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Structuring Complexity – Why we Need a Typology for Systemic Risks

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Abstract

Systemic risks are increasingly recognized as a defining challenge for contemporary societies, yet research and governance efforts remain fragmented across disciplines, sectors, and institutions. Existing approaches often rely on domain-specific definitions, probabilistic models, or case-based analyses that limit comparability, cumulative learning, and coherent risk governance. This paper responds to the need for greater analytical clarity by developing a conceptual foundation for a typology of systemic risks. The paper is intentionally theory-building and focuses on establishing the analytical approach for typology development rather than deriving an empirical classification.

We argue that a central obstacle in systemic risk research is the absence of analytically meaningful boundaries that allow risks to be compared without reducing their dynamic and interconnected nature. To address this challenge, we position systemic risk characteristics as expressions of system behavior and propose systems thinking as an appropriate analytical lens for relating system structures, dynamics, and observed patterns. Building on this perspective, we clarify the distinction between system structure and behavior and show how this distinction enables the identification and differentiation of recurring systemic risk characteristics across heterogeneous cases.

The paper contributes by (1) outlining the conceptual limitations that hinder cross-sectoral and consistent systemic risk classification, (2) clarifying the role of a typology for systemic risk research and governance, and (3) providing a conceptual basis for the development of a typology that supports comparison, generalization, and cumulative knowledge building across domains. The proposed framework offers a foundation for future typology development and for more coherent systemic risk governance approaches.

1. Introduction

Systemic risks are characterized by complex interdependencies that generate non-linear causal relations across coupled systems. Coupling enables systemic risks to propagate across spatial and sectoral boundaries and manifests through compounding conditions and cascading impacts. These core characteristics are recognized in the scientific literature (Renn & Klinke 2004; Renn et al. 2022; Schweizer 2021) and by institutional actors (OECD 2003; UNISDR 2015). Yet they remain broad descriptors: Their specific meanings, interactions, and implications are often insufficiently defined. The broad disciplinary and sectoral scopes and conceptual ambiguities surrounding systemic risk definitions challenge both research and governance (Renn 2016; Renn et al. 2022; Schweizer & Juhola 2024). Systemic risk research therefore faces persistent conceptual challenges. Fragmented and discipline-specific definitions and understandings (e.g., financial, environmental, disaster-related) hinder the development of shared



conceptual foundations, methods, and analytical tools. Such fragmentation restricts interdisciplinary comparison, generalization, and cumulative knowledge building by reinforcing incompatible vocabularies and analytical traditions (Hochrainer-Stigler et al. 2023; Renn et al. 2022; Schweizer 2021; Sillmann et al. 2022).

Governance systems face similar constraints: fragmented mandates and rigid institutional boundaries, resulting in insufficient cross-sector coordination, exacerbated by mismatches between the scales at which systemic risks propagate and the jurisdictions responsible for managing them (Maskrey et al. 2022; OECD 2003; UNISDR 2015). As a result, governance structures designed for bounded, sector-specific risks struggle to capture the dynamics of systemic risks (Schweizer & Juhola 2024; Wernli 2023). Together, the limitations of systemic risk research and governance slow learning and lower the ability to anticipate or respond to systemic risks effectively. This underscores the need for a structured conceptual foundation for systemic risk research and governance, rooted in the widely acknowledged characteristics of systemic risks.

Building such a foundation requires the systematic development of shared concepts, tools, and methods grounded in a common language. Examples already exist in adjacent fields: for instance, the PLACARD project developed cross-linked taxonomies for climate change adaptation and disaster risk reduction to harmonize terminology, connect otherwise siloed knowledge platforms, and enable learning and collaboration across communities (Barrott, 2020). While research fields evolve in diverse and sometimes fragmented ways, a coherent conceptual structure can help channel this diversity into cumulative progress. We therefore propose the development of a typology for systemic risks. In this context, a typology is understood as an analytical classification framework that organizes cases according to shared underlying properties and dynamic patterns (Bailey, 2003; George & Bennett, 2005). A typology provides a shared structure for identifying and differentiating underlying characteristics of systemic risks, enabling comparison, generalization, and communication across research and governance fields by revealing recurring structures related to complexity, non-linearity, coupling, transboundary cascades, and compounding interactions. This paper addresses three core questions:

1. What conceptual limitations currently hinder our ability to consistently identify, compare, and study systemic risks across sectors?
2. Why is a structured typology crucial for research integration, interdisciplinary collaboration, and improved governance capacities?
3. How can systems thinking provide the overarching approach for developing a typology by revealing the systemic behaviors and structures that distinguish systemic risks across natural, technical, and societal domains?

