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The Topology of Global Trade: A Network Analysis of Logistics Performance and Tariff Rate Alignment

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Abstract
This study investigates the structural relationships between Most Favoured Nation Weighted Average (MFNWA) tariffs and the Logistics Performance Index (LPI) using graph theoretical analysis. While these metrics are fundamental to global trade, they are rarely analysed as intertwined networks. Utilizing World Bank data from 2007 to 2022, we construct independent association networks to measure how nations align with global tariff and logistics trends. Through measures of node degree and betweenness centrality, the research identifies nations that serve as pivotal hubs or outliers in the global trade ecosystem. Findings reveal a strong negative correlation between average MFNWA rates and LPI scores, yet a lack of correlation between their respective network degrees, suggesting that the factors driving logistics excellence and tariff alignment are governed by distinct economic drivers. The study provides a novel framework for policymakers to assess a nation's connectivity and strategic positioning within global trade networks.

Keywords: Logistics Performance Index (LPI), MFN tariffs, graph theory, network analysis, global trade, betweenness centrality.

JEL Classification: F12; F14; L91; C45; O19.

Introduction

A nation sets their Most Favoured Nation (MFN) tariff rate through a combination of domestic economic prioritizations, international trade negotiations, and strategic policy decisions. Under World Trade Organization (WTO) regulations, WTO member-nations must apply MFN tariffs uniformly to all other WTO members (WTO 2019).

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Factors such as sectoral competitiveness in international markets, level of industrialization, and political considerations impact MFN policy decisions (Helpman G et al. 2025). MFN weighted average (MFNWA) tariffs adjust MFN rate by import volume, providing an economically relevant measure that accounts for both tariff policy and trade flow patterns. Correlations between nations weighted average MFN tariffs can signal deeper economic integration. Specifically, shared tariff patterns between nations can reflect similar external pressures, including terms of trade incentives (Bagwell & Staiger, 2011) or result from trading bloc membership or common external tariffs set by customs unions (Ben-David, 1996). Furthermore, similar tariff trends can stem from comparable import composition shifts, such as simultaneous rising demand for lower-duty goods (Kuenzel & Sharma, 2021). In this work, we investigate a nation's MFNWA tariff trend similarity, observing how aligned it is with other nations' MFNWA trends to determine how much regional and global patterns influence its tariff burden.

MFN tariffs directly shape a nation's trade environment; lower tariffs tend to promote openness and increase the flow of goods across borders (Wacziarg & Welch, 2008). However, even with favourable tariff policies, trade can be severely limited if logistical systems are inefficient. Logistics Performance Index (LPI) reflects the quality of infrastructure, customs efficiency, and the overall ability to move goods reliably and on time (Arvis et al., 2018; World Bank 2024). A nation with low MFN tariffs but poor logistics may still struggle to attract trade, while strong logistics can amplify the benefits of tariff liberalization. Correlations across nations between LPI trends can reflect shared levels of trade facilitation capacity, infrastructure quality, and integration in global supply chains. High correlation may also arise from geographic and economic interdependence. Such relationships indicate that logistics performance is not purely a domestic matter but often a networked phenomenon influenced by regional cooperation, shared institutional frameworks, and participation in cross-border value chains (Arvis et al., 2018; Hausman et al., 2013). Here, we investigate a nation's LPI trend similarity to determine its level of alignment with other nations' logistics trends.

Finally, we investigate MFNWA and LPI jointly because they influence trade outcomes (Hausman et al., 2005; Bhukiya & Patel, 2023; UNCTAD, 2025). Together, efficient logistics and open tariff policies are associated with a favourable environment for both imports and exports, boosting overall trade competitiveness (Wacziarg & Welch, 2008; Jayathilaka et al., 2022). In this work, we use graph network analysis to investigate how logistic performance and tariff patterns across nations influence national wealth and trade involvement as well as relationships between MFNWA and LPI, two vital metrics in global trade.

