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Maladaptation in Supply Chains

The Unintended Consequences of Adaptive Actions Aimed at Enhancing Resilience

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ABSTRACT

Supply chains are increasingly suffering from widespread disruptions, leading to growing interest in supply chain resilience. Adaptation, a central concept of resilience, is conventionally assumed to effectively manage these disruptions. However, actions aimed at adaptation can have adverse consequences, a phenomenon known in the climate change literature as *maladaptation*. Supply chain studies discuss only a few instances of maladaptation, without providing an overarching logic that explains why and how such maladaptation emerges. This study brings the concept of maladaptation into supply chain research by developing a conceptual framework that combines maladaptation theory from climate change literature with resilience theory from social–ecological systems literature. This framework identifies the dynamic mechanisms of cross-level interaction, delayed feedback, path dependence, and governance, through which maladaptation emerges. The framework explains how specific supply chain characteristics, such as compressed timeframes, coordination, and competition, accelerate these mechanisms. Through the conceptualization of maladaptation in supply chain management, this study advances resilience theory by establishing a framework to analyze when and under what circumstances adaptive actions aimed at enhancing resilience become maladaptive.

1 | Introduction

Confronted with accelerating grand challenges, including climate transition, resource scarcity, and geopolitical instability, supply chains are under increasing pressure to remain resilient (Nikookar et al. 2025; Nikookar et al. 2024; Scholten and Schilder 2015). Resilience is the capacity to absorb and recover from disruptions, adapt through adjustments, and transform, leading to structural reconfigurations in response to new challenges (Folke et al. 2010; Wieland et al. 2023). Supply chain resilience is enacted through continuous adaptive actions in response to disruptions and evolving environments (Dube et al. 2024; Scholten et al. 2025; Wieland and Durach 2021; Wieland et al. 2023). Against this backdrop, understanding how such adaptive actions build or potentially undermine resilience has become increasingly urgent.

Adaptation is widely considered an effective approach for coping with an increasingly uncertain environment (Ambulkar et al. 2015). The notion of *maladaptation* was introduced in climate change and ecology literature to express when adaptation leads to adverse or undesired outcomes (Burton 1997; Lofflin and Kephart 2005; Urban 2006). However, supply chain adaptation can also be unsuccessful or counterproductive, as suggested by efforts to identify practices for successful adaptation (Namdar et al. 2022; Zhao et al. 2019). Additionally, a few studies have addressed maladaptation and supply chains in the context of climate change (Lim-Camacho et al. 2015; Ojea et al. 2020; Quezada et al. 2014). However, supply chain maladaptation is not limited to climate-related disruptions, as illustrated by, for example, Falagara Sigala et al. (2022). Thus, supply chain adaptation can be counterproductive across a range of disruption types and settings.

Existing supply chain studies address isolated instances of maladaptation, but share no integrating theoretical logic that explains *how* adaptive actions lead to maladaptive outcomes. Without such a logic, the field cannot identify the mechanisms by which adaptive actions will lead to maladaptive outcomes and hence cannot help supply chain managers prevent maladaptation. In contrast, climate change and social–ecological systems research has explicitly theorized maladaptation as an emergent process through which adaptation degrades resilience. Yet, this theoretical lens has seen little uptake in the supply chain resilience literature. Consequently, maladaptation remains under-theorized in the supply chain resilience literature, despite empirical indications and relevant conceptual foundations in adjacent fields.

Therefore, we develop a framework to explain how supply chain maladaptation emerges. Because supply chains resemble complex social–ecological systems far more than deterministic engineering systems (Wieland et al. 2023), we use social–ecological systems theory to study supply chain maladaptation. Supply chain maladaptation is framed as an adaptive process intended to enhance resilience, which inadvertently turns out counterproductive. From a management perspective, this framing distinguishes deliberate, ex ante, priced trade-offs such as flexibility versus redundancy (Kamalahmadi et al. 2022; Xue and Li 2023) from unintended degradation of resilience that emerges ex post. Building on this perspective, the research question is: What conceptual framework explains how adaptive actions aimed at enhancing resilience lead to maladaptation in supply chains?

To answer this question, this study draws on maladaptation theory from climate change research as well as resilience thinking from social–ecological systems research. It advances supply chain resilience theory in two ways. First, this study conceptualizes supply chain maladaptation as a process. The conceptualization also offers criteria for evaluating outcomes as adaptive or maladaptive. Second, this study develops a framework that specifies the underlying dynamic mechanisms by which maladaptation occurs in supply chains. For practitioners and policymakers, we argue that the framework can support the early identification of potential maladaptation pathways when designing adaptive strategies.

The remainder of this article is structured as follows. The next section presents the research approach and the process to develop the study's framework. Next, we provide a background on supply chain resilience, adaptation, and maladaptation. The insights from the background are synthesized into the definition of supply chain maladaptation and the conceptual framework. The final two sections cover contributions, implications, limitations, and directions for future research, followed by the conclusions.

2 | Research Approach

This study has developed its contributions through an integrative literature review combined with abductive, analogical theorizing (Breslin and Gatrell 2023; Sætre and Van de Ven 2021). An integrative review is suited to bridging research domains that study related phenomena using different conceptual languages. Such bridging leads to insights that neither community gains in isolation through the juxtaposition of concepts across domains (Cronin and George 2023). Studies from the domains of supply chain resilience, social–ecological systems theory, and climate-change maladaptation were reviewed. Supply chain resilience provides process and adaptation frameworks. Climate change maladaptation offers a rich body of conceptual knowledge on maladaptation, and social–ecological systems theory reveals the underlying dynamic mechanisms. The resulting framework represents these mechanisms as integrative analytical constructs that explain maladaptation by bridging levels of analysis, consistent with a constitutive stance (Cornelissen and Werner 2026). The mechanisms are posited as ontologically real, but whether an observed outcome is classified as a maladaptive outcome is epistemically conditional on explicit choices. This study, therefore, adopts a realist, open-systems perspective of supply chains as dynamic complex systems (Choi et al. 2001; Tukamuhabwa et al. 2015; Wieland et al. 2023).

In developing the theory for supply chain maladaptation, we used a five-step process. First, relevant studies were selected through an initial exploratory review. An iterative search in Scopus targeted (i) definitions of maladaptation, (ii) studies combining "supply chain" and "maladaptation," and (iii) process-based frameworks in supply chain adaptation and resilience and in social–ecological systems. Conceptual and synthesis articles, seminal articles, and recent state-of-the-art articles were prioritized and supported using backward and forward snowballing (Folke 2016; Folke et al. 2010; Ostrom 2009; Wieland et al. 2023). Second, the conceptual vocabulary and mechanisms were distilled by comparing process and social–ecological systems frameworks and synthesizing maladaptation definitions. The conceptual vocabulary refers to the concepts used across the reviewed domains. Dynamic mechanisms refer to the processes that generate system behavior over time. Third, analogical transfer is used as part of an abductive reasoning process to develop a definition and explanatory framing of supply chain maladaptation. Climate-change maladaptation and social–ecological systems research served as the source domains, and supply chain resilience as the target domain. We transferred both the evaluative logic for identifying what makes adaptation *maladaptive* and the associated dynamic mechanisms to a supply chain context (Gruner and Power 2023). Fourth, these mechanisms were recontextualized by examining how supply chain characteristics might accelerate, constrain, or reshape them. Fifth, the framework's conceptual elements—its internal boxes—were specified as an organized subset of the conceptual vocabulary and assembled with the dynamic mechanisms into an integrated conceptual framework. A brief case study of a rare-earth supply chain was used to illustrate the framework and demonstrate its plausibility and scope.

