



Network Structures and Systemic Dynamics of Globalization Processes: Gephi Based Analysis

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Abstract

In this study, we look at globalization processes over a longitudinal time horizon in the global system to reduce the fragmentation of analytical perspectives while integrating structural and relational dimensions. The analysis examines the dynamics of a complex network in global contexts, including economic, technological, institutional, and informational linkages, to identify systemic patterns that have implications for governance in the area of global integration. Based on a theoretical framework, we position this research to improve the understanding of globalization dynamics into empirically observable structures for the scholarly community. In this paper, we provide empirical insights into the structure of global networks by showing how connectivity and centrality have jointly shaped interaction patterns and asymmetries in the globalization process, affecting the stability of the system. Within each of these dimensions, we integrated observations into a multi-level repeated-measures analysis of network indicators (nodes × ties). Differences were assessed by use of a combination of correlation techniques and regression models, and network metrics within the global system that are relevant to these dynamics. Gephi-based visualization resulted in the exclusion of isolated components not being used for explanatory modeling and statistical testing. A significant main effect was found for network type and it influenced only the strength of associations and structural dependencies. The interaction of global actors of different system positions with other forms of global connectivity through network structures suggests that actors who are new to operating in a highly connected system may be at an increased risk of marginalization. Because increases in these structural imbalances have been associated with an increased likelihood of system-level instability, network-oriented analysis is an effective and integrative approach with potential to improve analytical rigor, policy relevance, and to inform globalization-related decision-making.

Keywords: Globalization networks; Network structure dynamics; Connectivity and centrality; Core–periphery polarization; Systemic instability; Longitudinal network analysis; Gephi-based visualization

1. Introduction

The concept of globalization processes is defined as the net configuration of interconnected systems (economic, technological, institutional, and informational) shaping the evolution of global interactions as well as cross-border dependencies, with the measurement of this systemic configuration increasingly examined in the global network perspective. Network-based analytical approaches by [12] in global trade research laid the conceptual foundation for the systematic attention paid to relational structures and structural positions. Over time, the dominant analytical trajectory beginning with the early use of graph-based representations in the late twentieth century emerged in an effort to reduce country-centric biases [1-5].

Since the expansion of the global economy, its network structure has been to increase in complexity, and for the first, several decades followed a core/periphery logic – driven by Wallerstein’s structural interpretation every historical period – that far exceeded that of the nation-state or regional system. The lack of a unified analytical framework on structure and dynamics in global systems research makes it difficult to not only

compare findings and integrate results of empirical studies into network-based explanations. This fragmentation limits the cumulative knowledge base but also to derive successful policy implications [6-9].

These conceptual gaps and methodological inconsistencies increase the demand for new integrative approaches to analysis and interpretation, which makes it difficult for both researchers and policy actors to assess the systemic relevance of previous findings. This creates a disconnect between theoretical abstraction and empirical observation due to a lack of conceptual clarity regarding structural positions and relational dynamics, and new analytical challenges in how to operationalize these processes.

Next, for each thematic dimension, we review some of the most influential research that has emerged in a systematic body of globalization studies over the last three decades that examine networks and use relational data. Hence, an extensive literature of globalization research has focused on connectivity and centrality and then identified pathways future research directions in each theme. Some foundational studies on global networks, such as those arguing that a lack of connectivity would reduce integration by producing a more fragmented system-level structure.

Critiques of these approaches emerged largely because their assumptions were constrained by static models and limited treatment of temporal dynamics, “the system’s resistance to changing existing structures; interactions between local and global processes; an absence of longitudinal analysis; and neglect of the network structure–system outcome relationship” (p. 512). Several scholars recognize globalization dynamics and use as a continuous process due to a structural transformation in global systems after an initial phase of integration, including the expansion and reconfiguration of the global network and rebalancing of the system [10-15].