1. Methods

1.1 Study Design, Data Collection and Processing

The MFNWA tariff time series data was collected from the World Bank WITS database (WITS 2022) and was confined to the years 2007, 2010, 2012, 2014, 2016, 2018, and 2022 to match the LPI dataset. A nation's MFNWA tariff for a given year is trade-weighted and is calculated by using each product's share of total imports as a weight for the product's MFN tariff rate, where all of the products' weighted rates are then summed up. This formula can be seen below (WTO 2006):

$$MFN\ weighted\ average\ tariffs\ (\%) = \frac{\sum_{i=1}^{n}(M_i + I_i)}{\sum_{i=1}^{n}(I_i)};$$

$M_i = MFN\ Tariff\ rate\ of\ product\ (i)$;

$I_i = Value\ of\ Imports\ of\ product\ (i)$.

LPI time series data from the World Bank database (World Bank) was also collected for 2007, 2010, 2012, 2014, 2016, 2018, and 2022. The LPI data comprises 6 dimensions, namely, customs, infrastructure, international shipments, logistics services, tracking and tracing, and timeliness. These 6 indicators are averaged to find the total LPI score, which can range from 1 (very low) to 5 (very high). For nations to be eligible in this study, they needed sufficient data coverage (at least six years) for both indicators. In total, 86 economic entities were included in this study (85 nations and the European Union).

Following this, we collected time series data of population (World Bank Group, 2025), total exports (World Bank Group, 2019), and total imports (World Bank Group, 2024) from the World Bank Group databases for the years 2007, 2010, 2012, 2014, 2016, 2018, and 2022. We create a trade volume per capita metric to measure a nation's level of trade involvement. The following formula was used to calculate the trade volume per capita (TVPC):

$$\frac{Merchandise\ Exports\ (USD) + Merchandise\ Imports\ (USD)}{population} = TVPC.$$

We also collected time series data of GDP per capita (GDPPC) from the World Bank database (World Bank Group 2024) for the same years as a measurement of a nation's level of wealth.

1.2 Network Construction

In this study, an MFNWA tariff graph network and an LPI score graph network were constructed. In each network, nodes represent eligible economic entities and edges represent Spearman correlations between nations' MFNWA or LPI trends. Spearman correlations were used in this study because rank-based correlations can better measure non-linear relationships and are robust against outliers (van den Heuvel & Zhan, 2022; de Winter et al., 2016). Spearman correlations among nations' MFNWA or LPI time series data that were greater than or equal to 0.5 were retained as edges on the graph network since a correlation at or above 0.5 represents moderate or strong monotonic trend similarity. The nodes and edges on the graph networks were organized in a spring layout to display proper repulsive forces created by the nodes. The spring layout was created using a total of 500 iterations to maximize reproducibility and reliability of the network and its corresponding data. Graph networks with 40 or fewer nodes generally use 50 to 100 iterations (Kobourov, n.d.), so the larger value of 500 fits our larger graph network of 86 nodes.

We used two main metrics to analyse the networks: node degree and betweenness centrality. Node degree represents the number of valid connections a certain node has within the graph network. A higher node degree indicates more involvement within the network. Betweenness centrality measures the frequency of a node being the shortest path between other nodes. This metric is weighted by the node degree of the nodes connected to it. Betweenness centrality shows the importance of a node in connecting different parts of the network, indicating a node's role in allowing for trend diffusion within the network. The node degree and betweenness centrality for each country is available in the supplementary tables.

All data processing and network construction was completed in Python using Visual Studio Code. Libraries that were utilized were Pandas for data manipulation, NetworkX for network construction, Matplotlib and Colorama for graph visualization, and Numpy for numerical computation for the data frames.