The subsequent chapters examine these questions and argue that a typology, as part of a shared interdisciplinary language for systemic risks, can substantially enhance conceptual clarity and strengthen both systemic risk research and governance. This paper does not present a completed typology for systemic risks. Instead, it develops the conceptual and analytical foundation required for such a typology by clarifying why existing fragmented approaches are insufficient and by establishing systems thinking as a shared analytical basis for classification. The contribution lies in articulating how systemic risk characteristics can be interpreted as manifestations of system behavior and linked to underlying structural relations, thereby providing the necessary groundwork for subsequent typology construction, empirical operationalization, and governance application.

2. The Conceptual Limitations of Fragmented Research

One key function of defining the characteristics of systemic risks is to distinguish them from conventional risks. Traditional risk frameworks conceptualize risk as a quantifiable relation between well-defined events, their likelihood, and their consequences, formalized through the “set of triplets”, i.e., scenario, probability, and consequence (Kaplan & Garrick, 1981). These approaches assume that systems are sufficiently understood to allow meaningful estimation of probabilities and outcomes, making probabilistic models central to traditional risk assessment and risk management, which emphasize prediction, control, and reliability within bounded system definitions (Aven, 2017; Aven 2019). Such models work well in engineering and industrial safety contexts, where hazards can be treated as isolated and analyzable events, but they face significant limitations when system behavior is uncertain, interactions are complex, or key knowledge gaps prevent reliable probability estimation (Aven, 2017; Guikema 2009; Guikema 2020).

Moreover, a central challenge in risk research is the absence of a unified understanding of what constitutes “risk” (Aven 2017; Aven 2019). Probabilistic perspectives define risk through the triplet-lens, while cultural approaches emphasize perception, meaning, and value systems, and constructivist perspectives frame risk as context-dependent and relational (Rosa, 1998). These divergent paradigms generate a variety of risk understandings across fields and can completely shift the understanding of what constitutes a hazard, for example. Differences in analytical requirements, methodological traditions, and decision contexts further reinforce the emergence of domain-specific definitions (Aven, 2015). These differences bring the limitations of probabilistic models to the forefront, because fields that define risk in terms of perception, context, or relational properties do not identify events, consequences, or causal structures in the way probabilistic frameworks require, making it more difficult to establish shared analytical foundations for risks that extend beyond technical domains (Rosa, 1998; Aven, 2015).

At the governance level, differing risk definitions and assessment approaches create challenges for coordination. Sectoral authorities apply distinct assessment cultures and decision criteria, making it more difficult to align procedures and integrate information across technical, environmental, economic, and social domains. These difficulties become visible, for example, when engineering-oriented regulators emphasize probabilistic failure analysis while environmental or public-health agencies employ vulnerability- and exposure-based framings, complicating joint decision-making and cross-sector communication (IRGC, 2018). Additional challenges arise from sector-bound mandates, which lead institutions to operate with different aims, assumptions, models, and evaluative logics. These differences also influence which impacts and uncertainties institutions consider relevant, resulting in divergent problem framings that make it harder to align risk-related priorities across sectors (Renn, 2016). Sector-specific variation in definitions and analytical approaches therefore constitutes a structural barrier to integrated risk analysis and governance.

Traditional probabilistic approaches have been effective in situations where hazards can be represented as discrete physical events and where sufficient empirical knowledge exists to model their likelihood and consequences (Kaplan & Garrick, 1981; Aven, 2015). This applies not only to engineering and industrial safety but also to parts of disaster risk assessment, where probabilistic hazard models for earthquakes and floods have supported scenario development, impact estimation, and preparedness planning (UNISDR 2015). Such models have been useful when physical processes are well studied and when uncertainties can be parameterized, enabling structured evaluation of potential losses and informing early-warning and mitigation strategies. In these contexts, probabilistic methods have contributed to

substantial improvements in anticipating hazardous events and guiding risk-reduction measures (UNISDR, 2015).