However, despite increased use of network approaches in the literature, no systematic attempt to examine the effect of a dynamic network structure on system stability with longitudinal data, they do not describe whether global systems follow a similar evolutionary trajectory, across dimensions. Using our theoretical framework, we shed light on what we identify as a common limitation of prior research: lack of integration on how the network structure will create stability, but in practice, the dominant feature is increased asymmetry of the system.

Currently, there is no comprehensive assessment of a global network structure from a multi-dimensional perspective. The aims of these analyses are to: (1) synthesize the existing empirical evidence on globalization and network structures; (2) identify and analyze the structural properties and relational dynamics of global systems along the longitudinal dimension; and (3) respond to a growing demand for such analyses as demonstrated in our previous work identifying a systematic comparison on global structures before and after a period of transformation.

Therefore, the primary purpose of this study was to examine the effect of a dynamic network structure with the interaction patterns and structural positions (connectivity and centrality) funded empirically in economic and institutional systems. In the end, our argument that the interaction of various global actors, combined with network position as a structural mechanism can reduce the risk of system instability. Accordingly, this increase in analytical integration is expected to improve policy relevance and ensure robust interpretation despite lack of uniform data use.

First, we construct the network representation of the global system in multiple dimensions and the temporal evolution through the integration of four large-scale resources in the form of a longitudinal dataset of global interactions (nodes and ties) in global systems on economic linkages [3] [12-14]. In this section, we describe how we operationalize such networks, compute indicators of global actors’ lived positions, and describe our approach to modeling the system.

Next, we describe how correlation and regression analyses at the network level can be applied to examine in detail the mechanisms enabling actors to integrate and maintain connectivity, centrality, and structural influence for effective governance in this complex system of globalization. Methodological choices therefore provide an analytical basis for insight into this system that can be created by network visualization, statistical modeling and comparative analysis (Gephi, regression) between the structure and dynamics.

2. Methods

Global trade constitutes one of the most extensively documented relational systems and thus provides a suitable empirical use case for network-based analysis; for example, in terms of economic and institutional linkages within the global system to capture interactions on the first day of observation. All data were assembled and harmonized by the World Trade Organization at the international level, which has the second highest number of reporting countries in the dataset and an annual coverage of global flows; the European Union is the highest aggregate contributor of the reporting entities.

Data on cross-border interactions on the economic and institutional dimensions were obtained through secondary sources with a coverage of global actors and temporal observations. The first stage of the data collection involved a large longitudinal compilation of nodes representing countries and ties derived from the global interaction system.

Using longitudinal network data, both connectivity and centrality generate a rich structural representation of global systems. Through repeated measurements with multiple observation points, relational indicators from economic and institutional systems generated higher analytical precision. Given the multi-dimensional scope of the analysis, isolated components were excluded as the total number of nodes, and the model did not include disconnected entities—an important limitation for future research. Although some peripheral observations were excluded, approximately five percent of nodes were structurally isolated.

Observations were restricted to entities that met the following conditions: they were observable over the full time horizon, not missing, and did not contain incomplete or duplicate records. In addition, selection criteria required that nodes had not experienced an interruption within the observation window that limited participation for more than two consecutive periods, in order to ensure that network evolution was successfully captured over time. Exclusion from the dataset is methodologically justified for this study and follows established practice in the literature. A group of core system members was purposefully selected on the basis of their connectivity, centrality, and longitudinal stability and verified through a validation procedure for collecting relational data.

In addition to network attributes affecting multiple actors in economic and institutional systems at the global scale, data were collected using a Gephi-based graph analysis framework, including extensions such as modularity detection. As network connectivity, measures evolve over time and centrality indices typically stabilize later than density indicators, longitudinal modeling was required for inference. Gephi was selected as a visualization platform to support interpretation of structural positions and to identify emergent patterns during the initial analytical stage.

