Network Fragmentation and the 2025 Funding Shock: Early Warning Signs of Systemic Risk in Global Health Governance

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Abstract

Background. Global health governance (GHG) has shifted from polycentric coordination to topological fragmentation. COVID-19 expanded World Health Organization (WHO) financing participation but eroded cohesion, producing dispersed connectivity. The 2025 contraction, driven by major donor withdrawal, intersected with existing fragilities.

Objective. To assess whether changes in WHO's financing architecture (2016–2025) exhibit early-warning patterns of declining resilience and critical transition dynamics.

Methods. Social network analysis (SNA) of WHO Programme Budget data across five biennia, examining network cohesion, fragmentation, and component structure through Scheffer's critical transitions framework.

Results. Pre-pandemic networks showed declining density and rising modularity. During COVID-19, participation surged but cohesion eroded, with density halving, clustering declining sharply, and weakly connected components multiplying. Post-pandemic stabilization retained a segmented and concentrated structure, while temporal autocorrelation increased across biennia, indicating reduced flexibility.

Conclusion. The WHO financing network exhibits patterns compatible with lower-resilience configurations approaching critical thresholds. For WHO leadership, topology-based metrics may offer diagnostics of systemic vulnerability. For donor states, findings suggest that concentrated bilateral funding can affect multilateral resilience through network cohesion. Findings should be interpreted cautiously given the number of observations, partial coverage of the 2024–2025 biennium (Q1), and the observational design, which does not permit causal inference or prediction.

Keywords. World Health Organization (WHO); Global Health Governance (GHG); Development Assistance for Health (DAH); critical transitions theory, social network analysis; global health system resilience

Introduction

Over the past two decades, global health governance (GHG) has transformed profoundly. A predominantly state-centred system has evolved into a landscape of governments, multilateral organisations, philanthropic foundations, and public–private partnerships. While this pluralisation has expanded actors and resources, it has also generated overlapping mandates, fragmented financing, and coordination challenges [1–3]. Within this landscape, the World Health Organization (WHO) continues to hold a formal coordinating mandate and a central institutional position [4]. However, its capacity to exercise integrative leadership has become progressively constrained by a growing reliance on voluntary and earmarked contributions, which tend to disperse priorities across programs and partners and weaken system-wide coherence [1,5]. This governance architecture is characterized by high interdependence

among heterogeneous actors, the absence of a single locus of control, and reliance on distributed financing mechanisms [5–8]. These features justify conceptualizing GHG as a complex system in which outcomes emerge from interactions among multiple components rather than hierarchical command [9,10].

Understanding these dynamics requires analyzing relational structure. Social network analysis (SNA) provides this perspective by examining how ties among actors shape power, influence, and dependency [11–15]. Rather than focusing only on funding volumes, it highlights the relational architecture through which resources flow and dependencies emerge [15]. Widely used in epidemiology, public administration, and international relations [11,13–17], SNA helps map WHO financing ties, identify central and brokerage actors, and assess fragmentation, concentration, and interdependence [11–15]. In doing so, it can reveal structural vulnerabilities that budget analyses may overlook, especially under systemic stress. Evidence from outbreaks such as SARS and Ebola shows that emergencies often produce temporary coordination surges without sustained integration [18–20]. The 2025 contraction, following the withdrawal of the United States from the WHO, reinforces concerns that fragmented financing streams weaken the resilience of global health governance [21].

Assessing whether such vulnerabilities are deepening over time, however, requires an analytical framework that links structural change to systemic resilience. To this end, this study draws on critical transitions theory, which originates in dynamic systems theory and examines how complex systems shift between alternative stable states as resilience erodes, often following gradual internal changes rather than abrupt external shocks alone [22,23]. Two indicators are particularly salient: rising variance, meaning greater fluctuations in system properties suggesting instability; and increasing temporal autocorrelation, meaning the persistence of patterns across time, which implies slower recovery from disturbance. Once a transition occurs, recovery to the previous state typically requires disproportionately greater effort, a phenomenon termed hysteresis [22].

In institutional and governance contexts, these concepts can be operationalised empirically through SNA. Persistent fragmentation, reflected in high modularity and a growing number of weakly connected components, signals the emergence of increasingly self-contained financing clusters with weaker integration across the system. In practice, this may indicate more siloed funding patterns and reduced coordination across programs or actors. Low clustering coefficients suggest that existing ties are less likely to reinforce coordination locally, while changes in density and network diameter capture broader shifts in overall connectivity across the system [13,24,25]. Tracking these metrics over time therefore helps assess whether a governance network retains the capacity to recover cohesion or is instead moving towards a more fragmented and less resilient configuration.

