 4). In each case, the speed and coordination of emergency logistics systems profoundly affected the outcomes of cross-border and inter-regional relief efforts. For instance, the United Nations World Food Programme (WFP) maintains over fifty emergency hubs globally, enabling the delivery of prepositioned supplies to most disaster-stricken regions within 48 h of an emergency declaration. These examples underscore that emergency logistics is not merely a technical operation, but a complex governance problem situated at the intersection of technological infrastructure, finance, information, and institutional coordination (5, 6).

A substantial body of research has examined the determinants of emergency logistics capacity. For example, Patil and Madaan conducted a bibliometric analysis of humanitarian supply chains, identifying sustainability and performance measurement as emergent research clusters (7). Hosseinifard systematically reviewed 847 articles on non-profit organizations' contributions to disaster management, revealing resilience, emergency relief, and cross-sector collaboration as core thematic clusters (8). Carnero Quispe et al. (9) examined prioritization models in humanitarian logistics, noting that while most applications target sudden-onset natural disasters, tactical inventory management remains underexplored. Köstepen and Selim (10) provided a risk-oriented review, highlighting that insufficient risk analysis during logistics processes hinders effective management. Furthermore, Khalili et al. (11) focused on public transit-based evacuation planning, identifying data availability and stakeholder coordination as persistent challenges. Despite these valuable contributions, most existing studies share a common limitation: they predominantly focus on optimization algorithms, decision support systems, or the net effects of single factors, while the configurational perspective remains largely absent (12). That is, they ask "which factor matters most" rather than "what combinations of factors produce high responsiveness."

Moreover, although a growing body of literature has documented temporal and spatial heterogeneity in emergency logistics performance (13–15), configurational analyses that explicitly unpack how these spatiotemporal differences shape causal complexity remain extremely rare. In particular, the panel data QCA framework, which decomposes consistency into pooled, between-unit (temporal), and within-unit (spatial) components, has seldom been applied to emergency logistics. This gap is especially critical in the Chinese context. China's vast territorial expanse, uneven regional development, and rapidly evolving emergency governance system, including the establishment of the Ministry of Emergency Management in 2018 and the impact of the COVID-19 pandemic, make the spatiotemporal dynamics of emergency logistics responsiveness a compelling research frontier (16–18). Static QCA, which pools data without distinguishing spatial from temporal sources of variation, risks conflating distinct mechanisms (19, 20).

To address these interconnected gaps, this study introduces the concept of a configurational field. Drawing on Bourdieu's field theory (21, 22) and recent advances in Configurational Field Analysis (23), we conceptualize provincial emergency logistics responsiveness capacity (ELRC) as the outcome of conjunctural alignments across three theoretical dimensions: resource context, technological infrastructure, and governance capacity. The configurational field framework offers three analytical advantages. First, it directs attention to relational configurations rather than isolated attributes, consistent with the set-theoretic logic of QCA. Second, it foregrounds dynamism, recognizing that governance spaces are continuously reshaped by struggles over resources, attention, and legitimacy. Third, it provides a vocabulary for spatiotemporal heterogeneity, acknowledging that fields take different forms in different places and times because they are shaped by local institutional histories and resource distributions (24, 25). These features make field theory a natural theoretical partner for panel data QCA, which is designed to unpack precisely these forms of heterogeneity.

Methodologically, this study employs panel data QCA to investigate which configurations of conditions are consistently associated with high provincial ELRC in China from 2017 to 2024. This approach decomposes set-theoretic consistency into pooled, between-unit, and within-unit components, allowing us to assess whether a given configuration remains temporally stable, varies systematically across provinces, or exhibits both (19, 26). Using a balanced panel of twenty-nine provinces over eight years, we pursue three objectives. First, we identify equifinal pathways to high ELRC and examine whether these configurations exhibit temporal stability or spatial heterogeneity. Second, we introduce the concept of a configurational field to characterize how causal patterns can simultaneously display temporal continuity and spatial differentiation. Third, we derive region-specific configurations that can inform differentiated policy design.

This study makes three primary contributions. Theoretically, we advance the configurational field concept as a lens for understanding how emergency logistics capacity emerges and varies across provinces, moving beyond flat, decontextualized combinations of variables. Methodologically, we provide one of the first applications of panel data QCA to emergency logistics research. Unlike traditional net-effects models (e.g., linear regression) that assume symmetric and isolated impacts, Panel QCA is uniquely suited to capture the conjunctural and equifinal nature of disaster response. Furthermore, by explicitly decomposing consistency into temporal and spatial components, this approach empirically separates long-term institutional shifts from regional heterogeneity, providing a rigorous analytical tool for complex governance systems. Empirically, we identify region-specific pathways and structural boundaries that underscore the need for locally tailored implementation within China's governance system. By showing how central direction and local adaptation coexist within a unified institutional framework, this study contributes to comparative governance research on disaster preparedness in large, geographically diverse countries.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 presents the theoretical framework. Section 4 describes the research design. Section 5 reports the findings. Section 6 discusses the implications. Section 7 concludes.

2 Literature review

Consistent with the research objectives, the extant literature can be broadly categorized into three thematic streams:

(1) the integration of emergency logistics into natural disaster management;
(2) the determinants of emergency logistics capacity; and
(3) the spatiotemporal disparities in logistics development. While these streams offer valuable insights, they have largely evolved in isolation, lacking a unifying framework to explain how their findings intertwine within specific spatiotemporal contexts. This is precisely the theoretical gap that the Configurational Field framework, developed in Section 3, seeks to address. Consequently, this section synthesizes existing knowledge while simultaneously establishing the necessity of a configurational and field-theoretic approach.

2.1 Emergency logistics in natural disaster contexts

Emergency logistics has been widely recognized as a critical component of disaster response systems. Extensive research has examined the operational challenges and coordination mechanisms of relief supply chains following natural disasters such as earthquakes, floods, and typhoons. Foundational texts on disaster management have established the broader context within which emergency logistics operates (27, 28). Özdamar and Ertem (29) provided a comprehensive review of optimization models for disaster logistics, covering facility location, vehicle routing, and resource allocation under uncertainty. Holguín-Veras et al. identified the unique features of post-disaster humanitarian logistics, emphasizing the importance of immediate response and the coordination of multiple stakeholders (3). In the context of sudden-onset disasters, Caunhye et al. (30) developed optimization frameworks for relief distribution network design, while Balcik et al. (31) examined the role of coordination mechanisms in humanitarian supply chains. Kelle et al. (32) studied the coordination of relief item prepositioning strategies, and Huang et al. (33) evaluated emergency logistics performance using simulation methods. More recent work has extended this tradition by incorporating sustainability and resilience considerations into humanitarian logistics (6, 34–36). The role of public sector coordination in catastrophic disasters has also received increasing attention, with scholars highlighting the importance of adaptive governance and inter-organizational networks in crisis response (37–39). Despite these contributions, the strategic integration of emergency logistics into provincial-level disaster management systems, and its role as a systemic outcome rather than a set of isolated operations, remains relatively under-theorized.

2.2 Emergency logistics responsiveness: dimensions and determinants

Recent literature has increasingly emphasized resilience theory as a foundational lens for understanding how complex systems absorb shocks, adapt to disruptions, and maintain essential functions (40, 41). In disaster contexts, resilience is not merely about "bouncing back" to a prior state, but involves dynamic organizational and technical adaptability (42). Crucially, recent studies have highlighted that building resilience often involves complex trade-offs and synergies with other systemic transitions. For example, a recent study on sustainable urban energy systems demonstrates that resilience interacts dynamically with green transition pathways, requiring a careful balance of multiple conditions rather than isolated efforts (43). This trade-off and synergy perspective strongly resonates with emergency logistics, where high responsiveness emerges from the dynamic interplay of fiscal, technological, and governance resources, rather than from a single isolated determinant.

Building on this resilience perspective, the systematic study of emergency logistics responsiveness capacity (ELRC) can be traced to the mid-2000s. Kovács and Spens provided one of the earliest conceptualizations, distinguishing humanitarian logistics from commercial logistics and laying the foundation for disaster relief as a distinct operational field (4). Early assessment efforts relied heavily on subjective multi-criteria decision-making. For instance, Huang and Shi applied an intuitionistic fuzzy analytic hierarchy process to evaluate grain emergency logistics supply capacity (44). Xu and Gong constructed an evaluation index system based on triangular fuzzy entropy and the Choquet integral (45). These studies advanced the understanding of ELRC components but often suffered from subjectivity. A significant advance came when Chen et al. constructed a comprehensive evaluation index system using entropy-weighted TOPSIS, combining six dimensions, including freight turnover, logistics infrastructure, digitalization, and social support (13). Acimovic and Goentzel (46) also generated new emergency logistics indices based on stochastic optimization models, further enriching the measurement toolkit.

However, the majority of these studies adopt a net-effects perspective, assuming linear, additive contributions. This overlooks the configurational nature of ELRC, where multiple conditions combine in equifinal and asymmetric ways (47, 48). In natural disaster contexts, where cascading disruptions and interdependent constraints are the norm, the question is rarely which single factor matters most, but rather which configurations of factors produce high responsiveness under what conditions (49).