The conceptual limitations of interconnected, complex, i.e., systemic, risks, however, arise from the historical development of risk analysis within bounded technical systems and its structural separation across academic and governance domains. Traditional probabilistic models evolved in engineering contexts that treat hazards as discrete events with stable causal relations, making them ill-suited for risks that emerge from nonlinear interactions and cross-system dependencies (Kaplan & Garrick, 1981; Aven, 2015). The divergent traditions in risk research (Rosa, 1998) additionally shape how sectors define relevant properties, impacts, and uncertainties and reinforce domain-specific interpretations of what constitutes a risk (Aven, 2015). Together, these historically and structurally grounded differences hinder the consistent identification and comparison of systemic risks, whose behavior spans technical, environmental, social, and economic systems and therefore cannot be understood through fragmented conceptual frames. This demonstrates why a more integrative approach is necessary for coherent analysis.

While alternative approaches such as indicator sets, case-specific models, or sectoral assessment frameworks can address selected aspects of systemic risks, they do not resolve the underlying problem of conceptual fragmentation across domains. Indicators depend on prior agreement about what is being measured, and models are typically tailored to specific systems or hazards, limiting their comparability across contexts (Ostrom, 2007; IRGC, 2018). A typology addresses this gap by operating at an intermediate analytical level: it does not replace models or indicators but provides a shared conceptual structure within which they can be related, compared, and interpreted across cases and domains, thereby supporting cumulative learning and theory building (Bailey, 2003; George & Bennett, 2005).

3. Research and Governance Integration Through a Shared Analytical Framework

The conceptual and structural limitations outlined in the previous section create a fragmented foundation for systemic risk research. This fragmentation stems from the fact that systemic risks do not revolve around a single, domain-specific reference object. In ecology, for example, ecosystems function as a unifying analytical foundation that supports cross-case comparison and cumulative theory building (Holling, 2001). By contrast, systemic risks emerge from interactions among social, technical, environmental, and economic systems, none of which offers a natural disciplinary anchor for the field as a whole. In system dynamics, explicit modeling of feedback structure and accumulations provides a formal basis for analyzing complex behavior, offering a consistent way to represent and compare system interactions across cases (Sterman, 2006). Frameworks for studying social–ecological systems likewise show how shared diagnostic structures enable heterogeneous cases to be examined through common categories without assuming uniformity (Ostrom 2007). This demonstrates why a more integrative approach based on a shared conceptual basis that can relate heterogeneous approaches to one another is necessary for coherent systemic risk assessment. At present, systemic risks are mostly studied from particular sectoral and disciplinary perspectives, making it difficult to compare cases, identify underlying mechanisms across domains, or build cumulative insights that extend beyond these perspectives (Schweizer, 2021; IRGC, 2018). The absence of a common conceptual basis means that findings on cascades, feedbacks, or cross-scale interactions remain embedded in domain-specific vocabularies, limiting their broader analytical relevance.

Systemic risks pose a particular challenge because they do not come with clearly given analytical boundaries: interactions span domains and scales, and relevant system elements cannot be identified through hazard- or sector-based classifications alone. Yet research and governance require analytically defined boundaries to specify what is considered part of a system at risk and which interactions are relevant. From a risk-science perspective, this boundary problem is not ontological but analytical, reflecting how systems are framed for understanding risk under uncertainty and limited knowledge (Aven, 2017, 2019). Without such analytically constructed boundaries, cases remain difficult to compare, mechanisms cannot be generalized, and learning across domains is constrained. Addressing this meta-level problem therefore requires an analytical approach that can delineate systems in ways that remain sensitive to dynamic interactions and emergent behavior.

A typology can help address these limitations by providing a structured way of classifying systemic risks according to their underlying characteristics and properties rather than their disciplinary origin, thereby enabling a more coherent organization of heterogeneous knowledge (Sillmann et al., 2022). In doing so, it offers a foundation for cumulative, comparable, and cross-sectoral analysis, supporting both research integration and more aligned governance approaches.