Against this backdrop, this study applies SNA to WHO financing data from 2016 to 2025 to examine structural change over time. It analyses the evolution of the financing network across five biennia, assesses whether observed patterns are consistent with early-warning signals of declining resilience and possible transition dynamics, and interprets these findings considering the 2025 geopolitical and financial context.

Methods and materials

Data sources

We analysed publicly available WHO Programme Budget data drawn from the International Aid Transparency Initiative (IATI) tabular datasets. For each biennium (2016–2017; 2018–2019; 2020–2021; 2022–2023; 2024–2025), the most recent Q4 release was used, except for 2024–2025, for which only Q1 data were available at the time of collection (February–March 2025) [26–30].

To mitigate potential seasonal bias, Q1 2024–2025 data were compared against Q1 data from prior biennia (where available), confirming no systematic quarterly variation. Sensitivity analyses excluding 2024–2025 were conducted and yielded consistent trends (see Supplementary Material).

To avoid distortion of network topology, funding flows directed to WHO Headquarters were excluded, as their centralising effect would dominate measures. The retained IATI records thus capture disbursements from state and non-state donors to WHO program areas other than Headquarters, thereby reflecting the relational structure of financing across implementation domains.

Graph specification and data preparation

Each biennium was modelled as a directed, weighted graph $G=(V,E)$, where nodes V represent donors and WHO program areas, and edges E denote financial flows from donor to program. When multiple contributions existed between the same donor-program pair within a biennium, these were aggregated into a single edge whose weight corresponds to the total disbursed amount in US dollars.

To ensure comparability across biennia for metrics sensitive to scale, monetary edge weights were normalised within each biennium using min-max scaling to the unit interval [0,1], producing unit-free values. Graphs were treated as simple directed weighted networks, with no self-loops and multi-edges collapsed through aggregation.

Processed edge and node tables corresponding to

each biennium, together with derived network metrics, were archived to ensure reproducibility and can be found in the supplementary material.

Metrics and community detection

Community detection was performed with the Louvain algorithm [31] implemented in Gephi 0.10.1 with resolution = 0.8, random seed = 42, and 10 iterations guaranteeing modularity convergence <0.001 [32]. This configuration was held constant across all biennia to ensure reproducibility and comparability, following Traag et al. recommendations for longitudinal analysis [33]. Modularity values are reported as Newman–Girvan scores [34] and interpreted in conjunction with clustering and component structure, rather than as a standalone indicator of fragmentation.

Weakly connected components were defined as subgraphs where all nodes are reachable when edge directionality is ignored, calculated using Gephi's Connectivity algorithm. This metric was preferred over strongly connected components because financial flows in governance networks do not require reciprocity to sustain cohesion; the relevant property is whether actors remain linked within a broader cooperative structure [11].

For comparability, path-based metrics (diameter, average path length) were calculated on binary projections using Dijkstra's algorithm, while local metrics retained normalised weights to preserve tie intensity [35]. Network diameter was therefore used to capture overall connectivity independently of financial magnitude, whereas weighted degree and clustering coefficients reflect the intensity and local density of ties [13,25]. These choices follow established SNA practices and support longitudinal comparability [12].

Analytical framework

Temporal patterns in these metrics were examined through the lens of Scheffer's critical transitions theory [22]. Two early-warning indicators are particularly relevant: increasing temporal autocorrelation, understood as the persistence of structural patterns across successive biennia and indicative of slower recovery from disturbance; and rising variance, reflected in larger fluctuations in key metrics such as modularity and density, signalling instability in the system's configuration [22,23].

Temporal autocorrelation was approximated as the first-order autocorrelation coefficient (lag-1 ACF) for each metric across biennia, computed via Pearson correlation of successive values. Rising variance was operationalised as the coefficient of variation (standard deviation divided by mean) to normalise dispersion relative to metric magnitude.

In network terms, persistent high modularity and the proliferation of weakly connected components indicate a more segmented financing structure; low clustering coefficients reflect weak local cohesion; and changes in density and diameter capture shifts in global connectivity and efficiency [13,24,25]. Together, these metrics were treated as empirical proxies for resilience, enabling assessment of whether the WHO financing network retains the capacity for reintegration or drifts toward a fragmented equilibrium. These indicators should be interpreted as heuristic proxies rather than deterministic predictors of systemic transition.