3 | From Adaptation to Maladaptation

3.1 | Supply Chain Resilience

Resilience thinking has evolved significantly under the influence of social–ecological systems theory (Berkes et al. 2000; Folke 2016). Recent supply chain studies have moved away from the traditional resilience engineering paradigm of rapid recovery (Christopher and Peck 2004; Sheffi and Rice 2005) and have adopted social–ecological insights to describe the dynamic, multilevel nature of supply chains (Adobor 2020; Wieland and Durach 2021; Wieland et al. 2023). In these studies, actors are integrally linked to their surrounding environments, and feedback loops are critical in driving nonlinear system behavior (Azadegan and Dooley 2021; Choi et al. 2001; Tukamuhabwa et al. 2015; Wieland et al. 2023).

Resilience thinking distinguishes three interrelated responses to change—persistence, adaptation, and transformation—which together define a system's capacity for change (Folke 2016; Folke et al. 2010; Folke, Haider, et al. 2021). Here, adaptation and transformation are integral parts of resilience: a system may change yet retain its defining functions and structures ("identity") or, when existing configurations become untenable, cross thresholds into a new identity (Folke 2016). Following the framing of supply chains as social–ecological systems, persistence involves maintaining or restoring operations ("bouncing back"). Adaptation involves adjustments within the prevailing strategic logic. Finally, transformation involves a fundamental redesign of chain structures and objectives (Wieland et al. 2023). This study focuses primarily on the sequences of adaptive actions in existing supply chains and how these actions affect the capacities for persistence, adaptation, and transformation.

3.2 | Supply Chain Adaptation and Unintended Consequences

Adaptation is "adjusting the existing system in response to an actual or expected change or disruption" (Wieland et al. 2023, 3). This definition encompasses both post-disruption adjustments (e.g., rerouting shipments after port closure) and proactive adjustments to prepare for future disruptions (e.g., prepositioning buffer inventory). Supply chain adaptation unfolds dynamically across multiple levels (Wieland 2021) and can be triggered by a wide range of events with different timelines. The different characteristics of these triggers make effective adaptation inherently difficult.

Several adaptation process-based frameworks in supply chain management describe the connections between disruptions, adaptation processes, and their consequences (Adobor 2020; Altay and Pal 2023; Comes, Van de Walle, and Van Wassenhove 2020; Wieland 2021) (see Table A1). Some of these focus on restoring specific operational capacities (e.g., inventory and routing), whereas others emphasize business continuity or adjusting network structures. These frameworks address internal and external factors, such as supply chain cross-level interaction or competitors (Altay and Pal 2023; Wieland 2021). These factors influence which adaptive actions are implemented in response to disruptions and which targets are adapted. The need for rapid adaptation amplifies the effects of these factors (Comes, Warnier, et al. 2020). Most frameworks consider adaptations from the perspective of the focal firm. However, a supply chain spans individual actors, such as legally independent firms and their supply chain partners, across multiple tiers. Each actor decides autonomously yet must coordinate because the operations are interdependent. Accordingly, understanding adaptation requires a multi-actor, interdependent process view.

Adaptive actions to enhance resilience can lead to adverse outcomes. These outcomes reflect unintended, ex post system-level resilience degradation rather than trade-offs. Trade-offs refer to conscious, ex ante decisions about how to resolve conflicting objectives, such as cost versus performance or implementation speed versus generalizability (Chopra and Meindl 2015; Xue and Li 2023). In contrast, maladaptation refers to unintended and unforeseen effects of adaptive actions. For example, during the COVID-19 pandemic, personal protective equipment (PPE) supply chain managers sought to improve resilience by rapidly identifying new suppliers and increasing order quantities to ensure that they could meet the peak demand. However, the rush to secure PPE led to unintended consequences through increased capacity and diversification. The combination of global competition and unvetted suppliers resulted in inflated prices and poor-quality products. Therefore, these adaptive actions inadvertently created additional vulnerabilities instead of maintaining persistence or improving system functioning (Falagara Sigala et al. 2022).

We identified a few supply chain studies that investigate phenomena comparable to maladaptation. For example, Kettele and Lechner (2025) described unintended consequences and showed that simultaneous adaptive actions can lead to unexpected interactions. Similarly, Namdar et al. (2022) demonstrated that combinations of inventory and sourcing strategies may stabilize performance during disruptions but produce new vulnerabilities once conditions normalize. Stave and Kopainsky's (2015) work on resilience paradoxes examined how adaptation strategies intended to enhance resilience can create unforeseen vulnerabilities or side effects. Thus, current supply chain resilience research provides a process-based foundation and scattered indications of maladaptive outcomes.

3.3 | Insights From Climate Change Maladaptation Research

Widely cited definitions of climate change maladaptation agree that it refers to adaptive actions that ultimately lead to heightened or redistributed vulnerability and adverse outcomes, such as greater emissions or equity loss (Barnett and O'Neill 2013; IPCC 2023; Juhola et al. 2016; Schipper 2020) (Table A2). Thus, vulnerability is fundamental in climate change maladaptation, referring not only to human groups or sectors but also to natural ecosystems (Barnett and O'Neill 2010). A few studies of climate change maladaptation have considered supply chains. Of these, one illustrative study reveals how actions intended to enhance resilience in the energy supply chain transfer risks to downstream users (Quezada et al. 2014). Another study shows how adaptive actions are dependent on responses by other actors (Lim-Camacho et al. 2015). A third presents a typology in which short-term adaptive actions preserve individual persistence, but erode institutional resilience over time (Ojea et al. 2020). Hence, climate change maladaptation research provides insights into the notion of maladaptation and vulnerability.