Recognizing this gap, a small but growing body of literature has begun to adopt configurational methods. For instance, Dong et al. (50) combined QCA with machine learning to examine cross-organizational collaborative governance, and emerging research is increasingly exploring configurational resilience in public administration (51). Nevertheless, most existing configurational studies remain static. While recent methodological advances have introduced Panel QCA (19) and preliminary applications exist in regional emergency logistics (14), it remains highly underutilized in disaster governance to distinguish whether configurations are stable over time or vary across space.

2.3 Spatiotemporal heterogeneity in logistics development

A substantial body of literature has examined spatial and temporal disparities in logistics development. Methodologically, spatial econometric approaches have provided robust frameworks for analyzing regional interdependence and spatial spillovers (52).

Early empirical studies focused on regional logistics efficiency measured through infrastructure density, freight volume, and economic output (53, 54), consistently identifying a widening gap between eastern and western China. Some research has further explored the driving forces behind such disparities, including fiscal decentralization, marketization, and local government competition, with recent studies distinguishing between vertical pressure from higher-level governments and horizontal competition among peer jurisdictions (55–57). A few studies have considered institutional changes, such as the establishment of the Ministry of Emergency Management in 2018, and their potential impact on logistics coordination. Others have examined disaster-driven policy attention and the role of social organization in shaping logistics development (51).

Internationally, similar spatial disparities have been documented in other large federal or decentralized states (e.g., India, Brazil, and the US), where differences in infrastructure, fiscal capacity, and institutional quality lead to uneven emergency preparedness and response (37, 39, 58). However, most of these studies rely on cross-sectional data or static panel models, which cannot simultaneously capture temporal dynamics and spatial heterogeneity. Furthermore, the existing literature rarely focuses specifically on emergency logistics within natural disaster contexts. Consequently, how regional disparities in emergency logistics evolve over time, and how institutional and disaster-related factors interact with spatial heterogeneity, remain largely unexplored.

2.4 Research gap and contribution

Based on the above review, three interconnected gaps emerge. First, the existing literature has developed various evaluation methods for general logistics capacity, but systematic and objective assessments specifically targeted at ELRC in natural disaster contexts remain insufficient. Second, most studies have explored the determinants of ELRC through a net-effects lens, while the configurational approach, which focuses on how multiple conditions combine in equifinal and asymmetric ways, has received limited attention. Third, although spatiotemporal heterogeneity has been documented in general logistics development, few studies have explicitly incorporated China's institutional dynamics or examined how disaster-driven policy attention interacts with spatial disparities over time. These gaps reflect an absence of an integrative framework that can simultaneously accommodate configurational complexity, temporal dynamics, and spatial variation.

To address these gaps, this study offers three primary contributions. First, theoretically, it advances the "Configurational Field" framework. Moving beyond traditional configurational governance that treats conditions as flat inputs, this framework introduces structural constraints (explaining the causal asymmetry of the Structural Vulnerability Trap), relational dynamics (explaining spatial deviations), and temporal inertia (explaining stability across shocks). This provides a novel analytical lens for understanding disaster governance in large decentralized states.

Second, methodologically, it provides a rigorous application of panel data QCA. Drawing on the indicator framework of Chen et al. (13) and based on a recalculated ELRC index derived from the 2017–2024 provincial panel, this study identifies five equifinal pathways and categorizes them into four distinct models. By explicitly decomposing consistency into pooled, between-unit (temporal), and within-unit (spatial) components, it empirically separates temporal resilience from spatial heterogeneity, offering a reproducible approach to analyzing complex spatiotemporal dynamics.

Third, empirically, it reveals the structural boundaries of emergency logistics governance. The findings reveal causal asymmetry: while high ELRC is associated with multiple pathways, non-high ELRC converges into a "Structural Vulnerability Trap" (N1 and N2), where social participation cannot compensate for foundational fiscal and technological deficits. Furthermore, by examining the spatial deviations of specific provinces, this study provides empirical evidence for differentiated policy design tailored to local institutional and geographical contexts.

In doing so, this study provides a nuanced understanding of provincial ELRC in a large and regionally diverse country like China, where institutional reforms and disaster governance continue to evolve (59, 60). The Configurational Field framework, introduced in the following section, provides the conceptual architecture that integrates these three contributions.

3 Theoretical framework

3.1 Field theory and configurational field analysis

Pierre Bourdieu conceptualized the field as a structured social space defined by the objective relations among agents occupying different positions (61). A field is never an aggregate of isolated individuals; rather, it is a relational network with its own operational logic (21). In any field, actors compete to define and allocate all types of capital, including economic capital, cultural capital, social capital and symbolic capital (62). This competition endows the social space with inherent conflict and dynamism. Fields are therefore never static; they are continuously reshaped by struggles and negotiations, implying that their internal logics and boundaries remain open to change (22). The relational architecture of fields thus underscores that social outcomes emerge not from isolated attributes but from the configuration of positions and capital distributions within a field (25).

Over the past two decades, field-theoretic thinking has been extended across disciplines. Neil Fligstein and Doug McAdam (22) advanced a synthetic theory of strategic action fields, defining them as constructed social arenas where actors with varying resources vie for advantage, and where both stability and change co-evolve. Their framework explicitly links field-level dynamics to organizational strategies, governance arrangements, and institutional change, resonating with the study of public management and policy implementation (24). More recently, Abbas Jong advanced Configurational Field Analysis (CFA) as a reconfigured extension of Bourdieu's field theory, specifically designed to overcome the limitations of static global field theory in capturing the fluidity and contextual embeddedness of contemporary social interactions, especially under transnational conditions (23). CFA

reconceptualizes fields as dynamic, contextually embedded social spaces that emerge from specific historical and situational configurations rather than pre-given homogeneous structures (23). In CFA, fields are arenas where power, capital and influence are continuously reinterpreted and recalculated by agents who consciously respond to emergent opportunities and constraints (23). This perspective has two crucial implications for empirical research. First, the same configuration of conditions may generate different outcomes across different historical periods because the field itself evolves over time. Second, outcomes may vary systematically across different regional spaces because the field takes distinct forms depending on local institutional and resource contexts. Consequently, configurational pathways to given outcomes cannot be presumed universal or temporally invariant; they must be empirically identified and compared across both time and space (26).

The distinctive characteristics of natural disaster emergency logistics make field theory a particularly apt analytical lens. Unlike routine logistics operations, emergency logistics in natural disaster contexts is characterized by sudden onset, extreme uncertainty, infrastructure disruption, and the involvement of multiple actors with divergent institutional logics (3, 29). These features render conventional factor-based explanations inadequate; what matters is how diverse conditions configure within specific spatiotemporal contexts. Field theory offers three analytical advantages for studying such configurational dynamics. First, it directs attention to relational configurations rather than isolated attributes. This aligns with the configurational logic of QCA and resonates with the empirical reality that emergency logistics capacity in natural disasters is rarely determined by a single factor in isolation but rather emerges from the interplay of multiple conditions (63). Second, it foregrounds dynamism and contestation, recognizing that disaster response governance is not a fixed institutional arrangement but an arena of ongoing negotiation over resources, authority, and operational priorities among state and non-state actors (64). Third, it provides a vocabulary for contextual embeddedness, acknowledging that disaster response fields take different forms in different places and times because they are shaped by local institutional histories, resource endowments, and the legacies of previous disaster experiences (65). These features make field theory a natural theoretical partner for panel data QCA, which is designed to unpack precisely these forms of spatiotemporal heterogeneity in natural disaster governance.

Motivated by these theoretical developments, this study develops a Configurational Field framework specifically tailored to provincial emergency logistics. The framework builds on the notion of configurational space in set-theoretic research (66) and extends CFA into the domain of emergency logistics management. In this study, the Configurational Field denotes a dynamic, relationally structured governance space that emerges from specific contextual conditions, where multiple conditions coalesce into configurations that produce either high or non-high ELRC. Based on the above reasoning, this study adopts a three-dimensional analytical framework to capture the constituents of the Configurational Field in emergency logistics (Figure 1).

3.2 A Three-dimensional configurational field framework

The selection of the three dimensions is grounded in both theoretical reasoning and empirical relevance, each addressing a distinct facet of emergency logistics responsiveness capacity (ELRC). The resource context dimension draws on resource dependence theory (67, 68), which holds that organizations must manage external constraints and internal resource endowments to navigate environmental uncertainty. In natural disaster contexts, this translates directly into the dual challenge of responding to disaster-induced shocks while mobilizing adequate fiscal resources (3, 17). The infrastructure dimension builds on logistics and digital governance research, recognizing that technical and information connectivity are necessary conditions for effective relief operations (53, 69, 70). The governance capacity dimension is anchored in collaborative governance theory (71, 72) and agenda-setting theory (73, 74), which together underscore the importance of both state-led attention and societal mobilization in disaster response. Crucially, these three dimensions are not independent layers but mutually constitutive: resource constraints shape technological development, technology determines how resources can be mobilized, and governance capacity influences both resource allocation and infrastructure use. Together, they form a dynamic whole in which no single dimension is sufficient to explain ELRC on its own.