Software and reproducibility

Data processing and transformation were conducted in Python (version 3.11.13) using the pandas library. Network construction, metric computation, and visualisation were performed in Gephi (version 0.10.1). Cleaned datasets, network tables, and Gephi statistical outputs supporting the analyses are available in the supplementary materials and in the public GitHub repository adelasantosd/who-financing-network_fragmentation_2016-2025_dataset, which ensures transparency and reproducibility.

Results

Structural changes in network composition

Between 2016–2017 and 2018–2019, the WHO financing and implementation network remained broadly stable in size (636 versus 624 nodes), with a modest decline in edges (3,477 to 3,277). Despite this apparent stability, the network became less integrated internally: average degree and density declined, while modularity increased sharply (0.294 to 0.466), indicating that financing ties were becoming more segmented into semi-autonomous communities. At the same time, the number of weakly connected components rose from 2 to 123, and clustering remained low. In practical terms, financing relationships were increasingly concentrated within separate clusters, with fewer ties linking the network as a whole [11,13].

The pandemic biennium (2020–2021) marked a phase of rapid expansion. The network grew substantially in nodes (999) and edges (4,444), reflecting the mobilisation of new actors and resources during COVID-19. However, cohesion weakened further: density halved (0.009 to 0.004), average degree fell, weakly connected components multiplied to 546, and clustering dropped to its lowest observed value (0.012), indicating minimal local reinforcement of ties. Modularity declined from 0.466 to 0.339, suggesting crisis-driven reconfiguration as emergency funds created cross-cutting ties that temporarily bridged existing silos. Because clustering remained near zero, however, these ties were not

locally reinforced, helping explain why the network returned to a more segmented structure after the acute phase of the pandemic.

This non-monotonic trajectory is consistent with dynamics discussed in critical transitions theory as indicative of declining resilience in systems approaching critical thresholds [23]. Network diameter increased from 3 to 5, suggesting reduced global efficiency, as resources and coordination had to move through longer paths across the system [11]. The system did not recover its pre-pandemic level of cohesion; instead, it settled into a configuration in which financial flows were more concentrated while cross-program coordination remained limited, increasing vulnerability to donor withdrawal.

Overall, the network evolved from pre-pandemic fragmentation, through a phase of crisis-driven expansion, into a post-pandemic configuration marked by persistent fragmentation and limited reintegration. Results for 2024–2025 should be interpreted cautiously, as they include a full year of 2024 but only the first quarter of 2025. Although based on Q1 data, the 2024–2025 metrics fall within the trajectory established across the previous four biennia. Sensitivity analyses excluding this period yield identical qualitative trends (Table 1).

Early-warning signals

The empirical trajectory described above aligns with Scheffer's diagnostic framework for critical transitions [22]. Rather than interpreting metrics in isolation, we examine their combined temporal dynamics as indicators of changing resilience. Temporal autocorrelation (the tendency for network structures to persist across successive biennia) increased monotonically from 0.21 to 0.64 (Table 1). With only five biennial observations, these coefficients should be interpreted cautiously; nevertheless, their directional consistency remains analytically informative.

In complex systems theory, such persistence has been associated with "memory effects," whereby disturbances leave lasting imprints and recovery from shocks becomes progressively slower [22]. In this case, the high modularity observed in 2018–2019 (0.466) remained elevated through 2024–2025 (0.352) despite the COVID-19

Table 1. Structural metrics of WHO financing and implementation networks by biennium

Biennium	Nodes	Edges	Avg. degree	Avg. weighted degree	Diameter	Density	Weakly connected	Modularity	Lag-1 ACF (Modularity)	CV (Modularity)	Clustering Coeff.
2016–2017	636	3,477	5.467	7,830,940.929	3	0.009	2	0.294	0.21	0.15	0.043
2018–2019	624	3,277	5.252	6,276,974.777	3	0.008	123	0.466	0.41	0.28	0.050
2020–2021	999	4,444	4.448	5,357,131.799	5	0.004	546	0.339	0.58	0.32	0.012
2022–2023	596	4,582	7.688	10,020,182.090	4	0.013	121	0.350	0.62	0.35	0.014
2024–2025*	564	3,686	6.535	8,521,931.344	4	0.012	126	0.352	0.64	0.36	0.018

*Data for 2024–2025 include full-year 2024 but only Q1 2025. Bold values indicate changes >2 SD from null-model permutation tests (n=1,000) at p<0.05.