3.4 | Maladaptation: Insights From Social–Ecological Systems Frameworks

Understanding maladaptation as a dynamic process requires paying attention to its dynamic mechanisms. Social–ecological frameworks identify several dynamic mechanisms that shape whether an adaptive action delivers benefits or backfires (see Table A3). First, feedback delay occurs when the consequences of actions loop back and influence future decisions. Feedback loops are processes in which a system's output is fed back into the system as input (Meadows 2008). This process then shapes subsequent actions, decisions, or outputs. Thus, feedback can dampen or reinforce later behavior, sometimes amplifying hidden risks (Folke 2016; Schlüter et al. 2019). Second, cross-level interaction occurs when adaptive actions at one organizational, temporal, or spatial level impact other levels. In panarchy frameworks, such cross-level interaction connects the nested levels of a system. Rapid changes at lower levels can cascade upward and destabilize higher-level structures. In turn, higher levels can stabilize or constrain lower levels (Folke et al. 2010; Gunderson and Holling 2002). Cross-level feedback occurs when these effects return to their original levels (Cumming et al. 2006; Ostrom 2009; Schlüter et al. 2019). Third, path dependence refers to situations in which initial adaptive actions constrain future options for adaptation. Thus, the flexibility for subsequent adaptive actions is reduced (Haider et al. 2021; Schlüter et al. 2019). Fourth, governance determines who has the authority or influence to make decisions regarding what and when to adapt, and to establish the rules for including or ignoring particular feedback signals (Ostrom 2009; Schlüter et al. 2019). Path dependence and governance determine which series of adaptive actions remain open and which become closed (Haider et al. 2021).

Folke, Polasky, et al. (2021) have illustrated how path dependence can lead to reduced capacity over time. Adaptive actions that repeatedly apply the same strategy to familiar disruptions enhance short-term robustness (Folke 2016; Folke, Polasky, et al. 2021). However, over time, these efficiency-oriented adaptive actions tighten interdependencies and reinforce existing structures, making systems increasingly difficult to change (Folke, Polasky, et al. 2021). Across social–ecological systems frameworks, adverse or undesired outcomes are primarily expressed in terms of undesired system states rather than maladaptive outcomes. One manifestation of adverse or undesired outcomes is the system's reduced capacity to adapt or transform. Lower adaptive capacity increases vulnerability, whereas lower transformative capacity increases long-term vulnerability (Folke et al. 2010). In conclusion, social–ecological systems frameworks supply the dynamic vocabulary and mechanism-based perspective that this study extends to the supply chain management domain.

4 | A Supply Chain Maladaptation Framework

4.1 | Cross-Domain Synthesis and Supply Chain Recontextualization

This section synthesizes the insights identified in the previous sections. Climate change research provides outcome categories used to identify maladaptation. Social–ecological systems research establishes the dynamic mechanisms of complex systems. Supply chain resilience research contributes the domain-specific decision-making and supply chain planning contexts in which maladaptation occurs. Table 1 maps the adaptation concepts across social–ecological systems, climate, and supply chain studies. These concepts provide the conceptual vocabulary and are input for the specification of the framework's conceptual elements (i.e., the boxes in Figure 1). Each row represents a concept, and the rightmost column highlights how concepts relate specifically to supply chain management.

Table 2 maps maladaptive outcome categories from climate change studies to supply chains. Climate change studies vary in whether they define maladaptation as an action or an outcome (Table A2). Across the definitions, maladaptive outcomes are the increased, shifted, or newly created vulnerabilities arising from adaptive actions. Social–ecological resilience thinking (as discussed earlier) introduces a complementary, process-oriented perspective, in which adaptive actions can erode adaptive or transformative capacity. This erosion increases vulnerability over time. Applied to supply chains, this social–ecological perspective implies that maladaptive outcomes are not limited to immediate increases or shifts in supply chain vulnerability, but also concern reduced adaptive or transformative capacity. The synthesis of these two perspectives underpins our definition of supply chain maladaptation (presented in the following section).

Table 3 lists the four dynamic mechanisms (feedback delays, cross-level interaction, path dependence, and governance). For each mechanism, it specifies the supply chain manifestation and the supply chain characteristics that condition its expression. From Table 3, we conclude that dynamic mechanisms tend to be more accelerated and fragmented than in classic social–ecological systems.

Tables 1, 2, and 3 show that supply chains exhibit three specific characteristics that affect how maladaptation dynamic mechanisms unfold. First, compressed timeframes for decision-making between trigger and impact reduce deliberation time, making unintended consequences both harder to anticipate and faster to emerge (Eisenhardt 1990). Second, coordination across many legally independent yet operationally interdependent supply chain actors with distributed decision-making creates stronger information and power asymmetries than expected in most social–ecological systems (Vosooghidizaji et al. 2020). Third, competition and a focus on specific performance goals and business continuity may incentivize supply chain actors to optimize locally and neglect system-wide thinking (Chopra and Meindl 2015). These characteristics imply that supply chain maladaptation operates through fragmented and accelerated versions of the dynamic mechanisms of traditional social–ecological systems. On this basis, the framework incorporates supply chain-specific characteristics alongside the dynamic mechanisms.

4.2 | Defining Supply Chain Maladaptation

In climate change maladaptation research, the evaluation of maladaptive outcomes focuses on vulnerability and externalities (e.g., greenhouse gas emissions); resilience is often implicit. As a result, maladaptation definitions emphasize “increased or

TABLE 1 | Synthesis of adaptation concepts in social–ecological systems, climate change maladaptation, and supply chain resilience and adaptation studies for supply chain maladaptation analysis.

Adaptation concept	Social–ecological systems studies	Climate change maladaptation studies	Supply chain resilience studies	Relevance for supply chain management
Adaptation trigger (temporality)	Fast- and slow-moving variables (Walker et al. 2004)	Shocks (e.g., extreme weather events) and trends (e.g., gradual sea level rise)	Shocks (e.g., sudden supplier bankruptcy) and trends (e.g., rising transport costs)	Compressed decision timeframes with shorter lead times between trigger and impact
Adaptation trigger (origin)	Exogenous (e.g., climate change) Endogenous (e.g., overfishing)	Global (CO_2 emissions) Local (e.g., land use change)	External (e.g., tariffs) Internal (declining performance)	Disruptions often propagate rapidly throughout the network (due to multi-tier interdependency), blurring the distinction between internal and external (Scheibe and Blackhurst 2018).
Adaptation target—What system element is adapted?	Ecological elements Social structures Governance E.g., (Ostrom 2009)	Physical infrastructure Institutions Economic systems (insurance) Behavior (IPCC 2023)	Network structure Planning systems Operational processes (Rozhkov et al. 2022)	Coordinated system adaptation: technical, social, and economic elements need to be adapted in alignment and often simultaneously
Adaptation objective	Persistence Adaptation Transformation (Folke et al. 2010)	Reduced vulnerability Human well-being Equity GHG emission reduction (IPCC 2023)	Supply chain persistence Adaptation Transformation (Wieland et al. 2023) E.g., Maintaining operating capability (Christopher and Peck 2004)	Underlying objective: business continuity (Ponomarov and Holcomb 2009) (each actor aims to survive, leading to competition)
What actors are involved in decision-making?	Resource users Local communities Authorities E.g., (Schlüter et al. 2019)	Individuals Communities Local–national governments	Individual supply chain actor Supply chain partners Industry networks Regulatory bodies	Nominally independent actors take autonomous decisions but must coordinate because their operations remain interdependent
Decision cycles	Multiple nested timescales Slow-fast dynamic mechanisms	Time for deliberation is available. Long-term typically spans decades, for example, in climate change water management (Haasnoot et al. 2013)	Short-term typically spans hours/days (operational rapid disruption response); long-term spans months or a few years (strategic reconfiguration)	Relatively short adaptation timeframes due to fast market dynamics

TABLE 2 | Maladaptive outcome categories and the evaluative dimension 'vulnerability' from climate change maladaptation studies applied to the supply chain context.