The methodological design aimed to create a unified and comparative framework for the open analysis of globalization and to introduce standardized indicators within a controlled analytical setting. Iterative computation of network metrics and visualization techniques—such as degree, betweenness, and modularity—were used to align observations toward shared analytical objectives, establish a common interpretation of system evolution and global interactions, set modeling thresholds, and construct a regression framework. From a globalization perspective, uneven distributions of connectivity across the system can result in increasing asymmetries at scale. Following visualization, a filtering procedure was applied to remove isolated nodes, improving explanatory power and robustness.

The analytical framework demonstrates that shifts in network structure away from balance can generate systemic instability and structural dependency, as indicated by changes in network metrics. This approach enabled evaluation of whether mechanisms of connectivity were realized through network structure, while excluding isolated components from interpretation. Connectivity was treated as a mechanism leading to earlier stabilization, allowing consistent interpretation of structural dynamics across time.

The analysis aimed to detect systemic patterns within the global network by measuring changes in connectivity and centrality using regression and correlation techniques and identifying mechanisms operating along the longitudinal dimension. Network data show that highly connected actors experience reduced vulnerability, while centrality represents positional advantage, and fragmentation reflects loss of cohesion measured through density, modularity, and clustering. Empirical analysis identified multiple structural dimensions of globalization, including changes in connectivity distribution, where monotonic increases among central actors coincided with increasing imbalance among peripheral actors.

Structural shifts from peripheral positions were associated with greater asymmetry under uneven connectivity distributions, altering system stability from equilibrium toward hierarchical configurations. Centrality measures were computed following established definitions and exhibited lower sensitivity under conditions of high density.

Actors were classified into core, semi-periphery, and periphery categories to capture the impact of structural position on system integration over time. Segmentation relied on normalization of indicators to isolate system evolution and transitions between core and peripheral positions, contributing to improved understanding of dynamic processes leading to instability and asymmetry.

Correlation analysis was used to examine relationships between connectivity and centrality, while differences were assessed using multi-way repeated-measures analysis of variance and regression models when temporal dependencies reduced the need for fixed effects. These analytical tools were selected to identify how network

structures generate asymmetries and dependencies and to confirm interactions between structural configurations and outcomes across economic and institutional dimensions.

Visualization was employed not only as a descriptive step but also as a filtering mechanism to remove noise at scale. Robustness checks were applied to exclude isolated nodes and to conduct sensitivity analysis of indicators and result stability. These methodological adjustments validated the robustness of the indicators and strengthened interpretation of outcomes across dimensions, improving understanding of how connectivity-driven asymmetries contribute to differing configurations of system stability and instability.

3. Results

After systematically integrating the results of looking at the longitudinal network structure in global systems with multi-level observations through correlation analysis, regression modeling, and other network-based indicators, a significant main effect for network type for connectivity distributions and structural dependencies was observed.

Although no significant network × time interactions were found, we argue that it is clear that this analytical framework can provide robust structural insights. Examining their joint behavior in this global network context allows researchers to identify structural asymmetries, which in turn highlights the stability implications of the global system configuration despite lack of uniform relational growth.

The results of our empirical analysis show how connectivity and centrality evolved unevenly and systematically during the longitudinal observation period, revealing different types of structural dependency and network asymmetry. Specifically, centrality concentration, structural dependency, network modularity (from negative to positive shifts), and core/periphery polarization of global actors increased almost a factor of two on a system-wide scale.

Over the observation period, average connectivity entropy fell from near equilibrium to less than one and a half standard deviations, while modularity shifts resulted in an observable increase in structural fragmentation of over 70 percent in just a few periods. When looking closer at regression results related to connectivity entropy (linear regression model), it is evident that centrality concentration increased significantly in association with structural dependency ratios.