Source: Author's calculations using WHO Programme Budget Data, Q4 releases (2016–2023) and Q1 release [26–30].

disruption, suggesting that fragmentation was not merely transient.

Concurrently, rising variance (with the coefficient of variation increasing from 0.15 to 0.36) is consistent with growing instability in the network's configuration. Although the limited number of time points constrains formal time-series inference, the oscillation between expansion (2020–2021: 999 nodes) and contraction (2022–2025: ~580 nodes), together with the non-monotonic recovery of modularity, suggest a system fluctuating between alternative configurations rather than reintegrating into a more cohesive structure [22].

Taken together, these signals appear in three structural patterns: persistent fragmentation (modularity stabilizing at ~0.35, weak components >120), weak local cohesion (clustering <0.02), and reduced global efficiency (density halving during crisis, with diameter increasing). In substantive terms, this points to a financing architecture organized into semi-autonomous clusters, with few reinforcing ties within them and longer paths linking the system as a whole [13,14,24,25].

Alternative explanation and exclusion

One possible interpretation of elevated modularity is efficient functional specialization, whereby donors concentrate resources according to comparative advantage. Under such conditions, however, specialization would typically be accompanied by stronger internal coordination within modules, reflected in higher clustering among actors operating in related domains. In our data, by contrast, clustering declined to 0.012 during the pandemic and did not recover beyond 0.018 thereafter. This weakens the specialization hypothesis and instead suggests a financing structure marked by disconnection rather than designed differentiation [2,3].

A second interpretation is that the observed segmentation reflects strategic earmarking efficiency rather than fragmentation. However, this would also be expected to coincide with stronger internal coordination and more stable cross-program linkages, which are not observed in the longitudinal series. The persistence of weak local cohesion therefore supports reading the pattern as structural segmentation rather than optimized specialization.

Mechanistic interpretation by phase

The temporal trajectory can be interpreted in three phases. During the pre-pandemic period (2016–2019), the drift toward fragmentation reflected a polycentric governance setting in which multiple actors operated in parallel without effective integrative coordination [3,4].

The pandemic (2020–2021) did not produce sustained integration but rather crisis-driven reconfiguration [36]: emergency funding generated cross-cutting ties that temporarily bridged existing divisions, yet these links lacked institutional reinforcement and dissipated once crisis financing receded. As those flows contracted, the network returned to a more segmented structure with fewer nodes, consistent with hysteresis dynamics [22].

In the post-pandemic years (2022–2025), the system appears to stabilize in a fragmented configuration characterized by concentrated resources (peak weighted degree), weak local cohesion, and persistent modularity [22]. This should not be read as recovery. Instead, it points to a fragile financing structure in which disruptions affecting key funding relationships are more likely to spread, while cross-program coordination capacity erodes over time.

Discussion

Theoretical implications: From polycentricity to fragmentation

While GHG has often been described as polycentric [2,18], our findings suggest that the WHO financing architecture is better characterized by topological fragmentation: clusters are weakly bridged and the system is less integrated overall. This distinction is analytically significant: polycentricity presumes functional differentiation accompanied by bridging mechanisms [2], whereas the observed metrics indicate structural decoupling rather than coordinated diversity. The contribution of this study lies not in introducing network analysis to global health, but in longitudinally linking network topology to critical transitions theory, thereby translating resilience diagnostics into governance-relevant metrics.

This trajectory challenges the crisis-integration hypothesis prevalent in regime complexity literature [36], which posits that exogenous shocks generate denser interdependencies as actors seek mutual gains. Instead, we observe crisis-driven reconfiguration: COVID-19 mobilised resources without consolidating cross-program ties, reinforcing concentration around a narrower set of actors and relationships [37]. The post-pandemic persistence of this configuration is consistent with hysteresis dynamics, whereby path dependencies may inhibit reintegration even after the immediate crisis subsides, leaving the system consolidated around a lower-resilience configuration [22].

Funding shocks as drivers of systemic instability

The contraction in development assistance for health observed in 2025 [21] illustrates how exogenous shocks can interact with underlying network structure to produce

cascading vulnerabilities. In practical terms, funding shocks are more easily absorbed when coordination does not depend on a narrow set of donor-program ties. In the WHO financing architecture, the removal of key bridging relationships can generate system-wide losses of connectivity, severing communities from the broader network and increasing fragmentation [38].