Evaluative focus	Climate change maladaptation studies	Relevance for supply chain management
What counts as maladaptation?	a. Increased GHG emissions b. Increased climate vulnerability c. Shifted climate vulnerability d. More inequitable outcomes e. Diminished welfare (IPCC 2023)	Unintended degraded resilience through a. Increased, shifted, or new supply chain vulnerabilities b. Vulnerabilities emerging through degraded adaptive or transformative capacity
Vulnerability (who/what becomes more at risk because of adaptive action)	Vulnerability of a. Humans, other sectors, targeted groups, or other groups b. Natural ecosystems (Barnett and O'Neill 2010)	The extent to which a supply chain is susceptible to a specific or unspecific risk event (Heckmann et al. 2015)

TABLE 3 | Maladaptation dynamic mechanisms, applied from social–ecological systems to the supply-chain context.

Dynamic mechanisms	Relevance for supply chain management
Feedback delay	Feedback delays stem from managerial supply chain decisions that reward short-term KPIs, asynchronous planning, and asynchronous material and information flows (Sahay et al. 2014; Sterman 1989). Because decision cycles are more compressed than in classic social–ecological systems, feedback delays unfold more quickly.
Cross-level interaction	Cross-level interaction and feedback occur across organizational and tier boundaries (Ivanov et al. 2010; Scheibe and Blackhurst 2018). Competition and contractual silos confine managers to a one-tier view, so cascades travel farther (geographically) and faster, even beyond supply chains (Wieland 2021).
Path dependence	Asset and relational dependencies: Sunk investments and high switching costs lock firms to specific partners and locations, reinforcing established pathways and limiting scope for change (Sydow et al. 2009).
Governance	Governance in supply chains is typically fragmented: Distributed decision-making across multiple independent, profit-driven firms, with coordination relying on contracts and power and information asymmetries (Vosooghidizaji et al. 2020).

shifted vulnerability" without explicitly using the term resilience. In contrast, in social–ecological systems thinking, resilience itself is a valued systems property. To accommodate this difference and incorporate the two-part outcome structure summarized in Table 2, maladaptation in supply chains is defined as follows:

> Supply chain maladaptation is a process in which adaptive actions intended to improve supply chain resilience, via complex system dynamic mechanisms, generate unintended consequences that degrade resilience by (1) increasing, shifting, or creating new vulnerabilities to supply chain disruptions, or (2) undermining adaptive or transformative capacity.

Two clarifications of this definition are useful. First, whether an observed outcome is classified as maladaptive is conditional on the actors' choices of time horizon, system boundary (e.g., dyad, network, or region), and resilience goals. Accordingly, *mal-* refers to a loss of resilience relative to those goals and scope. Second, while climate change maladaptation tends to amplify the underlying environmental triggers, supply chain maladaptation primarily affects internal supply chain vulnerabilities. However, if maladaptation amplifies the frequency or severity of future disruptions, such as by reinforcing geopolitical dependencies, we regard this as maladaptation as well.

Maladaptive outcomes vary along two dimensions: the time horizon and the impacted actor(s). Typically, the outcomes within the supply chain occur in the short term (less than twelve months) and long term (a few years), which is much faster than the timeline for climate change adaptation. Outcomes may also be distributed unevenly across supply chain actors and levels: vulnerabilities may shift across the spatial, temporal, and organizational levels in supply chains. The impacted actors include the initiating actor as well as downstream or upstream actors. Some actors, such as policy makers, operate within a broader boundary that encompasses multiple actors and time horizons. Within that boundary, *combined* evaluation across actors can reveal how resilience loss is distributed and shifted. Because outcomes of adaptive actions can propagate upstream and downstream, the impacted actor is sometimes not immediately visible (Carter et al. 2015). Resilience loss can therefore arise when vulnerabilities are shifted across actors and levels, or emerge over longer timeframes than the initiating actor assumed. The definition primarily focuses on internal vulnerabilities within supply chains. However, adaptive actions can also have implications for a broader social–ecological system in which a supply chain is embedded (Gualandris et al. 2024), such as regional unemployment or increased interdependence in other sectors. Consequently, actors who neither initiated nor anticipated adaptive actions may also be affected.

4.3 | Framework Structure: Conceptual Elements and Dynamic Mechanisms

The framework draws on the adaptation concepts, outcome categories, dynamic mechanisms, and supply chain characteristics explored in Tables 1, 2, and 3. Figures 1 and 2 present the integrated conceptual framework for analyzing and explaining how maladaptation occurs. Figure 1 depicts the conceptual elements and the dynamic mechanisms connecting them, as shaped by supply chain characteristics. Figure 2 elaborates on Figure 1 by grounding these supply chain characteristics in actor-level behavior, consistent with complex adaptive systems thinking (Schlüter et al. 2019). In applying the framework, the user specifies the system boundary, actor perspective, and time horizon at which outcomes are assessed, as this specification determines whether an observed outcome is classified as maladaptive.

4.3.1 | Conceptual Elements

This framework includes the following conceptual elements: adaptation triggers, adaptive actions, and outcomes. First, the elements are discussed, followed by the connections between