By grouping cases according to shared systemic risk features and patterns of system behavior (Sillmann et al., 2022), such as coupling, compounds, cascades, or feedbacks, a typology enables interconnected risks from different domains to be analyzed within a shared analytical structure through which insights from one domain can inform others. This shifts comparison away from sectors of origin and toward the mechanisms that shape systemic behavior central to systemic risks. Domain-specific research already documents these mechanisms in diverse contexts: cascading failures in infrastructure networks (Pescaroli & Alexander, 2016), contagion dynamics in financial systems (Haldane & May, 2011), and interacting climatic drivers that create compound extremes (Zscheischler et al., 2018). Although these studies focus on different systems, they highlight recurring forms of systemic behavior that a typology can systematically relate. By organizing cases through these underlying properties, a typology enables cross-domain learning and supports the development of a cumulative evidence base in which recurring elements and dynamics become analytically comparable across otherwise disconnected fields, thereby facilitating generalization and improving coherence in methodological choices across the broader field.

A typology further strengthens systemic risk governance by translating cumulative, cross-domain advances from research into a more coherent context for institutional actors. By classifying systemic risks through common systemic characteristics and dynamics, it supports more consistent ways of recording and structuring information across cases, which in turn enables greater data interoperability and comparability for monitoring. As such evidence accumulates, recurring patterns become easier to recognize, which can inform the identification of indicators and contribute to the longer-term development of early-warning systems and resilience-building. Moreover, a typology helps clarify where governance responsibilities intersect: by making visible how systemic connections link social, technical, environmental, and economic systems, it allows institutions to see which actors become relevant and at which stages coordination is required (IRGC, 2018; Schweizer & Juhola, 2024). This clearer understanding of role alignment and timing supports more targeted and timely interventions, facilitates institutional learning across events, and improves risk communication by creating a shared language for describing systemic behavior, and thus, supporting more coherent decision-making. In this way, a typology does not replace existing governance processes but enables them to operate more coherently within interconnected systems.

4. Systems Thinking as the Shared Analytical Approach for a Systemic Risk Typology

The preceding discussion has shown how a typology can advance systemic risk research and governance by enabling cumulative knowledge building, improving comparability across cases, and supporting more coherent institutional coordination. Yet developing such a typology requires greater conceptual clarity about the systemic structures and characteristics it seeks to classify. Structural features such as system coupling and feedback dynamics shape how risks propagate and evolve, while systemic characteristics such as cascading impacts and compounding effects (e.g., Schweizer, 2021) describe recurring patterns in system behavior. Differentiating these systemic elements therefore depends on an analytical approach capable of capturing how interactions unfold across interconnected social, technical, environmental, and economic systems. Without such an approach, a typology risks remaining descriptive rather than providing a structured basis for integrated classification, comparison, and assessment.

Systems thinking is an analytical approach that conceptualizes phenomena as parts of interconnected systems, emphasizing how interactions, feedback structures, and accumulations among system elements enables dynamic behavior over time rather than focusing on isolated components or linear cause–effect relations (Forrester, 1961; Meadows, 2008; Sterman, 2006). It is concerned with understanding how system structure shapes patterns of behavior, including non-linearity, emergence, and change, across different contexts and cases. Systems thinking is closely aligned with complexity science, particularly the study of complex adaptive systems, which examines how system-level patterns emerge from interactions among multiple, adaptive components rather than from linear causal chains (Holland, 2005). From this perspective, phenomena such as non-linearity, emergence, and adaptation are not anomalies but intrinsic features of system behavior, a view that has been central to understanding resilience and regime shifts in complex systems (Holling, 2001). Building on these perspectives, systems thinking provides an analytical approach for explaining systemic risk characteristics by relating observed risk patterns to the underlying system structures from which they emerge and vary across cases. The following section applies systems thinking to relate system structures, behaviors, and systemic risk characteristics, thereby enabling the development of a typology for systemic risks and, thus, their comparative assessment across different domains.

Systemic risks are differentiated most meaningfully by their behavior over time. In systems thinking, structure and behavior are analytically distinct: structures define relations, constraints, and feedbacks among system elements, while behavior refers to the dynamic patterns that emerge from these structures over time (Forrester, 1961; Sterman, 2006). In this paper, systemic risk characteristics, such as cascading impacts or compounding effects, are therefore treated as recurring patterns of system behavior, while structures describe the configurations of relations and feedbacks through which such behavior is generated. Because systemic behavior emerges from underlying structures and cannot be inferred from structure alone in complex systems, it provides the most suitable basis for distinguishing systemic risks. Through behavior, the combined effects of multiple structural interactions become visible and comparable across cases. Systemic risk characteristics capture such recurring behavioral patterns rather than properties of individual system components. Interpreting systemic risk characteristics as manifestations of system behavior therefore provides a coherent basis for typology development, allowing systemic risks to be distinguished by how they behave dynamically while preserving differences in underlying structures and domains.