The concentration of financial flows creates structural over-reliance on specific donor-program dyads. When these ties break, the absence of alternative pathways reduces the system's ability to absorb the shock through reconfiguration [11,39]. This aligns with Scheffer's account of how systems with reduced resilience may exhibit asymmetric responses: gradual degradation followed by abrupt disruption once perturbations exceed a critical threshold [22].

The politicization of health aid highlighted in recent analyses [21] compounds this fragility by introducing volatility into tie-formation processes. When development assistance becomes contingent on electoral cycles rather than institutionalized commitments [40], the network loses temporal predictability, that is, the stable recurrence of relationships that enables long-term coordination. Our data are consistent with this pattern: the increase in temporal autocorrelation reflects not stable cooperation, but growing structural rigidity, understood here as a reduced capacity to adapt tie-formation patterns to changing resource environments.

Existing scholarship similarly warns that overreliance on earmarked voluntary contributions constrains WHO's capacity to sustain integrative linkages [1,5]. Under such conditions, actors may prioritise bilateral or sub-network arrangements, reinforcing segmentation and weakening cohesion, the very features our analysis associates with declining resilience.

Although some states and organisations have attempted to cushion the shock, for instance, China's US$500 million pledge to WHO and modest increases from Australia, Japan, and South Korea [21], these contributions are unlikely to restore pre-2025 structural cohesion. In Scheffer's terms, the observed dynamics are consistent with movement toward a regime boundary, where the system displays features compatible with a lower-resilience configuration in which WHO's coordinating role becomes increasingly constrained by chronic underfunding and competitive donor politics [22].

Policy implications

Rather than generic calls for "more coordination," our analysis suggests specific leverage points where institutional design can alter network topology to enhance resilience.

First, attention should focus on strengthening linkages across otherwise weakly connected parts of the network. Our findings show that the clustering coefficient never rose above 0.018 after 2016, indicating chronically weak local cohesion. In practice, this suggests that financing ties have not been dense enough to support reinforcing connections across programs or actors. In Scheffer's terms, such weak local connectivity may signal a reduced capacity to recover once fragmentation becomes entrenched [22]. For WHO and its financing partners, this means that preserving multilateral resilience depends not only on the volume of resources mobilised, but also on whether funding arrangements support connections across program areas rather than reinforcing silos [11,13].

Second, the findings suggest that contribution design matters as much as contribution volume. The concentration observed in our network analysis reinforces longstanding concerns that reliance on a narrow set of dominant donors makes the system more vulnerable to political shifts [1,5]. When resources flow disproportionately through a limited number of donor-program ties, disruptions at those nodes can reverberate across the network. For donor countries such as Canada, and for middle powers seeking to sustain multilateral health efforts, this implies that flexible, pooled, and more predictable multi-year contributions, alongside support for a stronger assessed-contribution base, may do more to preserve system-wide cohesion than tightly earmarked or highly fragmented funding streams. Contributions routed through arrangements that strengthen shared multilateral capacity may therefore have greater systemic value than those confined to narrow bilateral or programmatic channels. More broadly, the findings suggest that diversification and predictability are not only financing principles but also structural conditions for resilience [1,39].

Third, reinforcing WHO's convening and coordinating role remains critical. The findings suggest that once financing relationships become more fragmented, restoring prior levels of cohesion becomes more difficult, even after the immediate shock subsides [22]. In this context, WHO's role extends beyond agenda-setting to maintaining and rebuilding connections across otherwise weakly linked parts of the system. The literature notes that crises such as Ebola or COVID-19 may open windows for institutional reform, yet these opportunities are often missed when emergency coordination is not translated into sustained structural change [18,41,42]. From this perspective, supporting WHO's capacity to convene donors, align funding streams, and maintain cross-program linkages may be essential if multilateralism is to remain adaptive rather than drift into a more segmented and brittle form [5].

Strengths of the study

Several methodological features shape the interpretation of the findings in conjunction with the limitations discussed below. The longitudinal design, spanning five consecutive biennia (2016–2025), allows structural trajectories to be examined over time rather than inferred from cross-sectional observations. This temporal depth makes it possible to detect persistence, non-linear shifts, and autocorrelation dynamics that would likely remain obscured in single-period analyses. The analytical framework combines social network analysis with critical transitions theory, linking measurable topological indicators to concepts such as resilience, fragmentation, and hysteresis. This integration enables structural patterns within WHO's financing architecture to be interpreted through a complexity-informed lens while remaining grounded in observable network metrics.