3.2.1 Resource context dimension

The first dimension is the resource context dimension. It captures both the external shock pressure generated by disasters that demand immediate response and the internal fiscal capacity that enables local governments to mobilize resources. Disaster Cost (DC) represents the external trigger that activates the entire emergency logistics system. Without such shocks, the need for high ELRC may not arise (3). Fiscal Autonomy (FA) represents the internal resource baseline that determines whether a province has the financial means to translate triggered demand into effective action. If a province faces high disaster costs but lacks fiscal capacity, it cannot respond effectively. Thus, these two conditions form the external boundary of the Configurational Field. Drawing on resource dependence theory (68), which highlights how organizations manage external constraints and internal resource endowments to navigate uncertainty (67, 68), this dimension defines the boundary conditions under which emergency logistics operates, reflecting how provincial governments confront resource constraints and fiscal pressures in disaster situations (17).

3.2.2 Infrastructure dimension

The second dimension is the infrastructure dimension, representing the intelligent foundations for emergency logistics. While physical road networks are often severely compromised during disasters (69), intelligent dispatch platforms and information systems are essential for maintaining coordination

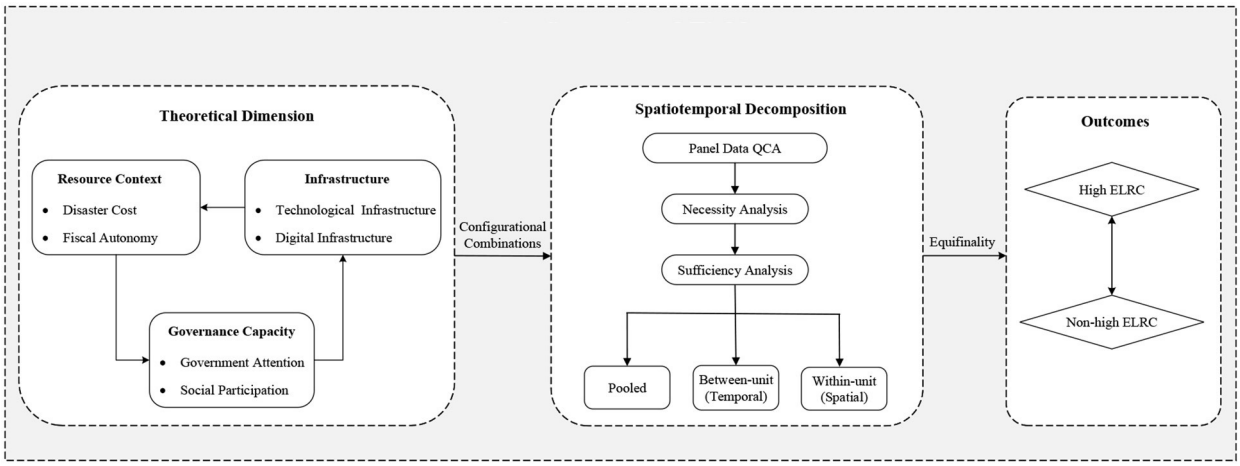

FIGURE 1
Configurational field analytical framework.

and re-routing relief supplies. These technological systems have thus become core infrastructural components of modern emergency logistics. Since the construction and maintenance of these systems rely heavily on government fiscal support, we measure the first facet using Local Fiscal Expenditure on Science and Technology. The second facet, Digital Infrastructure, enables real-time coordination and decision-making, with strategic digitalization emerging as a key enabler for resilience (70). Digital platforms enhance resource allocation (75), and empirical evidence confirms that smart city infrastructure significantly improves disaster response (42). We measure this using the Open Data Index, reflecting institutional capacity for cross-departmental data sharing. Together, fiscal support for intelligent systems and data interoperability determines the speed and transparency of relief operations. According to resource dependence theory, these technical resources are critical for reducing environmental uncertainty (68). Thus, this dimension constitutes the technological backbone of the Configurational Field.

3.2.3 Governance capacity dimension

The third dimension is the governance capacity dimension. It consists of Government Attention (GA) and Societal Participation (SP), reflecting both internal political willingness and the mobilization capacity of external societal actors. Government attention signals political priority and directs bureaucratic resources. The government undertakes three fundamental roles in humanitarian logistics: the host regulator, the funder and responder, and the coordinator (76). Agenda-setting theory (73, 74) establishes that policy attention is a scarce resource that determines which issues receive government action; in emergency logistics, higher government attention accelerates bureaucratic responses and resource allocation. Social participation captures the mobilization of non-state actors, including non-profit organizations, community groups, and private enterprises. We measure this using Social Organization Density (number of organizations per 10,000 residents). Collaborative governance theory (71, 72) emphasizes that effective disaster management depends not only on formal institutional arrangements but also on sustained political commitment and inclusive partnerships. Social participation is not an alternative to state capacity but an extension of governance capacity itself, reflecting the ability of the state to mobilize and coordinate societal resources in disaster response (24). Cross-organizational governance for extreme disaster risk represents a critical challenge, and emerging technologies transform collaborative governance through complex adaptive mechanisms (50). Emergency response network resilience exhibits dynamic adaptability and is significantly associated with organizational attributes and behaviors, highlighting the importance of multi-subject governance (77). Collaboration between non-profit organizations and enterprises plays a crucial role in disaster preparedness (51), and social assistance networks have been proposed as new disaster response logistics structures to improve relief operation efficiency (78). In the Configurational Field, this dimension drives the organizational and social dynamics that shape ELRC.

It is the combination and interaction of conditions across the three dimensions that produces high or non-high ELRC. A province may have abundant fiscal resources but weak infrastructure, in which case high ELRC remains unattainable. Another province may have well-developed infrastructure but insufficient governance capacity, leading to disorganized responses. Thus, the six conditions can only be understood as elements of a configurational whole. The Configurational Field framework does not ask which single factor matters most; instead, it asks what combinations of factors, under what contextual conditions, lead to high responsiveness. Guided by this theoretical framework, the study employs panel data QCA to empirically identify and compare the configurational pathways to high ELRC across Chinese provinces from 2017 to 2024.

4 Research design

4.1 Research approach

This study employs panel data QCA (26) to examine the configurational pathways to high ELRC. Table 1 situates panel data QCA within the broader QCA family by comparing its core features with other major QCA approaches.

As summarized in Table 1, Panel data QCA explicitly decomposes consistency into pooled, between-unit, and within-unit components. This decomposition directly aligns with the theoretical logic of the Configurational Field developed in Section 3, allowing us to identify which pathways are generalizable across Chinese provinces and which vary over time or specific regions. Following the calculation logic of Castro and Ariño (26), we define between-unit variation as the cross-sectional relationship fixed by year, thereby reflecting temporal stability, and within-unit variation as the longitudinal relationship fixed by case, thereby capturing spatial heterogeneity.

The analytical procedure follows the standard two-stage logic (26). The first stage is necessity analysis, which assesses whether any single condition is necessary for high ELRC. Following Schneider and Wagemann (20), we consider a condition necessary if its pooled consistency exceeds 0.9. Importantly, panel data QCA also calculates between-unit (temporal) and within-unit (spatial) adjustment distances for each condition. The second stage is sufficiency analysis, which identifies the configurational pathways through truth table construction and Boolean minimization. Following best practices in configurational research, we carefully consider calibration decisions, model specification, and the interpretation of intermediate solutions to ensure the transparency and replicability of our analysis (47). All variables are calibrated into fuzzy-set membership scores using the direct method of calibration (66). All data preprocessing and panel decomposition were conducted using Python scripts, while the necessity and sufficiency analyses were performed using fsQCA 4.0 software.

Based on the methodological framework, this study constructs a balanced panel dataset covering 29 Chinese provinces from 2017 to 2024. Tibet and Xinjiang are excluded due to severe data missingness in key provincial statistical yearbooks, while Hong Kong, Macao, and Taiwan are excluded because their distinct administrative systems are not directly comparable to mainland provinces. The total number of observations is 232. This time window captures the establishment of the Ministry of Emergency Management in 2018 and a series of major natural disasters, providing rich empirical variation (16). Although the COVID-19 pandemic occurred within this window, the analytical focus lies in the structural trends of disaster-driven logistics. This concern is partially mitigated by directly measuring disaster costs via economic losses and government attention via policies specifically related to natural disaster emergency logistics.

4.2 Variable measurement

This section operationalizes the six condition variables and the outcome variable within the three-dimensional Configurational Field framework. All variables are measured annually for each province from 2017 to 2024. Detailed calculation procedures, the complete indicator list, and data sources are provided in **Appendix A** (Supplementary Tables A1, A2).