1.3 Statistical Analysis

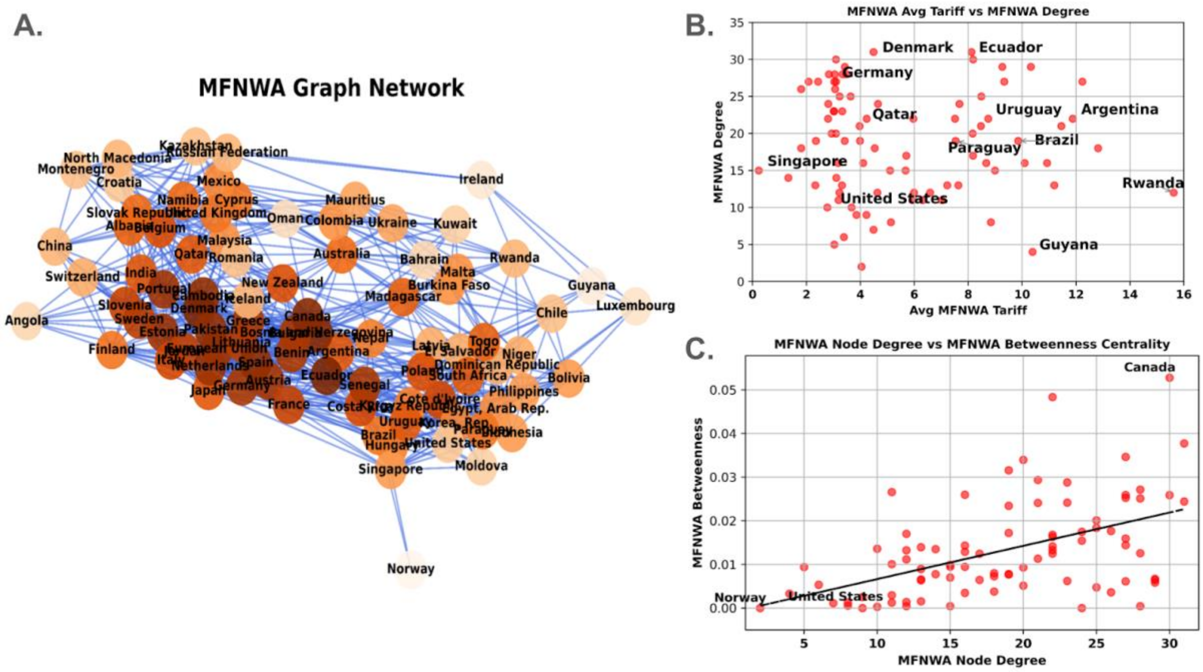
Upon the completion of the two networks, we performed graph theoretical analysis using data from both networks. To accomplish this, we utilized Pearson correlations to measure linear relationships and logarithmic regressions to measure non-linear relationships. We also constructed violin plots to analyse relationships between MFNWA and LPI node degree and GDPPC and TVPC.

2. Results

21. Global Analysis of Most Favoured Nation Weighted Average (MFNWA) Tariff Rates

The average weighted MFN rates of 86 nations investigated in this study range from 0.23% to 15.62%, with Singapore having the lowest rate and Rwanda the highest (Figure 1A). The median average MFNWA rate in this study is at 4.36% (between Qatar and Denmark). Nations below this value have a relatively liberal MFNWA rate, encouraging imports, increasing competition, and potentially lowering prices.

Figure 1: Network Analysis of MFN Weighted Average Tariff Rates (MFNWA)



Note. Higher node degree and betweenness centrality indicate greater structural importance within the MFNWA network and stronger influence on tariff dynamics. *Panel A* shows the MFNWA correlation network, where nodes represent countries and edges denote Spearman correlations above 0.5; darker nodes indicate higher connectivity. *Panel B* presents the relationship between node degree and average MFNWA rates (2007–2022). *Panel C* illustrates the association between MFNWA betweenness centrality and node degree with a linear fit.

To investigate relationships between nations' average MFNWA rate and MFNWA trend similarity with other nations, we analysed the average MFNWA rate vs MFNWA degree graph (Figure 1B). The nations with relatively low average MFNWA rates (<4.35%) had a large node degree range of 2 to 31. For example, while the United States and Germany have similar average MFNWA values of 2.77% and 3.03% respectively, their degrees of 10 and 27 notably differ. The United States' relatively low degree is consistent with the fact that while the global MFN weighted average tariff levels fluctuated from 2007-2022, the United States MFNWA trend was relatively flat, suggesting independence from global tariff burden patterns.

Germany's high degree of 27 can suggest similarity with other EU nations. Nations in this customs union set the same MFN rate since the European Commission required a Common External Tariff (CET) for all members. MFNWA tariffs are also heavily influenced by import composition patterns, suggesting EU nations with high MFNWA node degrees exhibit similar import shifts, a pattern that is consistent with the strong regional connections and similarities of many EU nations (Bratu & Mărgărita, 2024). Overall, many EU nations exhibit above average MFNWA node degrees in the network. Elevated degrees from EU nations align with the EU's CET and similar import composition shifts among EU nations that may occur through their economic ties and interdependence.