Building on this behavioral basis, systemic risk dynamics can be linked back to the structural relations through which they are produced and propagated. Examining how behavior emerges from feedbacks and interdependencies allows system components to be interpreted according to their functional role in systemic risk propagation, including whether they tend to absorb, transmit, amplify or dampen risks across systems. These functional roles are not intended as fixed attributes of components but as analytical heuristics that support comparison across cases by highlighting how structural positioning influences systemic risk propagation. Interpreting components in functional terms is analytically important because it reveals where interventions can alter propagation pathways and clarifies which actors are positioned to influence risk mitigation.

At the same time, treating such roles as generic analytical constructs enables comparison across domains by revealing similarities and differences in risk dynamics, even when the underlying systems and contexts differ. Together, these analytical elements establish the conceptual foundation for the typology of systemic risks developed in the following section.

5. Conclusion

Advancing systemic risk research and governance requires moving beyond fragmented, sector-specific conceptualizations toward a shared analytical foundation capable of integrating the complex, interdependent, and dynamic behavior of systemic risks. While systemic risks are commonly described through characteristics such as non-linearity, cascading impacts, and transboundary propagation arising from coupled systems, these characteristics have often remained broad descriptors rather than analytically differentiated elements. As a consequence, research and governance continue to face challenges in comparability, cumulative knowledge building, and coordinated action across domains (IRGC, 2018; Schweizer & Juhola, 2024).

Risk frameworks rooted in bounded systems, probabilistic reasoning, and domain-specific traditions remain essential for many contexts, yet they are structurally limited in capturing systemic risk behavior that spans interconnected social, technical, environmental, and economic systems (Kaplan & Garrick, 1981; Aven, 2015; Schweizer, 2021). These limitations are particularly evident where risks arise from non-linear interactions, feedbacks, and cross-system interdependencies that cannot be adequately addressed through sectoral vocabularies or stable causal assumptions (Rosa, 1998; OECD, 2003). A typology offers a way to address these challenges by organizing heterogeneous insights around shared systemic properties, enabling cross-case comparison, generalization, and interdisciplinary integration while remaining sensitive to contextual specificity (Ostrom, 2007; IRGC, 2018).

Systems thinking provides the overarching analytical approach for developing such a typology by relating system structures, system behaviors, and systemic risk characteristics within a coherent conceptual framework (Forrester, 1961; Meadows, 2008; Sterman, 2006). By centering differentiation rather on how systems behave and evolve than on sectors, hazards, or disciplinary perspectives, systemic risks can be compared according to how they unfold dynamically over time. Interpreting systemic risk characteristics as manifestations of system behavior, and linking them to underlying structural relations, further allows system components to be understood in terms of their functional role in risk propagation. This system behavior- and structure-based rationale provides the foundation for identifying leverage points for intervention and clarifying where responsibilities intersect, thereby strengthening the connection between analytical insight and governance relevance (Meadows, 2008; IRGC, 2018).

Treating functional roles and behavioral patterns as generic analytical constructs also supports comparison across domains, even where systems, institutions, and contexts differ. This enables similarities and differences in systemic risk dynamics to be identified without reducing diverse cases to uniform categories, supporting cumulative learning across research fields and policy domains (Schweizer, 2021; Schweizer & Juhola, 2024). In this way, a behavior-centered typology complements domain-specific analyses and governance arrangements by providing a shared conceptual structure through which systemic risks can be related, compared, and coordinated more coherently (IRGC, 2018).

This paper is intentionally conceptual and theory-building, responding to the need for analytical clarity prior to typology construction. The analytical framework presented here provides a conceptual foundation for developing a typology of systemic risks. By relating system structure, behavior, systemic risk characteristics, and functional component roles within a systems thinking perspective, it offers a structured way to organize heterogeneous insights across domains while remaining sensitive to contextual and structural differences. Its value lies in clarifying how systemic risks are identified, compared, and interpreted, thereby supporting cumulative knowledge building and more integrated approaches to assessment and governance. Building on this foundation, future work can apply and refine the analytical logic through comparative case analysis, empirical operationalization, and governance-oriented applications, strengthening its contribution to the understanding and management of systemic risks.

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