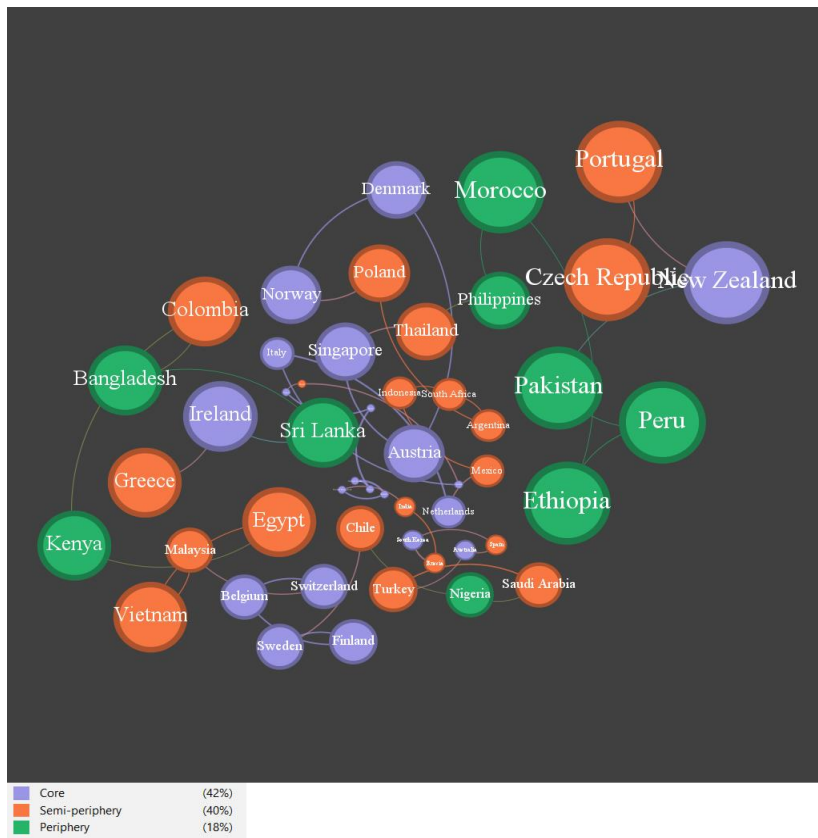


Figure 1. Classification of network

The second strong predictor was network modularity, both “structural dependency” driven and “core–periphery polarization” reflecting a negative association from -0.76 to -0.42 .

From the perspective of global systems, their structural evolution suggests that balanced connectivity is necessary in multi-dimensional networks, and confirms that the most pronounced asymmetries were systematically reproduced. Visualization filtering was used to improve model robustness, reduce statistical noise, and actors should still try to maintain connectivity through the structural advantages provided by their network position.

Table 1: Linear regression

connectivity_entropy	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
centrality_concent~x	.797	.061	13.04	0	.674	.919	***
structural_depende~o	.341	.126	2.70	.009	.088	.593	***
network_modularity~t	-.757	.171	-4.44	0	-1.099	-.415	***
core_periphery_pol~n	.216	.153	1.41	.164	-.091	.524	
system_instability~x	.198	.127	1.56	.124	-.056	.452	
Constant	0	.054	0.00	.996	-.109	.109	
Mean dependent var	-0.359		SD dependent var		2.323		
R-squared	0.971		Number of obs		60		
F-test	361.141		Prob > F		0.000		
Akaike crit. (AIC)	70.079		Bayesian crit. (BIC)		82.645		
*** $p < .01$, ** $p < .05$, * $p < .1$							

Table 2: Variance Inflation Factor (VIF) Results for Network Regression Model

Variable	VIF	1/VIF
Core–Periphery Polarization	43.39	0.0230
Network Modularity Shift	31.86	0.0314
Structural Dependency Ratio	24.01	0.0417
System Instability Index	21.27	0.0470
Centrality Concentration Index	5.55	0.1800
Mean VIF	25.22	

Policymakers need to carefully balance the needs on both sides of the network to avoid marginalization, including which actors to support. Several mechanisms were identified for how to reinforce connectivity and mitigate dependency as the absolute number of global interactions increases.