The nations with high average MFNWA rates (>4.35%) also have variable degrees. Guyana, with an average MFNWA level of 10.38%, has one of the lowest node degrees out of all nations at 4. While Paraguay (7.53%), Ecuador (8.12%), Uruguay (8.74%), Brazil (9.85%), and Argentina (11.88%) all had conservative MFNWA values like Guyana, their node degrees of 19, 31, 22, 19, and 22 are notably higher. All these nations are either members or associates of the Mercosur trading bloc, which, like the European Union, sets a CET on imports from non-member nations. Changes in the CET directly affect MFN rates for member states (Brazil, Paraguay, Uruguay, and Argentina) and can plausibly affect MFN rates for associate members such as Ecuador, a nation with strong regional connections and agreements with Mercosur members. The above-average degree of Mercosur members and associates may suggest that these nations could be similarly impacted by global trade patterns affecting import composition.

To investigate the nations that play important roles in trade synchronization, we utilized betweenness centrality, which measures the frequency of nodes falling on the shortest path. As seen in Figure 1C, MFNWA betweenness centrality and MFNWA node degree are positively correlated (r = 0.495), suggesting that nations with more trend-based connections also tend to serve as bridges in global policy alignment. Canada has the highest betweenness centrality (0.052), likely because it belongs to major trade blocs such as USMCA and CPTPP, along with having an ongoing trade partnership with the EU. Thus, while Canada does not have the highest node degree, it influences connections between major economic entities. Conversely, Norway has the smallest betweenness centrality value of 0, indicating that it does not have major roles as a bridge in policy synchronization, and is a periphery in the network. This is consistent with Norway's heavily concentrated oil exports (Machado, 2025), which often take place under long term contracts or preferential terms, causing it to bypass MFN enforced trade.

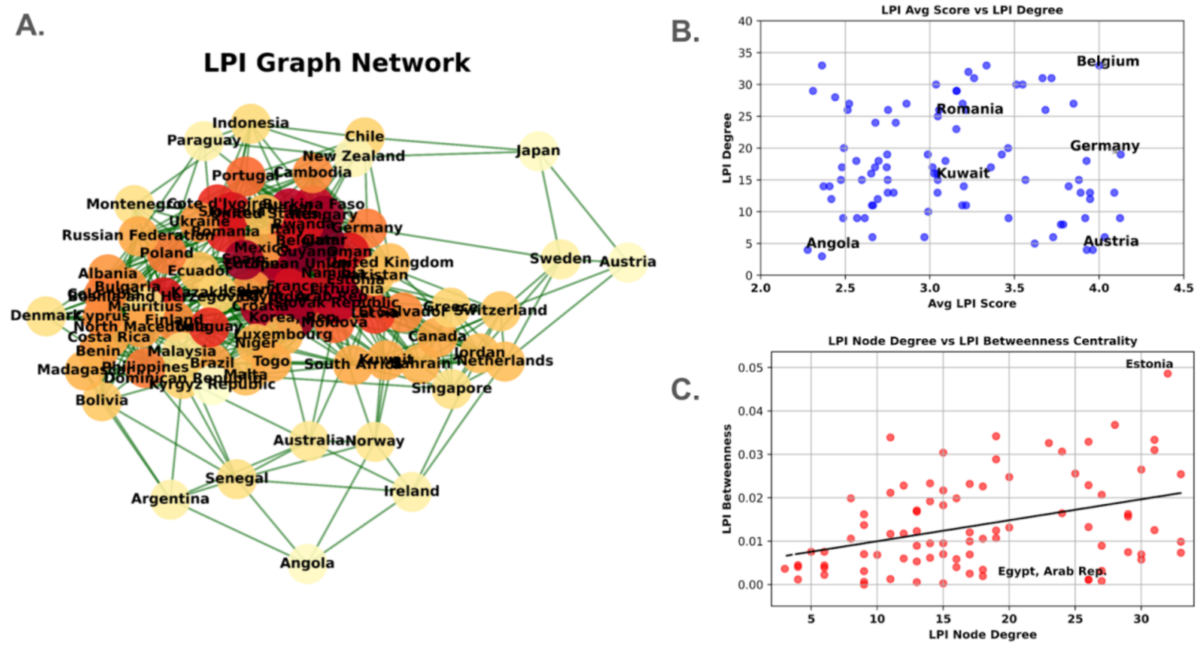
2.2 Global Analysis of Logistics Performance Index (LPI)