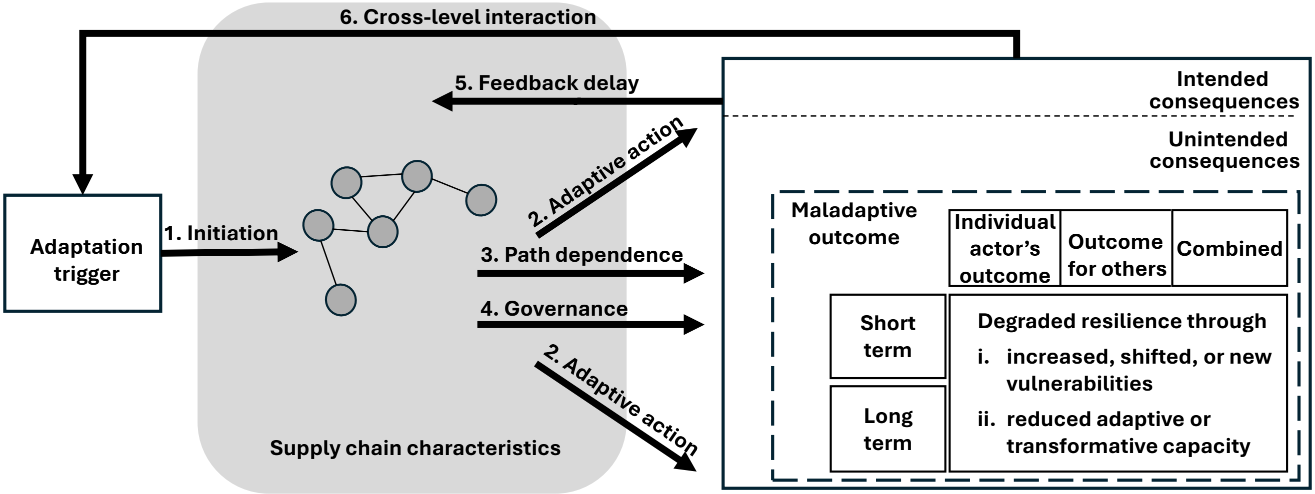

FIGURE 1 | Supply chain maladaptation framework. Arrow 1 indicates initiation from an adaptation trigger to an adaptive action. Arrows 2 indicate the range of potential adaptive actions and their links to outcomes. Arrows 3 (path dependence), 4 (governance), 5 (feedback delay), and 6 (cross-level interaction) represent the dynamic mechanisms through which maladaptation may emerge.

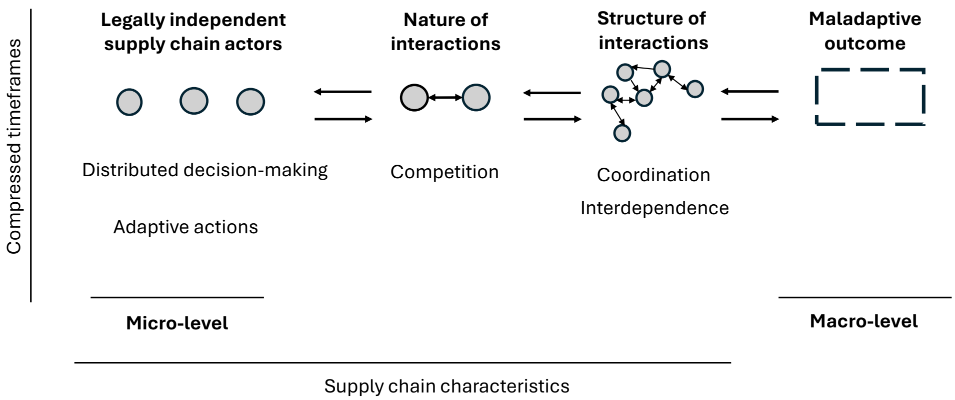

FIGURE 2 | From micro-actions to macro maladaptation: Adaptive actions taken by legally independent firms under compressed timeframes shape the nature of interactions (e.g., competition). The nature of interactions shapes, through multi-actor coordination and interdependence, the emerging relational interaction structure of the supply chain system. This structure ultimately gives rise to a maladaptive outcome. The paired arrows denote a bidirectional relationship of shaping (left to right) and being shaped by (right to left), that is, the resulting macro conditions feed back to shape subsequent micro behavior. Adapted from Schlüter et al. (2019).

the elements. Figure 1 shows these elements and their connections (indicated by arrows). Supply chain characteristics are visualized as the gray background layer behind these arrows, indicating the context that shapes the mechanisms.

Adaptation triggers include a wide range of disruptions that prompt supply chain adaptation (Scheibe and Blackhurst 2018). Disruptions can be characterized by their origin (internal or external), temporality (duration, propagation speed, and urgency), key characteristics (frequency and severity), and impact (Altay and Pal 2023; Scheibe and Blackhurst 2018; Zhao et al. 2019). *Adaptive actions* entail both decision-making (Altay and Pal 2023; Comes, Van de Walle, and Van Wassenhove 2020) and interventions in supply chain elements, including network structure, coordination mechanisms, and planning or operational actions. As defined earlier, adaptive actions aim to enhance persistence, adaptation, and transformation (Wieland et al. 2023). These actions involve different actors in the supply chain and range from operational to strategic decisions. At the micro level, individual actors' adaptive actions occur continually and are often guided by operational constraints and short-term economic incentives. *Outcomes* of adapted supply chain systems can be intended consequences that improve resilience or unintended consequences that are positive or negative. Maladaptive outcomes are the unintended negative consequences of adaptive actions, consistent with the definition of supply chain maladaptation introduced earlier. The *supply chain characteristics*—coordination and interdependence, competition, and compressed timeframes (Table 1)—shape how maladaptation dynamic mechanisms unfold (Table 3 and detailed in Figure 2). These characteristics capture actor behavior, interaction patterns, and the resulting multi-tier network structure.

4.3.2 | Maladaptation Dynamic Mechanisms

The elements of this framework are interconnected, and together shape maladaptation dynamic mechanisms. These mechanisms are represented by the bold and numbered arrows in Figure 1. Arrow 1 shows the starting point; the expectation of a disruption or the disruption itself can trigger an adaptive action (Sheffi and Rice 2005; Wieland 2021). An adaptation trigger initiates decision-making regarding what to adapt and which actors to involve, resulting in adaptive actions. Specific disruption characteristics, such as duration, shape how supply chain actors interpret the situation and choose adaptive actions (Namdar et al. 2022). Some triggers directly cause adaptation within the supply chain, such as when a key actor goes bankrupt and disappears (Zhao et al. 2019). Arrow 2 visualizes the adaptive actions of supply chain actors leading to outcomes (Altay and Pal 2023). Arrows 3 and 4 indicate two mechanisms, path dependence and governance, through which adaptive actions can translate into maladaptive outcomes.

4.3.2.1 | Path Dependence (Arrow 3). During disruptions, decision options are often narrowed down to a limited set of pathways (Scholten et al. 2025). This limited set makes some actions likely to create enduring asset or relational commitments that are difficult to reverse. Unlike the gradual build-up of path dependence in many social–ecological systems, such dependencies in supply chains can arise from rapid responses to disruptions. For example, emergency sourcing decisions can create long-term contractual obligations (Choi and Krause 2006). A second, related example is rapid capacity reallocation or reshoring decisions, which may create specialized assets that are costly or slow to redeploy (Butollo et al. 2025). Both situations restrict the room for future adaptive actions as conditions change. This explanation leads to the following theoretical statement on path dependence.

S1. Maladaptation emerges when supply chain adaptive actions create enduring asset or relational dependencies that constrain future adaptive options and degrade resilience as conditions change.

4.3.2.2 | Governance (Arrow 4). Governance acts as a filter in supply chains by determining which adaptive actions should be prioritized. Unlike governance in most classic social–ecological systems, this filter is difficult to predict because decision-making is fragmented across many actors with different incentives, power, and information. Moreover, supply chain governance can itself be adapted through renegotiation of contracts or coordination (Comes, Van de Walle, and Van Wassenhove 2020; Fiksel 2015). Governance in supply chains also shapes who bears which risks because decision rights and power asymmetries determine how exposure to disruption is distributed across tiers and regions (Suder et al. 2024). This explanation leads to the following theoretical statement on governance.