4.2.1 Outcome variable: emergency logistics responsiveness capacity (ELRC)

ELRC reflects a province's ability to mobilize, transport, and distribute relief supplies swiftly and effectively during natural disasters. Following the indicator framework of Chen et al. (13), we adopt the entropy-weighted TOPSIS method to construct the ELRC index. This index comprises six first-level dimensions and 24 third-level indicators. The calculation procedure, illustrated in Figure 2, involves five stages: data input, min-max normalization, entropy weighting, TOPSIS evaluation, and final output.

To accurately capture the structural characteristics of our research period, we collected the raw data for all 24 indicators across the 29 provinces from 2017 to 2024. The entropy weights were calculated based on this newly constructed panel dataset, and the ELRC scores were subsequently computed using the TOPSIS method. The complete indicator list, newly calculated weights, and calculation steps are provided in **Appendix**

TABLE 1 A typology of QCA approaches.

Approach	Core logic	Data requirement	Temporal treatment	Key references
csQCA	Set membership is binary	Dichotomous variables (0/1)	Not addressed (static)	(88)
mvQCA	Set membership is multi-category	Multi-category variables	Not addressed (static)	(89–91)
fsQCA	Set membership is continuous	Continuous variables (calibrated to 0–1)	Not addressed (static)	(66)
TQCA	Introduces event sequences to csQCA	Dichotomous variables and temporal order information	Sequence order (event sequence)	(92)
Panel Data QCA	Decomposes consistency into pooled, between-unit (temporal), and within-unit (spatial) components	Panel data	Decomposed into between-unit (temporal) and within-unit (spatial)	(26)

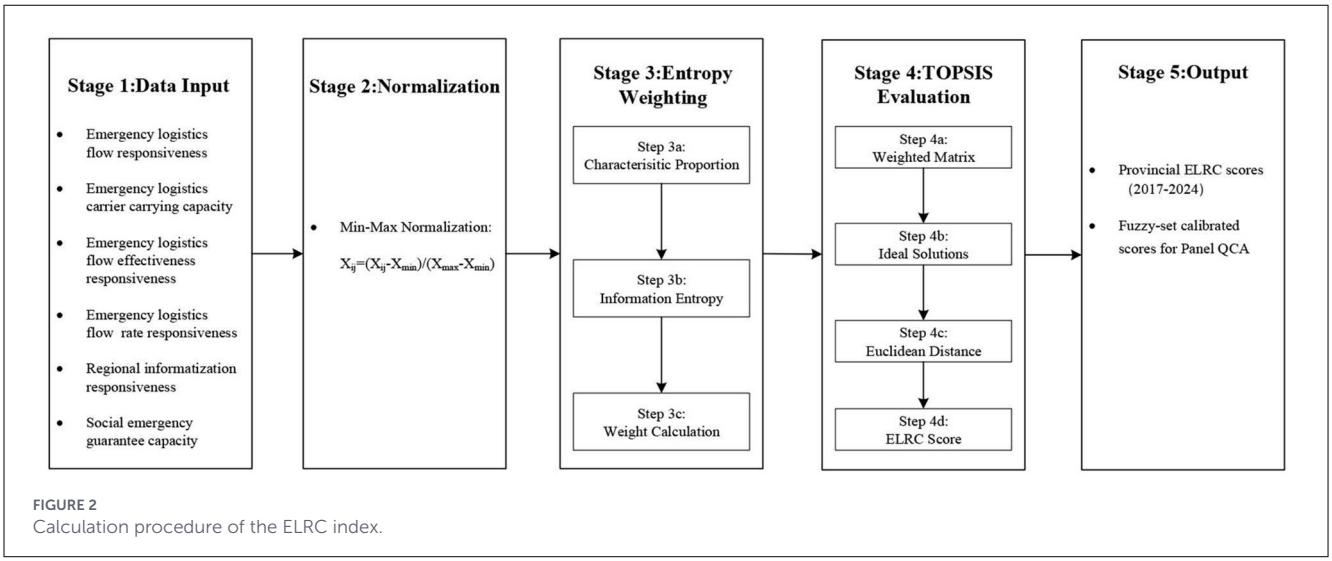

FIGURE 2
Calculation procedure of the ELRC index.

A (Supplementary Table A1). Higher ELRC scores indicate stronger responsiveness.

4.2.2 Condition variables

4.2.2.1 Disaster cost (DC)

Within the resource context dimension, DC captures the external shock pressure that triggers demand for emergency logistics. It measures the direct economic loss caused by natural disasters (in billion yuan), reflecting the severity of disaster impact (3). Provinces with higher disaster losses face stronger pressure to activate emergency logistics systems. Data are sourced from the *China Statistical Yearbook*.

4.2.2.2 Fiscal autonomy (FA)

Within the resource context dimension, FA captures the internal fiscal capacity that enables provincial governments to mobilize resources in response to disaster shocks. It is the reversed vertical fiscal imbalance (VFI) index computed from provincial budgetary revenue and expenditure. Greater fiscal autonomy means that a province can allocate its own resources more freely, which directly affects its ability to invest in emergency logistics infrastructure and operations. Following the Eyraud-Lusinyan method (79–81), VFI is calculated as:

$$VFI = 1 - \frac{Fiscal\ revenue\ decentralization}{Fiscal\ expenditure\ decentralization} \bullet (1 - Fiscal\ self - sufficiency\ gap)$$

where:

- $Fiscal\ expenditure\ decentralization = \frac{(Provincial\ per\ capita\ revenue)}{(Provincial\ per\ capita\ revenue + Central\ per\ capita\ revenue)}$
- $Fiscal\ revenue\ decentralization = \frac{(Provincial\ per\ capita\ expenditure)}{(Provincial\ per\ capita\ revenue + Central\ per\ capita\ revenue)}$
- $Fiscal\ self - sufficiency\ gap = 1 - \frac{(Provincial\ revenue)}{(Provincial\ expenditure)}$

Data are derived from the *China Statistical Yearbook* and *China Fiscal Yearbook*. We define FA = 1–VFI, so that higher FA values indicate stronger fiscal autonomy. China's fiscal system has undergone significant decentralization reforms, yet central-local fiscal relations remain a key determinant of local government behavior and policy priorities (59, 60).

4.2.2.3 Technological infrastructure (TI)

Within the infrastructure dimension, TI captures the technological and innovative capacity that underpins modern emergency logistics systems. It is measured by local government expenditure on science and technology (in hundred million yuan). This indicator reflects the provincial government's fiscal commitment to investing in intelligent dispatch platforms, real-time monitoring systems, and data-driven disaster response (70). Higher values indicate greater technological investment. Data are sourced from the *China Statistical Yearbook*.

4.2.2.4 Digital infrastructure (DI)

DI constitutes the informational backbone that enables real-time coordination. It is measured by the provincial Open Data Index published by Fudan University's Digital Governance Research Center, which evaluates data availability, platform functionality, and data usability. Digital infrastructure is a critical enabler for coordinating multi-agency emergency logistics in real time (70). Higher scores indicate more developed DI for information sharing and coordination. Data sources are the China Statistical Yearbook and the Fudan index reports.

4.2.2.5 Government attention (GA)

Within the governance capacity dimension, GA captures the political willingness of the state to prioritize emergency logistics. It is measured by the number of policy documents related to emergency logistics and emergency supplies issued at the provincial level. The initial document corpus was retrieved from the PKULaw database and provincial government websites using a keyword search encompassing "emergency logistics" "emergency supplies" and "disaster relief materials." These keywords were selected based on the emergency logistics literature (4) and validated through a pilot review. The initial results were manually screened to exclude policies clearly unrelated to natural disasters. For each retained document, we assigned a weight based on the authority level of its issuing body:

- 1.0: Documents jointly issued by the Provincial People's Congress and the Provincial Government
- 0.8: Documents issued by either the Provincial People's Congress or the Provincial Government alone
- 0.5: Documents issued by other provincial departments

This weighting scheme reflects the institutional hierarchy of China's policy-making system, where higher-level and multi-body issuances indicate stronger political commitment and broader inter-agency coordination. In China's governance system, local government attention is shaped by a combination of vertical pressure from above and disaster-driven demands from below (56). The weighted sum of all documents in a given province-year constitutes the GA score. Higher attention signals stronger political priority, which tends to accelerate bureaucratic responses and resource allocation for emergency logistics.

4.2.2.6 Social participation (SP)

Within the governance capacity dimension, SP captures the mobilization capacity of external societal actors that can supplement government efforts in relief operations. It is measured by the density of registered social organizations (number of organizations per 10,000 residents). Social organizations are crucial in disaster response due to their flexibility, rapid response capabilities, and in-depth knowledge of local communities. A higher density suggests a more vibrant civil society that can supplement government efforts in relief distribution (51, 82). Data are drawn from the China Statistical Yearbook.