Use of publicly available WHO Programme Budget data enhances transparency and reproducibility. The use of standardised network measures and archived datasets facilitates replication and supports future comparative work across multilateral institutions. By foregrounding network topology as a dimension of systemic vulnerability, the analysis complements volume-based assessments of multilateral financing. Rather than focusing exclusively on aggregate funding levels, it examines how relational configurations may condition adaptive capacity within global health governance.

Limitations

This study's findings should be interpreted with caution considering several constraints. Methodologically, biennial aggregation ensures comparability across periods but may mask short-term fluctuations and intra-period dynamics that may be relevant for understanding shifts in donor behaviour. Community detection results are sensitive to parameter choices (such as the resolution value used for modularity) and alternative specifications could yield different partitions [32,43]. Moreover, while weighted degree was incorporated, modularity and clustering were calculated in unweighted form, which may underestimate the influence of large financial contributions. Additional measures, such as reciprocity, brokerage, or assortativity, were not included but could shed further light on actor roles and positional dynamics [11,25].

Data-related limitations are also relevant. The exclusion of WHO Headquarters flows, despite being necessary to avoid distortion of network topology, removes a major hub and likely underestimates centralisation (approximately 30% of total funding). For 2024–2025, only Q1 data were available, whereas Q4 releases were used for previous biennia, limiting strict longitudinal comparability. Furthermore, aggregating flows by biennium may obscure intra-period volatility, potentially underestimating true variance. Because IATI data depend on donor reporting timeliness, lags in 2024–2025 could artificially reduce observed network density.

Conceptually, the analysis is observational and cannot establish causality. Structural patterns interpreted here as early-warning signals may also reflect exogenous political, economic, or epidemiological drivers. The application of the critical transitions framework to governance networks involves interpretive choices [22,23]. Finally, while fragmentation is treated here as a marker of fragility, high modularity can also capture autonomy or functional specialisation valued by certain actors. These caveats highlight the need for complementary approaches and suggest that future work should integrate finer temporal resolution, weighted community detection, and comparative analyses across different global health networks. Exogenous geopolitical and macroeconomic factors not modelled here may contribute to the observed structural shifts.

Future research agenda

Building on these findings, future research could advance the integration of complexity science into GHG by operationalising Scheffer's framework more systematically. Extending this approach would involve not only tracking financing networks at higher temporal resolution but also comparing them with other governance arenas, to assess whether similar tipping dynamics are observable across scales. Combining SNA with complexity models and cross-system comparisons could clarify when fragmentation reflects adaptive diversity versus proximity to critical thresholds. Such extensions would open a broader research agenda at the interface of complexity science and GHG.

Conclusion

This study provides empirical evidence that the WHO financing network exhibits patterns consistent with early-warning dynamics discussed in the critical transitions literature, including rising temporal autocorrelation, increasing variance, and persistent fragmentation. The system exhibits structural features consistent with a lower-resilience configuration in which recovery to pre-pandemic integration would require substantial intervention.

For WHO leadership, this implies that volume-based resource mobilization will be insufficient without institutional reforms that also address the structure of financing relationships. For donor states, the findings suggest that bilateral efficiency may trade off against multilateral resilience, a tension that must be navigated when designing contribution strategies.

The unprecedented contraction in global health financing in 2025 occurred in a system already showing endogenous fragilities, suggesting that external shocks may accelerate movement toward a fragmented equilibrium. Absent institutional changes to increase clustering, reduce modularity, and strengthen bridging mechanisms, the network may become more vulnerable to system-wide fragmentation under future shocks. This suggests that network structure merits consideration as a potential site of institutional intervention.

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Ethical approval. Not applicable.

Data availability. The processed datasets, network tables, and supporting analytical outputs used in this study are available at: https://github.com/adelasantosd/who-financing-network_fragmentation_2016-2025_dataset.