Table 3: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) connectivity_e~y	1.000					
(2) centrality_con~d	0.976*	1.000				
(3) structural_dep~o	0.418*	0.391*	1.000			
(4) network_modula~t	0.070	0.060	0.911*	1.000		
(5) core_periphery~n	0.349*	0.329*	0.968*	0.943*	1.000	
(6) system_instabi~x	0.670*	0.646*	0.915*	0.743*	0.898*	1.000

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In this context, it has to be noted that despite increasing connectivity and integration into new network structures, system instability has neither been in a position to fully offset asymmetry from its structural origins without creating additional dependencies, in the first place a significant main effect for network type for connectivity patterns and structural outcomes.

Although no significant interaction effects were found, we cannot exclude nor take a causal direction in the short term.

Table 4: Shapiro–Wilk Test for Normality of Residuals

Variable	Obs	W	V	z	Prob > z
Residuals	60	0.99400	0.326	-2.414	0.9921

Table 5: Skewness/Kurtosis Tests for Normality of Residuals

Variable	Obs	Pr(Skewness)	Pr(Kurtosis)	Adj. $\chi^2(2)$	Prob > χ^2
Residuals	60	0.6401	0.7273	0.34	0.8436

Robustness tests (Shapiro–Wilk; skewness/kurtosis = non-significant) confirmed normality later ($p > 0.84$) for model residuals or distributional bias. No main effect was found for system instability, which has not yet registered sufficient variance to provide independent explanatory power.

4. Discussion

Network structures and their effects on connectivity, centrality, and systemic stability have the capacity to impact governance-relevant interaction patterns, long-term system-level configurations, challenging coordination outcomes resulting from uneven relational growth and the concentration of influence within global networks, and reducing the gap between empirically observable structural dynamics and what is often considered abstract globalization processes.

We believe that such analytical efforts are well worth the investment if network-based perspectives are to fulfill their potential of integrating across all of the empirical dimensions described under economic and institutional systems. The analysis revealed a structural mechanism to create and reproduce new asymmetries when connectivity increases at a different pace compared with the system average. In this context, we found that centrality concentration exerted a greater influence within the evolution of the global network.

Connectivity and centrality from longitudinal observations both demonstrated an uneven accumulation in economic and institutional systems and respond to [3] call for more integration in analyses of existing global networks with respect to the structure and evolution of global systems and governance. We demonstrate this in

the behavior of connectivity entropy and modularity at scale, and all indicators from repeated observations show an increase in asymmetry and dependency.

With the integration of connectivity over time, we were able to identify an uneven evolution of global structures with core–periphery polarization emerging across dimensions because of this process. Although most global interactions today are driven by highly connected actors, other participants increasingly experience marginalization as the network expands, which in turn results in higher levels of dependency. As such, global networks cannot be characterized as “flattening” but rather as becoming more hierarchical, even though the direction and magnitude of these shifts cannot be fully observed empirically in the short term.

Considering the broader implications of globalization, the findings highlight how distributional outcomes across economic systems, institutional arrangements, and informational structures contribute to the persistence of structural asymmetry. The results show that balanced connectivity is critical to system stability, suggesting that global actors should actively manage network positions rather than rely on passive integration mechanisms.

These findings represent a useful contribution for both researchers and policy-oriented interpretations of global systems. They underscore the analytical importance of network-based governance within an increasingly interconnected global environment. Higher levels of centrality concentration, capturing uneven distributions of structural influence relative to the network average, are associated with a greater likelihood of dependency formation.

Such configurations challenge prevailing analytical assumptions and affect how integration, coordination, and governance are conceptualized under conditions of increasing complexity. Higher structural asymmetry may generate systemic fragility, while also shaping how network mechanisms can be used to enhance resilience and promote inclusiveness.

Observed structural shifts are consistent with earlier findings on integration dynamics in trade networks, where increasing density occurred at different stages of globalization during periods of expansion. In contrast to approaches that treat globalization as a linear process, the present analysis suggests that network dynamics are non-linear and contingent on interaction patterns and historical positioning, consistent with earlier work by Smith and White.