All variables are calibrated into fuzzy-set membership scores using the direct method of calibration (66). The three qualitative anchors (full non-membership, crossover, and full membership) were set at the 5th, 50th, and 95th percentiles of the pooled distribution. This choice is substantively and theoretically justified on three grounds. First, the 5th and 95th percentiles protect the calibration from extreme outliers, preventing anomalous cases from distorting the fuzzy-set boundaries. Second, using the pooled distribution provides a fixed measuring rod across all years. If year-specific percentiles were used, the crossover point would shift annually, making cross-year comparisons (temporal stability) statistically invalid (20). Third, regarding the potentially skewed distributions of Government Attention (GA) and Social Participation (SP), we examined their annual distributions (mean, median, min, max) from 2017 to 2024 (Supplementary Table A3). The results confirm that their structural shifts were marginal, thereby validating the use of pooled anchors across the entire period.

The calibrated fuzzy sets are used in the subsequent necessity and sufficiency analyses. Table 2 summarizes the definitions and data sources, and Table 3 reports the calibration thresholds.

5 Findings

5.1 Necessity analysis

Following the panel data QCA framework (26), we calculated the necessity metrics (pooled consistency, pooled coverage, and adjustment distances) for all six conditions and their negations against both the presence (ELRC) and absence (∼ELRC) of high ELRC. The between-unit and within-unit adjustment distances diagnose whether a condition's necessity relationship suffers from significant temporal or spatial heterogeneity. Following Fan et al. (55), we set the threshold at 0.2: an adjustment distance below 0.2 indicates that the pooled estimates are reliable; otherwise, the relationship varies notably across years or provinces, warranting further spatiotemporal decomposition. As shown in Table 4, we report the pooled consistency, coverage, and adjustment distances for all conditions and their negations.

5.1.1 Pooled consistency analysis

For high ELRC, the pooled consistency of all conditions and their negations fall strictly below the conventional necessity threshold of 0.9. The highest values are Fiscal Autonomy (FA) at 0.789 and Technological Infrastructure (TI) at 0.782. Similar patterns are observed for non-high ELRC (∼ELRC), where no condition exceeds 0.9. This indicates that no single factor alone can determine emergency logistics responsiveness, thereby necessitating a configurational sufficiency analysis.

Regarding the between-unit adjustment distances, all values are below 0.2, suggesting strong temporal stability. In particular, the between-unit distances of Technological Infrastructure (TI/∼TI) and Digital Infrastructure (DI/∼DI) are relatively small, indicating their influence has been highly consistent over time. Concerning the within-unit adjustment distances, most values exceed 0.2, indicating pronounced spatial heterogeneity. For instance, the within-unit distances of ∼Technological Infrastructure (∼TI) and Fiscal Autonomy (FA) are 0.372 and 0.368, respectively, meaning their effects vary greatly across provinces.

5.1.2 Between-unit effect analysis

To further reveal the temporal dynamics of the relationships between each antecedent condition and ELRC, Figure 3 plots the annual consistency trends of each condition from 2017 to 2024.

Overall, the annual consistency of all conditions remains consistently below the 0.9 necessity threshold, affirming that no

TABLE 2 Variable definitions and data sources.

Variable	Abbr.	Operationalization	Data source	Time span
Outcome				
Emergency logistics responsiveness capacity	ELRC	Entropy-weighted TOPSIS composite index based on six first-level dimensions	China Statistical Yearbook;	2017–2024
Conditions				
Disaster cost	DC	Direct economic loss from natural disasters (billion yuan)	China Statistical Yearbook	2017–2024
Fiscal autonomy	FA	Reversed vertical fiscal imbalance (1-VFI), computed via the Eyraud-Lusinyan method.	China Statistical Yearbook; China Fiscal Yearbook	2017–2024
Technological infrastructure	TI	Local government expenditure on science and technology	China Statistical Yearbook	2017–2024
Digital infrastructure	DI	Provincial Open Data Index	Fudan University Digital Governance Research Center (http://4cool.ifopendata.cn/case)	2017–2024
Government attention	GA	Weighted count of provincial policy documents on emergency logistics	PKULaw database; provincial government websites	2017–2024
Social participation	SP	Density of registered social organizations (per 10,000 residents)	China Statistical Yearbook	2017–2024

TABLE 3 Calibration thresholds.

Variable	Full non-membership (0.05)	Crossover (0.50)	Full membership (0.95)
ELRC	0.081	0.214	0.445
DC	352.62	641.50	698.48
FA	0.092	0.243	0.672
TI	25.555	106.625	717.147
DI	1.400	24.145	66.964
GA	1	4	10
SP	3.905	5.726	10.353

single condition independently determines ELRC. Notably, Fiscal Autonomy (FA) and Technological Infrastructure (TI) exhibit the highest consistency levels throughout the period, demonstrating their long-term structural importance. In contrast, Disaster Cost (DC) and Government Attention (GA) display pronounced fluctuations, experiencing a sharp decline in 2021, a year marked by the concurrent shocks of the COVID-19 pandemic and severe natural disasters. While these event-driven shocks temporarily alter the necessity consistency of specific conditions, they do not necessarily imply a breakdown of the overall governance system. Whether these fluctuations alter the sufficient configurations of conditions will be examined in the subsequent sufficiency analysis.

5.1.3 Within-unit effect analysis

To rigorously address spatial heterogeneity without violating the independence assumption of province-year observations, we aggregated the data to the provincial level and calculated the mean consistency scores for each of the 29 provinces across the 2017–2024 period.

As shown in Figure 4, there is pronounced spatial variation in the mean necessity consistency across provinces. Northern and coastal provinces such as Shanxi, Inner Mongolia, Hebei, and Shandong, exhibit exceptionally high mean consistency scores above 0.99. This indicates that their emergency logistics governance aligns closely with the nationally prevalent institutionalized routines and diversified networks (83, 84). In contrast, provinces like Chongqing (0.165), Fujian (0.337), and Hainan (0.350) display significantly lower scores. This suggests that their underlying governance logics are highly idiosyncratic and deviate from the national template. For these regions, local structural dependencies and binding constraints (e.g., geographic limitations or specific disaster profiles) may override the general necessity of the six conditions, leading to distinct configurational realities (77, 85). These spatial variations in necessity consistency reflect the distinct nature of the Configurational Field across different regions. They provide the empirical basis for understanding why a differentiated policy design is required, which will be further elaborated in Section 6 (86).

5.2 Sufficiency analysis

We further conducted sufficiency analysis to reveal the equifinal pathways to high and non-high emergency logistics responsiveness. The raw consistency threshold was set to 0.85, the frequency threshold to 2, and PRI consistency was monitored at the recommended minimum of 0.75 (20, 47). Directional expectations were set such that all six conditions are expected to contribute positively to ELRC. The resulting configurations are presented in Table 5.

TABLE 4 Necessity analysis results.

Condition	ELRC				∼ELRC			
	Pool_Cons	Pool_Cov	Between_Dist	Within_Dist	Pool_Cons	Pool_Cov	Between_ Dist	Within_ Dist
DC	0.616	0.692	0.063	0.348	0.643	0.735	0.057	0.342
∼DC	0.697	0.598	0.048	0.291	0.641	0.56	0.036	0.313
FA	0.789	0.8	0.05	0.269	0.52	0.537	0.043	0.368
∼FA	0.53	0.514	0.032	0.368	0.794	0.783	0.04	0.278
TI	0.782	0.791	0.023	0.239	0.51	0.526	0.05	0.355
∼TI	0.52	0.504	0.03	0.372	0.785	0.775	0.018	0.29
DI	0.679	0.711	0.038	0.309	0.596	0.635	0.023	0.347
∼DI	0.617	0.577	0.056	0.34	0.691	0.658	0.047	0.304
GA	0.664	0.683	0.079	0.322	0.601	0.629	0.051	0.34
∼GA	0.618	0.589	0.03	0.33	0.668	0.649	0.072	0.311
SP	0.629	0.66	0.051	0.348	0.676	0.722	0.06	0.346
∼SP	0.708	0.661	0.052	0.29	0.635	0.604	0.026	0.345

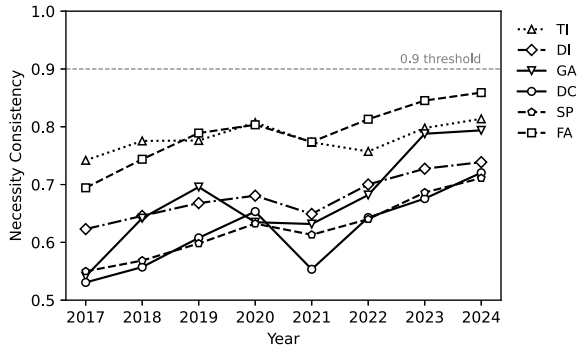

FIGURE 3
Annual consistency trends of each condition (2017–2024).

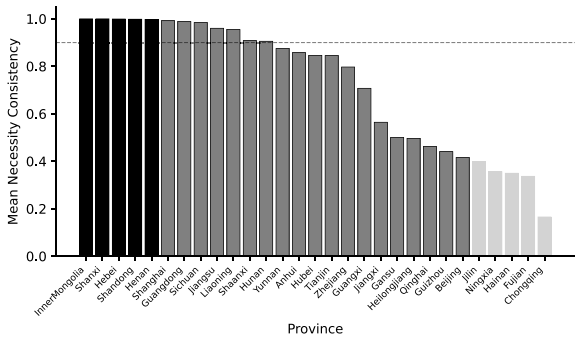

FIGURE 4
Provincial-level mean necessity consistency of conditions (2017–2024).