S2. Maladaptation emerges when supply chain governance filters or prioritizes information or concentrates decision rights in ways that promote locally beneficial actions that degrade resilience.

4.3.2.3 | Feedback Delay (Arrow 5). In complex supply chains, the consequences of adaptive actions take time to become visible and measurable. This delay time can lead to adaptive actions based on outdated information, creating reinforcing feedback cycles. Thus, poor outcomes prompt further maladaptive actions. Such delays are particularly problematic given the supply chains' compressed decision timeframes, in which short-term metrics (such as inventory levels) look healthy, whereas strategic objectives (such as network resilience) lag behind. This temporal mismatch becomes maladaptive when supply chain managers interpret early positive signals as validation of their adaptive actions. This validation leads to the reinforcement of these actions, as adverse consequences have not yet materialized. This explanation leads to the following theoretical statement regarding feedback delays:

S3. Maladaptation emerges when delays in feedback loops in supply chains turn initially beneficial adaptive actions into dynamics that degrade resilience over time.

4.3.2.4 | Cross-Level Interaction (Arrow 6). Supply chains can be seen as nested adaptive cycles at the organization, tier, and network levels, in which adaptive actions at one level influence the dynamics at other levels (Adobor 2020; Cumming et al. 2006; Ostrom 2009; Wieland 2021). Unlike those in many classic social–ecological systems, cross-level cascades in supply chains are fast and driven by the concurrent decisions of legally independent firms that respond to similar signals (e.g., prices, lead times, and contractual penalties). For instance, if multiple firms in the same tier simultaneously pursue similar resilience strategies (e.g., inventory buffers in the case of COVID-19), they can collectively create resource scarcity that degrades individual actors' benefits (Falagara Sigala et al. 2022). This emergence is unintended, because no single actor has visibility or control over network-wide adaptation patterns. Thus, cross-level interaction allows disruptions to propagate (Ivanov et al. 2014). This propagation ultimately degrades resilience. This explanation leads to a theoretical statement regarding cross-level interaction.

S4. Maladaptation emerges when cross-level interaction causes adaptive actions that strengthen resilience at one organizational, tier, or network level but degrades resilience at other levels.

Figure 2 depicts how the supply chain characteristics (compressed timeframes, coordination, and competition) shape the four dynamic mechanisms (Table 3). These characteristics exacerbate the consequences of the adaptive actions of legally independent actors by widening feedback delays, amplifying cross-level cascades, deepening path dependence and reinforcing lock-ins, and fragmenting governance (right-hand column, Table 3). The competitive and coordinative nature of interactions in Figure 2 corresponds to the cross-level interaction mechanism. It visualizes how micro-level adaptive actions aggregate into macro-level maladaptive outcomes (see dashed-line box). The resulting macro conditions (e.g., heightened vulnerability or systemic delays) then feed back to shape the next round of micro-level actions.

4.3.3 | An Illustrative Application of the Framework

A case from a rare earth supply chain, adjusted from Mancheri et al. (2019), illustrates how all four mechanisms interact to generate maladaptive outcomes (Figure 3). Triggered by China's export quotas, Western firms invested in new mining projects to enhance their resilience through supply diversification. However, a *governance* shift, the World Trade Organization ruling, forced China to relax export controls and altered global price signals. Meanwhile, the long lead times of mining projects introduced *feedback delays*. When prices were adjusted, sunk capital locked firms into uneconomic projects (*path dependence*). The *cross-level interaction* between global trade governance and national resource strategy undermined diversification efforts. The unintended consequence was a recentralization of supply in China and a reduction in the adaptive capacity of Western firms, despite the original intent to strengthen resilience (Mancheri et al. 2019).

With these elements and connections in place, the framework addresses how, for whom, and under what conditions the likelihood of maladaptation increases. In particular, when adaptive actions focus on a single actor or timeframe and ignore system-wide consequences or consequences for others, vulnerabilities elsewhere may emerge or increase, or adaptive capacity may degrade. Such outcomes are often driven by path dependence or feedback loops that decision-makers have not anticipated. Short-sighted decisions in compressed timeframes, in combination with delayed feedback, further amplify the conditions under which maladaptation emerges. While the framework identifies distinct dynamic mechanisms, it does not aim to reduce maladaptation to isolated cause–effect relationships. Instead, it seeks to capture how these mechanisms interact with and amplify each other in the context of dynamic multi-actor supply chains.

5 | Discussion

5.1 | Theoretical Contributions

Drawing on social–ecological system mechanisms, we propose a framework that links (i) triggers and continuous evolution, (ii) adaptive actions to enhance supply chain resilience, and (iii) four

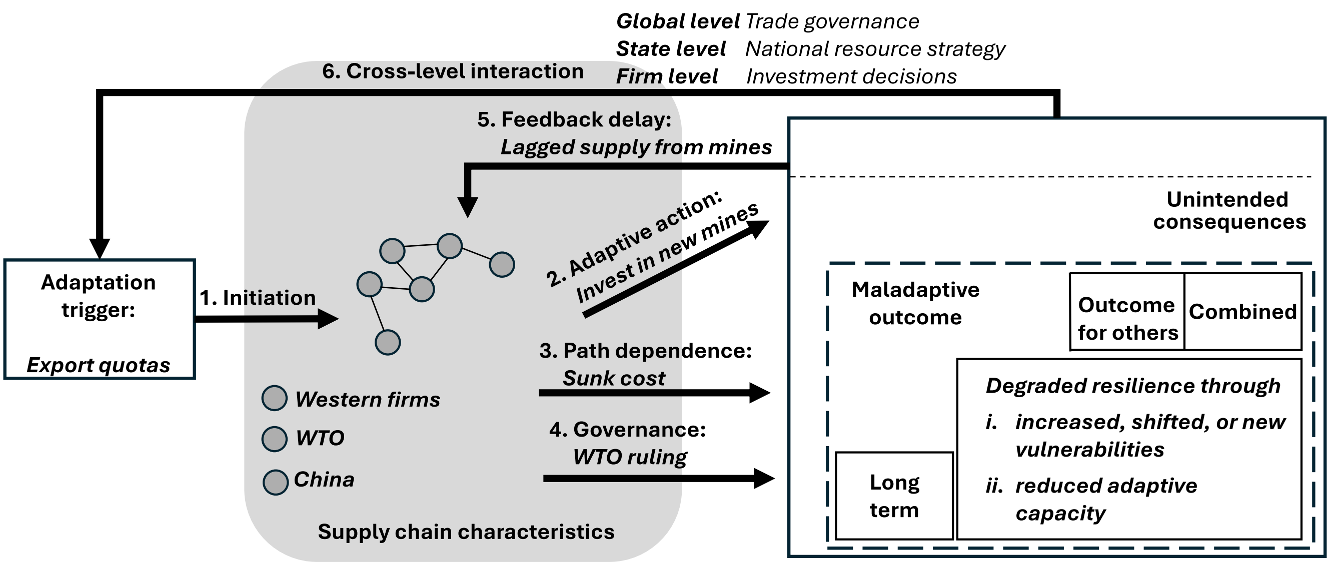

FIGURE 3 | Maladaptation in the global rare earth supply chain through cross-level interaction, governance change, feedback delay, and path dependence. Italic text indicates case-specific elements, and non-italic text denotes generic maladaptation mechanisms.