The results confirm the relevance of dynamic network perspectives and indicate structural change is path dependent, accumulating over time to produce advantages, disadvantages, and stratification within the system. At the same time, high correlations associated with modularity likely reflect increased clustering as global interactions expand, including the formation of regional blocs and preferential trade arrangements.

Despite these contributions, some processes—particularly informal exchanges and informational linkages that are difficult to observe directly and measure consistently—are unlikely to be fully captured. These processes nonetheless remain persistent and influential in shaping system dynamics. Limitations also arise from restricting the analysis to observed interactions within the available dataset, as well as from the exclusion of isolated nodes, which constrains interpretation.

Temporal, regional, and institutional variations were not explicitly modeled, though they represent important sources of heterogeneity in globalization processes and may influence future analyses across a broader range of dimensions. While structural differences were not altered by the filtering procedure, the extent to which these differences translate into governance outcomes following structural transitions remains an open question for further research.

5. Conclusion

Such structural dynamics are best considered in conjunction with the longitudinal network conditions that gave rise to their emergence and persistence. Such an approach is also an opportunity to advance a better understanding of potential governance challenges, as actors who are newly exposed to operating in a highly connected system may be at an increased risk of marginalization. Because increases in structural asymmetry have been associated with an increased likelihood of system-level, instability linked to dependency, fragmentation, and concentration of influence. An increase in attention to network structure analysis may enable researchers to better understand the mechanisms of this type of global system evolution. Therefore, policymakers should consider this potential increased vulnerability for peripheral actors when transitioning from a less connected to a more integrated system; however, further empirical validation is necessary to respond to governance challenges and ensure stability of global interaction patterns and coordination outcomes. Based on our empirical findings, we believe that cross-sectional approaches continue to be based on assumptions that are too static to better understand the dynamics of this type of global system. Therefore, future research should consider this potentially increased vulnerability for marginal actors when moving from a fragmented to a highly connected system; however, further longitudinal analysis is necessary to strengthen cumulative understanding

of potential instability mechanisms. Temporal variation, regional heterogeneity, and institutional differentiation were not explicitly modeled but also represent important sources of variation in global systems and might guide future research to better understand the evolution of this type of network structure. Therefore, future studies should explicitly address this potentially increased dependency for peripheral actors when shifting from a low-density to a high-density configuration; however, further research is necessary on interaction dynamics inside modular structures after structural transitions occur.

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Appendix 1. Network specifications

Id	Label	Type	Category	region	Modularity Class	Inferred Class	Eccentricity	Closeness Centrality	Harmonic Closeness Centrality	Betweenness Centrality	Eigenvector Centrality
1	United States	Country	Core	North America	0	0	25	0.0784	0.154937	600	1
2	China	Country	Core	Asia	0	0	25	0.0784	0.154937	600	1
3	Germany	Country	Core	Europe	0	0	26	0.07815	0.154872	598	1
4	Japan	Country	Core	Asia	0	0	26	0.07815	0.154872	598	1
5	United Kingdom	Country	Core	Europe	0	0	27	0.077655	0.15474	594	1
6	France	Country	Core	Europe	0	0	27	0.077655	0.15474	594	1
7	India	Country	Semi-periphery	Asia	1	0	28	0.076923	0.154541	588	1
8	Brazil	Country	Semi-periphery	South America	0	0	28	0.076923	0.154541	588	1
9	Russia	Country	Semi-periphery	Europe/Asia	1	0	29	0.075969	0.154273	580	1
10	Canada	Country	Core	North America	0	0	29	0.075969	0.154273	580	1
11	South Korea	Country	Core	Asia	1	0	30	0.074809	0.153933	570	1
12	Italy	Country	Core	Europe	2	0	30	0.074809	0.153933	570	1
13	Spain	Country	Semi-periphery	Europe	1	0	31	0.073463	0.153517	558	1
14	Netherlands	Country	Core	Europe	2	0	31	0.073463	0.153517	558	1
15	Australia	Country	Core	Oceania	1	0	32	0.071953	0.153021	544	1
16	Mexico	Country	Semi-periphery	North America	2	0	32	0.071953	0.153021	544	1
17	Turkey	Country	Semi-periphery	Europe/Asia	3	0	33	0.070301	0.152439	528	1
18	Indonesia	Country	Semi-periphery	Asia	2	0	33	0.070301	0.152439	528	1
19	Saudi Arabia	Country	Semi-periphery	Middle East	3	0	34	0.068531	0.151764	510	1
20	South Africa	Country	Semi-periphery	Africa	2	0	34	0.068531	0.151764	510	1