Overall, the solution consistency for high ELRC is 0.927 and the coverage is 0.565. The analysis identifies five equifinal pathways that explain how conditions coalesce to achieve high responsiveness (Table 5). Following the Configurational Field framework, we categorize these pathways into four distinct models of resource orchestration:

5.2.1 Routine administration pathway (H1 and H2)

The first pathway comprises H1 (FA*TI*∼GA*∼SP) and H2 (DC*FA*TI*∼GA*SP). The core conditions for both are high Technological Infrastructure (TI), high Fiscal Autonomy (FA), and low Government Attention (∼GA). This combination reflects a routine administration logic, where emergency logistics is embedded as an institutionalized function. In well-endowed provinces, robust fiscal and technological foundations enable the system to maintain high responsiveness without relying heavily on episodic political mobilization. H1 demonstrates that these provinces can operate effectively without relying on external social participation (∼SP), as their institutionalized routines are highly self-sufficient. H2 further incorporates high Disaster Cost (DC) and Social Participation (SP), indicating that in regions experiencing disaster shocks, these structural capacities facilitate the coordination of societal resources.

5.2.2 Collaborative governance pathway (H3)

This pathway (FA*TI*GA*∼DI*SP) represents a balanced collaborative model. Here, high technological and fiscal capacities are complemented by high Government Attention (GA) and societal mobilization (SP). This pathway aligns with collaborative governance theory (71), illustrating how political attention

TABLE 5 Configurational results ($N = 232$).

Conditions	ELRC					∼ELRC	
	H1	H2	H3	H4	H5	N1	N2
DC	○	●	○	⊗	○	●	●
FA	●	●	●	●	○	⊗	⊗
TI	●	●	●	⊗	●	⊗	⊗
DI	○	○	⊗	⊗	⊗	○	⊗
GA	⊗	⊗	●	○	⊗	⊗	○
SP	⊗	●	●	○	⊗	●	●
consistency	0.951	0.932	0.946	0.956	0.965	0.919	0.913
Raw coverage	0.308	0.330	0.306	0.323	0.282	0.367	0.397
Unique coverage	0.037	0.067	0.036	0.065	0.027	0.027	0.057
Between-unit adjustment distance	0.029	0.031	0.023	0.022	0.022	0.021	0.031
Within-unit adjustment distance	0.111	0.133	0.128	0.131	0.115	0.171	0.189
Solution consistency	0.927					0.909	
Solution coverage	0.565					0.424	

● indicates the presence of a core condition; ⊗ indicates the absence of a core condition; ○ indicates a peripheral condition.

can bridge state resources and societal forces to achieve high responsiveness.

5.2.3 Fiscal substitution pathway (H4)

H4 (∼DC*FA*∼TI*∼DI) demonstrates that under low disaster pressure (∼DC), high Fiscal Autonomy (FA) compensates for weak technological and digital infrastructure (∼TI, ∼DI). Rather than building internal technological platforms, these provinces rely on their financial capacity to procure external logistics services and relief supplies. This indicates that strong fiscal endowments can directly purchase responsiveness, acting as a functional substitute for local technological readiness during stable periods. However, it also implies that such a model is primarily effective under low disaster exposure.

5.2.4 Technological autonomy pathway (H5)

H5 (TI*∼DI*∼GA*∼SP) demonstrates a self-sufficient model driven primarily by high Technological Infrastructure (TI), operating effectively in the absence of digital interoperability (∼DI), government attention (∼GA), and social participation (∼SP). This indicates a highly autonomous emergency logistics system where traditional technological foundations alone are sufficient to maintain responsiveness, functioning independently of external political mobilization or cross-departmental data sharing. This autonomy implies that certain provinces have established highly standardized and self-sustaining operational routines within their logistics infrastructure, reducing their reliance on *ad-hoc* political mobilization (∼GA) or grassroots societal networks (∼SP) during emergencies.

5.2.5 Pathways to non-high ELRC: the structural vulnerability trap (N1 and N2)

The pathways to non-high ELRC exhibit a notable convergence. Both N1 (DC*∼FA*∼TI*∼GA*SP) and N2 (DC*∼FA*∼TI*∼DI*SP) share a highly similar core structure: high Disaster Cost (DC), low Fiscal Autonomy (∼FA), low Technological Infrastructure (∼TI), and high Social Participation (SP). Their primary difference lies in their peripheral conditions: N1 operates alongside low Government Attention (∼GA), whereas N2 operates alongside low Digital Infrastructure (∼DI).

This convergence illustrates the principle of causal asymmetry (48, 66). While achieving high ELRC is associated with a complex orchestration of multiple pathways, non-high responsiveness is largely constrained by a specific combination of structural deficits. Drawing on the concept of structural vulnerability in disaster risk management (34), this configuration indicates a "Structural Vulnerability Trap." When a province lacks both financial and technological foundations but faces severe disaster exposure, its capacity to respond is fundamentally compromised.

Furthermore, the presence of Social Participation (SP) in these pathways underscores the limits of societal mobilization. Aligned with collaborative governance theory, societal actors can supplement state efforts (71, 72). However, without foundational state capacities (FA and TI), societal mobilization is structurally constrained and unable to prevent non-high responsiveness. This confirms that state capacity and societal participation are not interchangeable; the latter requires a minimum threshold of state infrastructure to function effectively.

Finally, comparing the adjustment distances, the non-high pathways exhibit larger within-unit (spatial) distances (0.171–0.189) than the high pathways (0.111–0.133), while both maintain low between-unit (temporal) distances. This asymmetry further suggests that while high-performing models can be replicated more

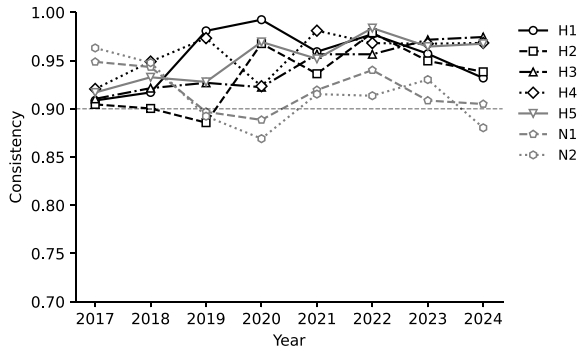

FIGURE 5
Annual consistency trends of each configuration (2017–2024).

uniformly across provinces, the conditions leading to failure are more sensitive to local spatial contexts and institutional variations.

5.2.6 Between-unit results

To verify the temporal stability of the configurational patterns for high and non-high ELRC, we plotted the annual consistency trends of each configuration from 2017 to 2024 (Figure 5).

The between-unit adjustment distances of all configurations range from 0.021 to 0.031, well below the 0.2 threshold recommended by Castro and Ariño (26), and their annual consistency remains above 0.86 throughout the period. This indicates that the core configurational patterns exhibit no significant temporal effects and possess strong temporal robustness.

Despite the overall stability, concentrated fluctuations occurred in 2020. The two non-high pathways (N1 and N2) declined to 0.888 and 0.869 respectively, reflecting the temporary disruption of transport networks and fiscal strain on provinces with weak technological and financial foundations. Conversely, the high-ELRC pathways mostly remained above 0.90, with H3 (the collaborative governance model) showing a steady upward trend from 0.910 in 2017 to 0.974 in 2024. These fluctuations remained within a narrow band, and all configurations returned to baseline levels by 2022. This suggests that while major events temporarily shift the explanatory power of different pathways, they do not fundamentally alter the underlying configurational logic.

The temporal stability carries important implications. It suggests that the Configurational Field exhibits institutional inertia that buffers against transient disruptions. Once a province settles into a particular configurational pathway, it tends to persist unless underlying conditions change systematically. Short-term shocks, while capable of producing temporary effects, are unlikely to permanently shift a province's configurational position.

5.2.7 Within-unit results

Figure 6 presents the consistency distribution of all seven configurations across the 29 provinces. Using the predefined 0.75 consistency threshold, most provinces exhibit high adherence to the mainstream configurational logic. Several provinces, however, show notable deviations below this threshold: Chongqing falls below 0.75 on all five high-ELRC pathways (H1–H5), whereas its membership in the non-high pathways remains high; this may plausibly relate to mountainous terrain that limits the substitutability of fiscal and technological endowments for routine logistics capacity (85). Jilin deviates only on H4 (the fiscal substitution pathway). Hebei, Inner Mongolia, and Shanxi deviate on both non-high pathways (N1, N2), and Shandong deviates on N1 only.