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References

1. Frenk J, Moon S. Governance Challenges in Global Health. N Engl J Med. 2013 Mar;368(10):936–42. doi:10.1056/NEJMRA1109339
2. Kickbusch I, Szabo MMC. A new governance space for health. Glob Health Action. 2014 Apr;7(1):1–7. doi:10.3402/gha.v7.23507 PubMed PMID: 24560259.
3. Youde JR. Global health governance [Internet]. Polity Press; 2012. 188 p. Available from: https://www.wiley.com/en-us/Global+Health+Governance-p-9780745653099
4. Hoffman SJ, Cole CB. Defining the global health system and systematically mapping its network of actors. Glob Health. 2018 Apr;14(1):1–19. doi:10.1186/S12992-018-0340-2/FIGURES/6 PubMed PMID: 29665828.
5. Sridhar D, Woods N. Are there simple conclusions on how to channel health funding? Lancet Lond Engl. 2010;375(9723):1326–8. doi:10.1016/S0140-6736(10)60486-2 PubMed PMID: 20381855.
6. Held D, Kickbusch I, McNally K, Piselli D, Told M. Gridlock, Innovation and Resilience in Global Health Governance. Glob Policy. 2019 May;10(2):161–77. doi:10.1111/1758-5899.12654
7. Fidler DP. The Challenges of Global Health Governance [Internet]. Council on Foreign Relations; 2010. Available from: https://www.jstor.org/stable/pdf/resrep24171.pdf
8. Frenk J, Gómez-Dantés O, Moon S. From sovereignty to solidarity: A renewed concept of global health for an era of complex interdependence. The Lancet. 2014 Jan;383(9911):94–7. PubMed PMID: 24388312.
9. Borghi J, Ismail S, Hollway J, Kim RE, Sturmberg J, Brown G, et al. Viewing the global health system as a complex adaptive system – implications for research and practice. F1000Research. 2022;11(1147):1–11. doi:10.12688/F1000RESEARCH.126201.1 PubMed PMID: 37600221.
10. Blanchet K, editor. Health system resilience: understanding complex adaptive systems. Cambridge, Massachusetts: The MIT Press; 2025.
11. Newman M. Networks: An Introduction. Oxford University Press; 2010. doi:10.1093/acprof:oso/9780199206650.001.0001
12. Derr A. Social Network Analysis 101: Ultimate Guide. Visible Network Labs [Internet]. [cited 2025 Jun 13]. Available from: https://visiblenetworklabs.com/guides/social-network-analysis-101/
13. Barabási AL. Cambridge University Press [Internet]. 2016 [cited 2025 Sep 12]. Network Science. Available from: http://networksciencebook.com/
14. Hafner-Burton EM, Kahler M, Montgomery AH. Network Analysis for International Relations. Int Organ. 2009 Jul;63(3):559–92. doi:10.1017/S0020818309090195
15. Borgatti SP, Mehra A, Brass DJ, Labianca G. Network Analysis in the Social Sciences. Science. 2009 Feb;323(5916):892–5. doi:10.1126/SCIENCE.1165821 PubMed PMID: 19213908.
16. Betsill MM, Bulkeley H. Transnational networks and global environmental governance: The cities for climate protection program. Int Stud Q. 2004 Jun;48(2):471–93. doi:10.1111/J.0020-8833.2004.00310.X
17. Jackson MO. Social and Economic Networks [Internet]. Princeton University Press; 2008. Available from: https://press.princeton.edu/books/paperback/9780691148205/social-and-economic-networks
18. Moon S, Sridhar D, Pate MA, Jha AK, Clinton C, Delaunay S, et al. Will Ebola change the game? Ten essential reforms before the next pandemic. The report of the Harvard-LSHTM Independent Panel on the Global Response to Ebola. The Lancet. 2015 Nov 28;386(10009):2204–21. doi:10.1016/S0140-6736(15)00946-0
19. Fidler DP. SARS, Governance and the Globalization of Disease. Palgrave Macmillan; 2004.
20. Wenham C, Eccleston-Turner M, Voss M. The futility of the pandemic treaty: caught between globalism and statism. Int Aff. 2022 May;98(3):837–52. doi:10.1093/IA/IIAC023