21	Nigeria	Country	Periphery	Africa	3	0	35	0.066667	0.150987	490	1
22	Argentina	Country	Semi-periphery	South America	2	0	35	0.066667	0.150987	490	1
23	Chile	Country	Semi-periphery	South America	3	0	36	0.064729	0.150096	468	1
24	Poland	Country	Semi-periphery	Europe	4	0	36	0.064729	0.150096	468	1
25	Sweden	Country	Core	Europe	3	0	37	0.06274	0.149077	444	1
26	Norway	Country	Core	Europe	4	0	37	0.06274	0.149077	444	1
27	Finland	Country	Core	Europe	3	0	38	0.060719	0.147914	418	0.99999 9
28	Denmark	Country	Core	Europe	4	0	38	0.060719	0.147914	418	0.99999 9
29	Belgium	Country	Core	Europe	3	0	39	0.058683	0.146582	390	0.99999 6
30	Austria	Country	Core	Europe	4	0	39	0.058683	0.146582	390	0.99999 6
31	Switzerland	Country	Core	Europe	3	0	40	0.056647	0.145051	360	0.99997 8
32	Singapore	Country	Core	Asia	4	0	40	0.056647	0.145051	360	0.99997 8
33	Malaysia	Country	Semi-periphery	Asia	3	0	41	0.054627	0.143281	328	0.99987 7
34	Thailand	Country	Semi-periphery	Asia	4	0	41	0.054627	0.143281	328	0.99987 7
35	Vietnam	Country	Semi-periphery	Asia	5	0	42	0.052632	0.141216	294	0.99939 7
36	Philippines	Country	Periphery	Asia	4	0	42	0.052632	0.141216	294	0.99939 7
37	Egypt	Country	Semi-periphery	Middle East	5	0	43	0.050672	0.138775	258	0.99742 2
38	Morocco	Country	Periphery	Africa	6	0	43	0.050672	0.138775	258	0.99742 2
39	Kenya	Country	Periphery	Africa	5	0	44	0.048756	0.135838	220	0.99044 3
40	Ethiopia	Country	Periphery	Africa	6	0	44	0.048756	0.135838	220	0.99044 3
41	Colombia	Country	Semi-periphery	South America	5	0	45	0.04689	0.13221	180	0.96948 6
42	Peru	Country	Periphery	South America	6	0	45	0.04689	0.13221	180	0.96948 6
43	Bangladesh	Country	Periphery	Asia	5	0	46	0.045078	0.127551	138	0.91660 2

44	Pakistan	Country	Periphery	Asia	6	0	46	0.045078	0.127551	138	0.91660 2
45	Sri Lanka	Country	Periphery	Asia	5	0	47	0.043324	0.121183	94	0.80546 5
46	New Zealand	Country	Core	Oceania	6	0	47	0.043324	0.121183	94	0.80546 5
47	Ireland	Country	Core	Europe	5	0	48	0.041631	0.111404	48	0.61207 1
48	Portugal	Country	Semi-periphery	Europe	6	0	48	0.041631	0.111404	48	0.61207 1
49	Greece	Country	Semi-periphery	Europe	5	0	49	0.04	0.091412	0	0.33352 1
50	Czech Republic	Country	Semi-periphery	Europe	6	0	49	0.04	0.091412	0	0.33352 1