dynamic mechanisms—feedback delay, cross-level interaction, path dependence, and governance—to (iv) maladaptive outcomes. The dynamic mechanisms explain why well-intentioned adaptive actions can degrade resilience. The manner in which these mechanisms unfold in supply chains is shaped by specific supply chain characteristics. Although the conceptual framework structures maladaptation through distinct mechanisms, this reductionist structuring supports only theory building and does not oversimplify the phenomenon.

Using the maladaptation lens advances supply chain resilience theory beyond the accounts of resilience paradoxes and tradeoffs. First, a causal–process conceptualization of supply chain maladaptation is developed. This conceptualization provides evaluative criteria based on vulnerabilities and degraded adaptive and transformative capacities. Second, we propose a framework specifying maladaptation dynamic mechanisms. This framework suggests how supply chain characteristics shape these mechanisms. The concept of supply chain maladaptation enables supply chain research to systematically learn from debates on maladaptation in the social–ecological and climate-change literature and supports efforts to anticipate and prevent maladaptation.

This study nuances the classic social–ecological triad of persistence, adaptation, and transformation. Adaptive actions can bifurcate. Through balancing feedback, these actions boost flexibility and adaptive capacity. However, through reinforcing loops, adaptive actions reduce future options and degrade (long-term) resilience. This pattern aligns with the proposition in social–ecological systems research that single-objective optimization can degrade resilience (MathisonSlee et al. 2022; Nelson et al. 2007; Walker et al. 2006). In this study, we extend the argument to supply chains and highlight how multi-objective decisions also erode resilience in the long term if actors do not adequately consider feedback loops and cross-level interaction (as illustrated by the PPE and rare-earth cases). Therefore, adaptation must be evaluated across time horizons, as opposed to only at the time of intervention. This insight shifts the understanding of the adaptation process from isolated, performance-improving adaptive actions to multilevel, interdependent, and path-dependent pathways that generate new vulnerabilities. In such pathways, it is very difficult to predict which capacities—persistence, adaptation, or transformation—will be critical for resilience (Folke, Haider, et al. 2021).

This study contributes to the ongoing debate on integrating social–ecological thinking into supply chain resilience promoted by Wieland et al. (2023). However, while social–ecological systems theory traditionally emphasizes continuous adaptation as a process, supply chains are characterized by accelerating dynamic mechanisms with short decision cycles, competition, and distributed decision-making. These supply chain characteristics, designed to enable flexibility and rapid adaptation, can contribute to maladaptive dynamic mechanisms that no single actor may fully control or anticipate. As such, this study moves the discussion beyond deciding whether to adapt or transform the supply chain. Instead, it highlights how supply chain decisions actively shape broader disruptions affecting both society and the environment.

5.2 | Managerial Implications

Labeling specific processes of adaptive action as maladaptation provides supply chain managers with an evaluative lens that is largely absent in current supply chain resilience practices. This lens helps managers distinguish between adaptive actions that genuinely enhance resilience and those that solve an individual actor's immediate problem while increasing vulnerabilities elsewhere. Hence, managers can detect when a sequence of locally adaptive actions is accumulating along a problematic pathway. This lens also helps managers justify investments in monitoring and more balanced solutions.

This study encourages managers to approach adaptation as a process that must be evaluated for its long-term and system-wide effects. The framework invites managers to shift from "How do we adapt?" to "How do we adapt without incurring future vulnerabilities for ourselves or others?" The framework supports managers in answering that second question by diagnosing where resilience degrades, for whom, and when. With that diagnosis, managers can design adaptive strategies that avoid accumulating hidden vulnerabilities over time and, ideally, anticipate and avoid maladaptation.

To illustrate how approaching adaptation may differ in practice, managers can draw on facilitation tools such as systems mapping or scenario planning (MacCarthy et al. 2022; Phadnis and Darkow 2021; Wright and Goodwin 2009). In a system-mapping workshop, managers from different firms jointly sketch decision points and interactions. Mapping these interactions can help to uncover hidden interdependencies and reinforce feedback loops before they degrade resilience. Scenario planning helps rehearse how the consequences of adaptive actions under a few plausible disruptions would play out along this map. Thus, considering maladaptation supports forward-looking managerial decisions that strengthen resilience, instead of creating new vulnerabilities.

5.3 | Policy and Societal Implications

Maladaptation in supply chains has societal implications when policy-relevant critical sectors such as healthcare, defense, and energy are involved. When these sectors are affected, unintended consequences of supply chain adaptive actions threaten public health, compromise national security, and disrupt basic services. For example, for defense technologies, adapting sourcing strategies toward cheaper global suppliers for semiconductors can increase the dependency on a small number of foreign manufacturers. This dependency undermines national security when geopolitical tensions disrupt semiconductor supply chains. Thus, the decisions of individual firms can unintentionally create disruptions that affect the entire sector or essential public functions. When such interactions occur across sectors, they can generate cascading effects and feedback loops that exacerbate systemic vulnerabilities, leading to maladaptive outcomes (see Figure 1, cross-level interaction and feedback). These cascading cross-sector effects render maladaptation a broad societal challenge.

Unintended societal consequences rarely remain external. As institutional theory predicts, firms that generate negative externalities may face legitimacy pressures and regulatory responses.

Those outcomes, in turn, can become new sources of disruption and vulnerability for the focal supply chain (Brammer et al. 2012). Therefore, in a world of grand challenges, avoiding maladaptation requires evaluating adaptive actions not only on their internal performance effects but also on their societal externalities and dynamic feedback across systems and time (Rouzaneh and Savari 2024).

5.4 | Limitations and Future Research

Recognizing maladaptation as a distinct theoretical lens opens new avenues for supply chain resilience and adaptation theories. As adaptive actions can follow diverging pathways that enhance or degrade resilience, future research should revisit established adaptive actions and strategies with this bifurcation in mind. Rather than treating redundancy, flexibility, visibility, or collaboration as uniform resilience enhancements, future studies can build on this maladaptation lens to identify the conditions under which these strategies shift from adaptive to maladaptive. This investigation implies theorizing adaptive actions not as static design principles, but as dynamic processes shaped by feedback delay, cross-level interaction, path dependence, and governance. Methodologically, the dynamic processes can be examined empirically using longitudinal, multi-actor designs. Process-tracing case studies can track adaptive actions over time and test whether the proposed mechanisms explain vulnerability shifts and erosion of adaptive capacity. Predefining evaluation timelines and boundary choices in these studies is essential to avoid inconsistent or arbitrary conclusions. Participatory techniques have been suggested to scope system boundaries (Mahajan et al. 2022), making them a promising tool for empirical application of this framework. By empirically exploring the mechanisms and interacting supply chain characteristics further, scholars can extend this maladaptation theory.