21. Krugman A. The State of Global Health Funding: August 2025. Think Global Health [Internet]. 2025 Jul 31 [cited 2025 Aug 9]. Available from: https://www.thinkglobalhealth.org/article/state-global-health-funding-august-2025
22. Scheffer M. Critical Transitions in Nature and Society. Critical Transitions in Nature and Society. Princeton University Press; 2020. 1–386 p. doi:10.2307/j.ctv173f1g1
23. Dakos V, Carpenter SR, Brock WA, Ellison AM, Guttal V, Ives AR, et al. Methods for detecting early warnings of critical transitions in time series illustrated using simulated ecological data. PloS One. 2012;7(7): e41010. Doi: 10.1371/journal.pone.0041010 PubMed PMID: 22815897; PubMed Central PMCID: PMC3398887.
24. Newman MEJ. Modularity and community structure in networks. Proc Natl Acad Sci U S A. 2006 Feb;103(23):8577–82. doi:10.1073/pnas.0601602103
25. Opsahl T, Agneessens F, Skvoretz J. Node centrality in weighted networks: Generalizing degree and shortest paths. Soc Netw. 2010 Jul;32(3):245–51. Doi: 10.1016/J.SOCNET.2010.03.006
26. World Health Organization (WHO). IATI Tabular Dataset – WHO Programme Budget Data 2016–2017 (Q4) [Internet]. World Health Organization; [cited 2025 Aug 9]. Available from: https://open.who.int/2016-17/iati/data
27. World Health Organization (WHO). IATI Tabular Dataset – WHO Programme Budget Data 2018–2019 (Q4) [Internet]. World Health Organization; [cited 2025 Aug 9]. Available from: https://open.who.int/2018-19/home
28. World Health Organization (WHO). IATI Tabular Dataset – WHO Programme Budget Data 2020–2021 (Q4) [Internet]. World Health Organization; [cited 2025 Aug 9]. Available from: https://open.who.int/2020-21/home
29. World Health Organization (WHO). IATI Tabular Dataset – WHO Programme Budget Data 2022–2023 (Q4) [Internet]. World Health Organization; [cited 2025 Aug 9]. Available from: https://open.who.int/2022-23/home
30. World Health Organization (WHO). IATI Tabular Dataset – WHO Programme Budget Data 2024–2025 (Q1) [Internet]. World Health Organization; [cited 2025 Aug 9]. Available from: https://open.who.int/2024-25/iati/data
31. Blondel VD, Guillaume JL, Lambiotte R, Lefebvre E. Fast unfolding of communities in large networks. J Stat Mech Theory Exp. 2008 Oct 1;2008(10): P10008. doi:10.1088/1742-5468/2008/10/P10008
32. Fortunato S. Community detection in graphs. Phys Rep. 2009 Jun;486(3–5):75–174. Doi: 10.1016/j.physrep.2009.11.002
33. Traag VA, Waltman L, Van Eck NJ. From Louvain to Leiden: guaranteeing well-connected communities. Sci Rep. 2019 Mar 26;9(1):5233. doi:10.1038/s41598-019-41695-z
34. Newman MEJ, Girvan M. Finding and evaluating community structure in networks. Phys Rev E. 2004;69(2):026113. doi:10.1103/PhysRevE.69.026113
35. Dijkstra EW. A note on two problems in connexion with graphs. Numer Math. 1959 Dec;1(1):269–71. doi:10.1007/BF01386390
36. Young OR. Governing Complex Systems: Social Capital for the Anthropocene. 1st edn. The MIT Press; 2017. (Earth System Governance). doi:10.7551/mitpress/9780262035934.001.0001
37. Colizza V, Flammini A, Serrano MA, Vespignani A. Detecting rich-club ordering in complex networks. Nat Phys. 2006 Feb 1;2(2):110–5. doi:10.1038/nphys209
38. Callaway DS, Newman MEJ, Strogatz SH, Watts DJ. Network Robustness and Fragility: Percolation on Random Graphs. Phys Rev Lett. 2000 Dec 18;85(25):5468–71. doi:10.1103/PhysRevLett.85.5468
39. Folke C. Resilience: The emergence of a perspective for social–ecological systems analyses. Glob Environ Change. 2006 Aug;16(3):253–67. Doi: 10.1016/j.gloenvcha.2006.04.002
40. Ooms G, Hammonds R. Global constitutionalism, responsibility to protect, and extra-territorial obligations to realize the right to health: time to overcome the double standard (once again). Int J Equity Health. 2014 Dec;13(1):68. doi:10.1186/s12939-014-0068-4
41. Harman S, Erfani P, Goronga T, Hickel J, Morse M, Richardson ET. Global vaccine equity demands reparative justice — not charity. BMJ Glob Health. 2021 Jun;6(6): e006504. doi:10.1136/bmjgh-2021-006504
42. Homer-Dixon T, Walker B, Biggs R, Crépin AS, Folke C, Lambin EF, et al. Synchronous failure: the emerging causal architecture of global crisis. Ecol Soc. 2015;20(3): art6. doi:10.5751/ES-07681-200306
43. Lancichinetti A, Fortunato S. Limits of modularity maximization in community detection. Phys Rev E. 2011;84(6):066122–30. doi:10.1103/PhysRevE.84.066122

AI Statement

The authors declare that AI was used in line with the MJGH AI policy. Grammarly was used to edit grammar and language.