These spatial variations highlight the spatial embeddedness of the Configurational Field. The efficacy of emergency logistics governance appears to be contingent upon local geographical and institutional contingencies, indicating that high responsiveness can emerge from distinct regional compositions rather than a universal template. This finding underscores the theoretical necessity of moving beyond standardized, one-size-fits-all policy prescriptions. Instead, it highlights that effective disaster response requires a context-sensitive approach, where policy interventions are carefully tailored to a province's unique structural endowments, historical legacies, and specific geographical constraints. Consequently, understanding these localized configurational logics provides critical insights for policymakers seeking to optimize resource allocation and enhance regional resilience in large, geographically diverse countries like China.

5.3 Robustness checks

To ensure the robustness of our findings, we conducted three sets of rigorous robustness checks: alternative calibration anchors, excluding the 2018 institutional transition year, and excluding the COVID-19 pandemic years.

First, we tested alternative calibration anchors (Table 6). We re-calibrated all variables using the 10th, 50th, and 90th percentiles instead of the baseline 5/50/95 percentiles. Under this specification, the solution consistencies remain highly robust at 0.933 (high ELRC) and 0.906 (non-high ELRC). The model yields four high-ELRC pathways (H1–H4) and three non-high pathways (N1–N3).

For the high-ELRC pathways, although the specific combinations of conditions reorganize into four pathways (down from five in the baseline), the fundamental driving forces remain intact: three of the four pathways (H2, H3, H4) contain high Fiscal Autonomy (FA), and three of the four (H1, H2, H4) contain high Technological Infrastructure (TI). This confirms the strong equifinality of high performance, where different calibration standards alter the specific recipes but not the underlying reliance on foundational capital. Crucially, the structural vulnerability trap remains evident for non-high ELRC. All three non-high pathways (N1-N3) share the core absence of Technological Infrastructure (~TI), reaffirming that the lack of technical foundations is the most fatal structural deficit. Furthermore, while N1 and N2 also lack Fiscal Autonomy (~FA), N3 demonstrates that even with high Fiscal Autonomy (FA), a province will still fall into the trap if it lacks technological

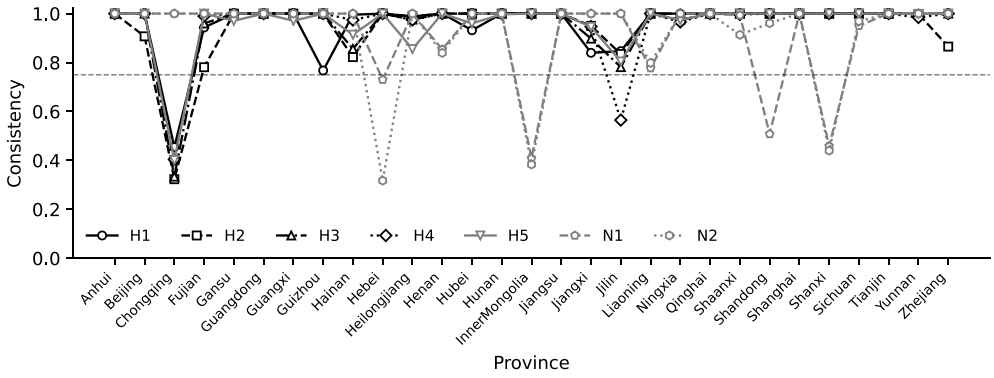

FIGURE 6
Consistency distribution of configurations across provinces.

TABLE 6 Robustness check: alternative calibration anchors (10th, 50th, 90th percentiles).

Conditions	ELRC				~ELRC		
	H1	H2	H3	H4	N1	N2	N3
DC	⊗	•	⊗	⊗	•	•	•
FA	○	•	•	•	⊗	⊗	•
TI	•	•	⊗	•	⊗	⊗	⊗
DI	⊗	⊗	⊗	⊗	•	⊗	•
GA	⊗	•	⊗	⊗	⊗	⊗	⊗
SP	⊗	•	○	⊗	○	•	•
consistency	0.953	0.942	0.964	0.938	0.929	0.925	0.937
Raw coverage	0.244	0.219	0.242	0.269	0.250	0.338	0.237
Unique coverage	0.030	0.062	0.053	0.056	0.034	0.144	0.021
Between-unit adjustment distance	0.021	0.014	0.015	0.034	0.034	0.027	0.056
Within-unit adjustment distance	0.114	0.138	0.121	0.137	0.159	0.171	0.146
Solution consistency	0.933				0.906		
Solution coverage	0.422				0.415		

infrastructure (~TI) and faces severe disaster exposure (DC). This specific finding strongly reinforces our theoretical argument that financial capital alone cannot substitute for technological readiness in disaster response.

Second, we excluded the 2018 institutional transition year (Table 7). The year 2018 marked the establishment of the Ministry of Emergency Management. Excluding this year ($N = 203$) yields six high-ELRC pathways (H1–H6) and two non-high pathways (N1–N2), with solution consistencies of 0.901 and 0.902. While the high-ELRC pathways increase from five to six, this reflects the temporary administrative fluidity during the reform, where dual-engine models (FA and TI combined) temporarily diverge into single-engine models. Specifically, H1 relies solely on high Fiscal Autonomy (~TI), whereas H4 and H5 operate with high Technological Infrastructure but lack Fiscal Autonomy (~FA). This indicates that during institutional transitions, provinces can still achieve high responsiveness as long as at least one foundational engine is strong. Conversely, the non-high pathways (N1 and N2) remain highly stable, as both are still characterized by the joint absence of FA (~FA) and TI (~TI) under high disaster pressure. This confirms that while high-performance recipes may fluctuate during transitions, the foundational threshold for failure remains rigorously constant.

Third, we excluded the 2020-2021 pandemic years (Table 8). The COVID-19 pandemic caused unprecedented systemic shocks to logistics networks. After excluding these two years ($N = 174$), the model returns to five high-ELRC pathways (H1–H5) and two non-high pathways (N1–N2), with solution consistencies of 0.931 and 0.914. While the number of pathways mirrors the baseline, the internal structure of the high-ELRC models exhibits a clear adaptive shift, specializing into distinct single-engine strategies. For instance, H1 relies primarily on Technological Infrastructure (TI) with Fiscal Autonomy (FA) as a peripheral condition, while H2 relies primarily on FA with TI absent. This reflects the reality of pandemic disruptions, where provinces either leveraged digital/technological dispatch (TI) or relied on strong fiscal capacity (FA) to overcome physical logistics blockades. Crucially, despite this adaptive shift in high-ELRC pathways, the non-high pathways

TABLE 7 Robustness check: excluding the 2018 transition year ($N = 203$).

Conditions	ELRC						∼ELRC	
	H1	H2	H3	H4	H5	H6	N1	N2
DC	⊗	○	●	⊗	●	⊗	●	●
FA	●	●	●	⊗	⊗	●	⊗	⊗
TI	⊗	●	●	●	●	●	⊗	⊗
DI	⊗	○	○	⊗	●	●	●	⊗
GA	○	●	○	⊗	●	⊗	⊗	○
SP	○	●	●	⊗	⊗	⊗	○	●
consistency	0.956	0.896	0.901	0.965	0.945	0.952	0.926	0.913
Raw coverage	0.322	0.454	0.475	0.277	0.276	0.272	0.301	0.402
Unique coverage	0.058	0.019	0.044	0.023	0.023	0.025	0.052	0.153
Between-unit adjustment distance	0.023	0.029	0.035	0.014	0.020	0.032	0.030	0.027
Within-unit adjustment distance	0.126	0.169	0.168	0.088	0.122	0.111	0.162	0.192
Solution consistency	0.901						0.902	
Solution coverage	0.689						0.454	

TABLE 8 Robustness check: excluding the 2020–2021 pandemic years ($N = 174$).

Conditions	ELRC					∼ELRC	
	H1	H2	H3	H4	H5	N1	N2
DC	⊗	⊗	⊗	⊗	●	●	●
FA	○	●	●	●	●	⊗	⊗
TI	●	⊗	●	●	●	⊗	⊗
DI	⊗	⊗	⊗	⊗	⊗	○	⊗
GA	⊗	⊗	⊗	●	⊗	⊗	○
SP	⊗	○	⊗	●	●	●	●
consistency	0.958	0.959	0.945	0.954	0.944	0.921	0.917
Raw coverage	0.296	0.228	0.319	0.256	0.286	0.383	0.406
Unique coverage	0.030	0.048	0.053	0.031	0.053	0.024	0.046
Between-unit adjustment distance	0.024	0.017	0.028	0.014	0.033	0.021	0.030
Within-unit adjustment distance	0.105	0.116	0.123	0.116	0.129	0.168	0.189
Solution consistency	0.931					0.914	
Solution coverage	0.499					0.429	

(N1 and N2) remain highly stable, as both continue to be strictly trapped by the joint absence of FA (∼FA) and TI (∼TI) under high disaster pressure. This confirms that while success recipes can adapt to exogenous shocks, the structural vulnerability trap remains fundamentally rigid.