Research on emergency settings promises additional insights because rapid and high-stakes decisions make these settings particularly susceptible to maladaptive outcomes. They often allow only limited time for adaptation, and decision-making may be skewed by cognitive and motivational biases (Paulus et al. 2024). Understanding how these biases contribute to maladaptation and how they can be mitigated requires translating the theoretical insights into practical real-time tools. Future studies should develop such tools, for example, early warning systems that capture maladaptation and multi-actor supply chain dynamic mechanisms. Such tools can help managers steer their supply chains more effectively during unpredictable and evolving disruptions.

6 | Conclusions

This article explains how adaptive actions intended to enhance supply chain resilience can lead to maladaptive outcomes: through dynamic mechanisms of feedback delay, cross-level interaction, path dependence, and governance. Supply chain characteristics of compressed timeframes, coordination, and competition accelerate and fragment these mechanisms, making maladaptation both faster and harder to anticipate than in traditional social–ecological systems. Classifying an outcome as maladaptive requires explicit choices about system boundary, actor perspective, and time horizon. The mechanism-based framework developed here offers an analytical lens for identifying where in the supply chain resilience degrades, for whom, and when, but applying it requires the user to make those choices explicit.

Supply chain resilience research has long assumed that we live in a world where adaptive actions to enhance resilience, taken in isolation, pay off. This article makes the case that such actions are part of multilevel, path-dependent pathways that can bifurcate and ultimately degrade the very resilience they sought to build. When pathways bifurcate, vulnerabilities emerge. These vulnerabilities can be temporal, emerging only after short-term benefits fade, or spatial, shifted beyond the focal point of the decision. Understanding this bifurcation enables supply chain managers to design resilience strategies that avoid hidden vulnerabilities and, ideally, anticipate and prevent maladaptation.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix A

TABLE A1 | Comparison of supply chain adaptation frameworks.

Framework Author, year	Outcomes[a]	Adaptation in response to[b]	Failure logic—Unintended consequences[c]	Elements of the framework[d]	Dynamic mechanisms[e]
Multi-structural framework for adaptive supply chain planning and control (Ivanov et al. 2010)	Output results	Internal and external disruptions		Supply chain structures, goals, uncertainty, adaptation, performance indicators, monitor, demand, adaptive planning, and operations engine	2-way interactions
Adaptation framework (Comes, Van de Walle, and Van Wassenhove 2020)		Evolving disaster(s)		Adaptation, evolving environment, sense-making, decision-making, information flow, information collection	Feedback loop governance
Coping framework (Altay and Pal 2023)	Outcomes	Disruptions, outcomes		Disruption, primary appraisal, secondary appraisal, coping, outcomes, internal and external factors	2-way interactions
Adaptive cycle(s) (Adobor 2020; Wieland 2021)	Phases	Continuous	Traps	Panarchy	Feedback Cross-level Adaptive cycles interacting across multiple levels
Supply chain resilience funnel (Scholten et al. 2025)	Persistence, adaptation	Disruptions		PPS configuration Resilience strategies Context Disruption characteristics	Adaptive cycles Co-dependence
Our proposed supply chain maladaptation framework	Outcomes, Consequences	Disruptions, Outcomes	*Focus of this research: maladaptation*	Adaptation trigger, adaptive actions, outcomes, supply chain characteristics	Feedback delays Cross-level interaction Path dependence Governance

[a] *Outcomes* refer to the results of the adaptive actions, for example, effects on resilience and side effects.
[b] *Adaptation in response to* refers to which types of events prompt adaptation.
[c] *Failure Logic—Unintended Consequences*: whether the framework explicitly addresses whether adaptive actions can lead to unintended negative consequences.
[d] *Elements* refer to key framework elements.
[e] *Dynamic mechanisms* capture the underlying mechanisms that drive how adaptation processes evolve. Terminology reflects the language of the original frameworks and is not standardized, as terms such as co-dependence, two-way interactions, and cross-level interaction capture related but distinct concepts.

TABLE A2 | Overview of definitions of maladaptation.

Source	Definition	Domain
Barnett and O'Neill (2010)	Action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups.	Climate
Juhola et al. (2016)	A result of an intentional adaptation policy or measure directly increasing vulnerability for the targeted and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society's vulnerability.	Climate
Schipper (2020)	1. A process whereby people become even more likely to be negatively affected by climate change. 2. An unexpected and unwanted outcome of an adaptation strategy that is originally implemented with good intentions.	Climate
IPCC (2023)	Actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.	Climate
Oxford English Dictionary (n.d.)	Imperfect or abnormal adaptation; an instance of this	General
Crespi (2000)	The prevalence in a population of a strategy (a form of a phenotype) that does not lead to the highest relative fitness of the strategies in the allowed set, that is, a population deviates from its adaptive peak.	Ecology

TABLE A3 | Comparison of social–ecological systems-oriented process frameworks.

Framework	Outcomes	Adaptation in response to	Failure logic—Unintended consequences	Elements of the framework	Dynamic mechanisms
Rethinking resilience (Haider et al. 2021)	Development pathways	Changing environmental and social contexts and needs		Social entities Ecological entities	Coevolutionary relations Coevolutionary entities Filtering
The transformation process framework (Folke, Polasky, et al. 2021)	Development pathways	Crises/shocks	Hyper-efficiency creates vulnerability	Preparation, transition, and consolidation Micro, meso, and macro level	Path dependence Cross-level interaction
SE-AS framework (Schlüter et al. 2019)	Emergent phenomena	System's outcomes and changing conditions	Lagged adaptation and reinforcing feedback, leading to traps	Interactions Linked interaction-situations Levels	Feedback Delay Cross-level interaction
Panarchy/adaptive cycle (Folke et al. 2010; Gunderson and Holling 2002)	System states	Disturbances, rigidity, slow changes	Efficiency and connectedness create fragility, leading to collapse	Nested adaptive cycles Dimensions: connectedness, resilience and potential	Cross-scale interactions
Resilience thinking (Walker et al. 2004)	System states, collapse	Disturbances, rigidity, slow changes	Entrapment in basins	Landscape System thresholds Resilience domains	Feedback/cross-scale interactions Thresholds
Social–ecological systems framework (Ostrom 2009)	Explicitly called outcomes	Scarcity Degradation Rewarding benefits of resources		Governance systems Resource systems Resource units Actors Interactions	Governance 2-way interactions Cross-scale interactions