In summary, across all three alternative specifications, while the specific combinations of high-ELRC pathways exhibit adaptive shifts in response to calibration changes and exogenous shocks, the fundamental causal asymmetry remains structurally stable. High responsiveness consistently requires the presence of at least one foundational capital (FA or TI), whereas non-high ELRC remains strictly trapped by their joint absence (∼FA*∼TI) under disaster pressure. This confirms that our core theoretical argument is highly robust and is not an artifact of specific calibration choices or exogenous shocks.

6 Discussion

This study set out to examine the configurational pathways to high and non-high ELRC across Chinese provinces from 2017 to 2024, with particular attention to spatiotemporal heterogeneity. The findings yield several insights that speak to both the emergency logistics literature and the broader study of governance capacity in China.

6.1 Theoretical contributions: the configurational field as an analytical lens

This study introduces the concept of a Configurational Field to capture how multiple conditions across resource context, technological infrastructure, and governance capacity coalesce into stable yet spatially varied configurations that produce either high or non-high ELRC. The concept extends Bourdieu's field theory and Configurational Field Analysis to emergency logistics governance (21–23). The theoretical contribution of this framework is reflected in three aspects.

First, it clarifies Structural Positions and Constraints to interpret causal asymmetry. The framework identifies that foundational capital (FA and TI) occupies a dominant structural position. This is consistent with why high-ELRC pathways are equifinal (H1–H5), consistent with QCA's principle (48, 66), while non-high ELRC converges into a "Structural Vulnerability Trap" (N1 and N2), where social participation cannot substitute for foundational deficits. Second, it emphasizes Relational Dynamics and spatial contingency. The efficacy of resources is context-dependent. This helps account for the pronounced spatial heterogeneity, providing a contextualized interpretation for why provinces like Chongqing deviate in the context of geographic constraints. This provides a contextualized understanding of emergency logistics governance across different regions (13, 15). Third, it highlights Temporal Inertia. The structural distribution of capital creates path dependence. This may account for why core configurations remain stable despite institutional reforms and shocks, suggesting that institutional inertia buffers against transient disruptions.

In summary, these three aspects collectively extend the Configurational Field beyond identifying "what works," offering theoretical explanations for why certain combinations are structurally feasible or infeasible across specific times and places.

6.2 Temporal stability and spatial heterogeneity

The findings reveal a striking contrast between temporal stability and spatial heterogeneity. The between-unit adjustment distances of all configurations are below 0.05, suggesting that the core pathways have remained remarkably stable from 2017 to 2024 despite major institutional reforms and external shocks. The temporary fluctuations observed in 2020 and 2021, specifically the variations in single conditions, reflect short-term adaptive responses rather than fundamental restructuring of the configurational logic.

The spatial heterogeneity is equally pronounced. The within-unit adjustment distances are substantially larger, indicating that the same configurational pathways operate differently across regions according to local institutional endowments. The routine administration model (H1 and H2) prevails in well-endowed provinces with strong fiscal capacity and technological infrastructure. The collaborative governance model (H3) characterizes provinces that effectively integrate political attention with societal mobilization. The fiscal substitution model (H4) reflects a logic where provinces with high fiscal autonomy can compensate for the absence of local technological and digital infrastructure through external procurement or service outsourcing. The technological autonomy model (H5) reflects highly self-sufficient systems. These cases suggest that local institutional legacies, what institutional theorists term "institutional bricolage," may generate effective governance solutions that diverge from national templates (87).

To contextualize the set relations identified in the non-high pathways (N1 and N2), we can look at specific provincial cases with high membership in these configurations, such as Qinghai, Gansu, and Ningxia. These western provinces typically face severe disaster exposure (DC) but are constrained by low fiscal autonomy (∼FA) and limited technological infrastructure (∼TI). For example, their logistics networks often rely on basic transportation, and limited local fiscal capacity restricts investment in advanced dispatch platforms. In these contexts, even though there is societal participation (SP), the structural deficits (lack of funds and technology) may fundamentally limit the local emergency logistics response. This process-level evidence empirically supports the "Structural Vulnerability Trap" and demonstrates that societal mobilization alone cannot substitute for foundational state capacities.

6.3 Policy implications: differentiated governance in the configurational field

The configurational field framework offers a fundamental reorientation in how emergency logistics capacity is understood and enhanced. Rather than treating capacity as a linear function of aggregate resources, the findings suggest that high responsiveness emerges from the structured alignment of conditions within each province's unique governance field. This implies that policy interventions should not be designed as generic checklists but as context-sensitive strategies that activate the latent combinatorial advantages already embedded in local institutional arrangements.

Three cross-cutting policy implications follow. First, the temporal stability of the core configurations suggests that emergency logistics capacity is not easily improved through short-term crisis-driven investments. The persistent dominance of these configurational models over the eight-year period indicates that capacity building requires sustained, long-term institutional commitment rather than episodic responses to major disasters. Policymakers should embed emergency logistics into routine governance structures, fiscal planning, and inter-agency coordination frameworks, a finding consistent with the broader literature on institutional capacity building in disaster governance (37, 38).

Second, the spatial heterogeneity uncovered in our analysis points to a nuanced policy challenge: capacity enhancement strategies must respect the existing configurational logic of each region. In provinces where high responsiveness is achieved through technological autonomy (H5) or collaborative (H3), further

investment in physical infrastructure without commensurate technological upgrading may yield diminishing returns. Conversely, in western provinces where basic infrastructure remains a binding constraint, premature investment in advanced digital platforms may divert resources from more foundational needs. The policy question is not "what to build" but "what combination of investments will resonate with the existing institutional fabric," a question that the Configurational Field framework is specifically designed to address.

Third, exceptional cases such as Chongqing illustrate the adaptive capacity embedded within China's multilevel governance system, where provinces achieve responsiveness through locally adapted institutional solutions. These regional variations highlight the role of the central government in facilitating cross-provincial learning, benchmarking, and the dissemination of successful local innovations. These regional variations highlight the role of the central government in facilitating cross-provincial learning, benchmarking, and the dissemination of successful local innovations, which enables provinces to formulate context-sensitive responses to their unique institutional and geographical endowments.

7 Conclusion

This study has investigated the configurational pathways to high ELRC across 29 Chinese provinces from 2017 to 2024, employing panel data QCA to distinguish spatial heterogeneity from temporal stability. The analysis reveals that high ELRC is associated with five equifinal pathways categorized into four models: Routine Administration, Collaborative Governance, Fiscal Substitution, and Technological Autonomy. These pathways exhibit temporal resilience despite major institutional changes and external shocks, yet vary significantly across regions. Non-high responsiveness is primarily explained by the "Structural Vulnerability Trap" (N1 and N2), demonstrating clear causal asymmetry.

The study makes three contributions. Theoretically, it develops the concept of a Configurational Field to capture how multiple conditions coalesce into stable yet spatially varied governance patterns, offering a new lens for understanding the structural logic of emergency logistics capacity formation. Methodologically, it provides one of the first applications of panel data QCA to emergency logistics, showing how this approach can empirically distinguish spatial heterogeneity from temporal stability. Empirically, it identifies multiple region-specific pathways that contribute to a more nuanced understanding of how emergency logistics capacity is achieved across China's diverse provincial contexts.

Several limitations should be acknowledged. First, the ELRC indicator framework follows Chen et al. (13), the entropy weights were recalculated based on our specific 2017–2024 panel, and the framework may not fully capture emerging dimensions such as AI-enabled coordination or real-time data analytics. Second, our analysis utilizes a proxy variable (Local Fiscal Expenditure on Science and Technology) to measure technological infrastructure, which may not fully capture physical infrastructure stocks (e.g., road density). Third, the provincial sample coverage is constrained to 29 provinces (excluding Tibet, Xinjiang, etc., due to data missingness), which may limit the generalizability of the findings. Fourth, the COVID-19 pandemic may have introduced confounding effects that could not be completely isolated, although our robustness checks help mitigate this concern. Finally, the Configurational Field framework requires further empirical testing across different governance contexts.

Future research could explore sub-provincial data, incorporate more direct measurements of physical infrastructure, or adopt multi-level QCA. Additionally, comparative studies across countries would help assess the generalizability of the Configurational Field framework. Despite these limitations, the Configurational Field framework offers both a diagnostic tool for identifying region-specific bottlenecks and a strategic guide for leveraging local institutional assets. In this sense, the Chinese experience provides a valuable reference for other large countries navigating similar trade-offs between infrastructure investment, digitalization, and institutional capacity building in disaster governance.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YZ: Resources, Methodology, Visualization, Writing – review & editing, Writing – original draft. XG: Project administration, Investigation, Funding acquisition, Supervision, Writing – review & editing. DW: Data curation, Writing – review & editing, Methodology, Software.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declared that Generative AI was used in the creation of this manuscript. Generative AI (OpenAI ChatGPT, GPT-4/4o) was used solely for language polishing and grammar improvement of the manuscript. It was not used for research design, data collection, data analysis, interpretation of results, or generation of scientific content. All AI-assisted text was reviewed, edited, and verified by the author(s), who take full responsibility for the final manuscript.

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Supplementary material

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