The same 86 nations were included to investigate average LPI scores, which ranged from 2.28 (Angola) to 4.13 (Germany). The median average LPI score was 3.046 (between Kuwait and Romania). Nations above the median average LPI score excel in a combination of the 6 dimensions of LPI described in the methods (Figure 2A).

Figure 2B shows a large variation in LPI degree. Austria and Belgium have high average LPI scores of 4 (Belgium) and 3.93 (Austria), yet their LPI degrees of 33 (Belgium) and 4 (Austria) differ. Large fluctuations in investment towards the dimensions of LPI can cause a nation to shift away from general LPI trends.

This may factor into Austria's lower node degree, as Austrian investment in infrastructure dipped from 2012-2014 since it was not prioritized as highly as social spending (Bakker et al., 2014). Austria's infrastructure score decreased from 4.05 in 2012 to 3.65 in 2014, causing overall LPI score to drop from 3.89 to 3.65 in the same time period. Large LPI fluctuations were common for Austria from 2007 to 2022, which contrasts Belgium's steady increase and plateau in its LPI score.

Figure 2. LPI Network Analysis



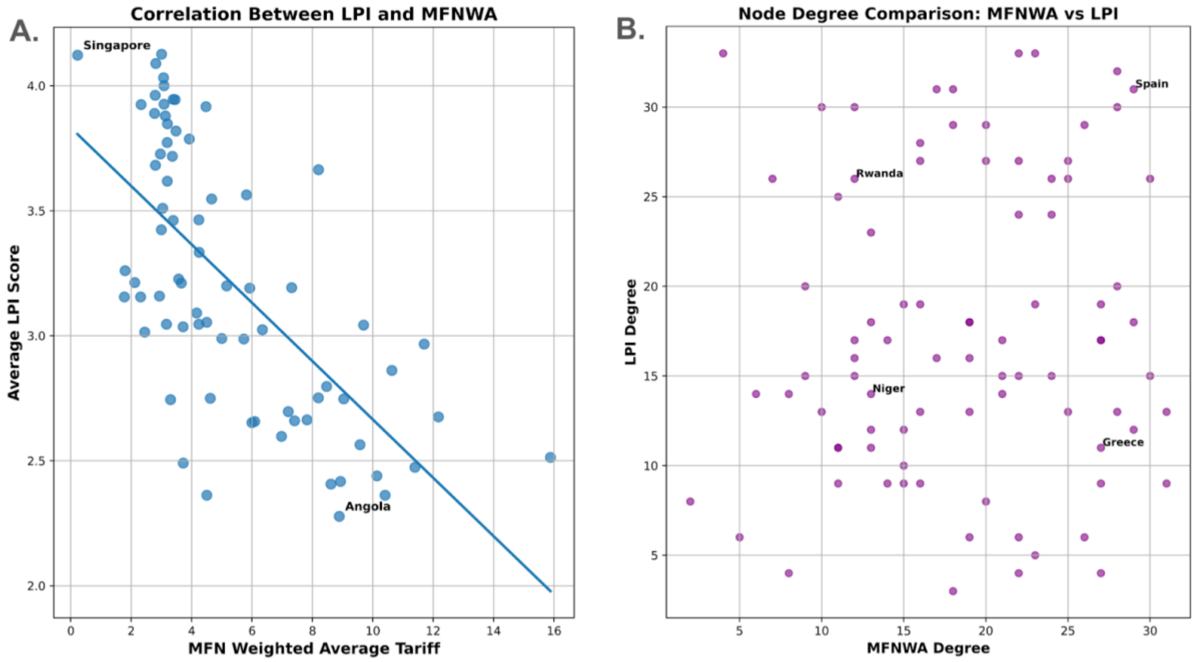
Note: Panel A: LPI correlation network, nodes represent countries, edges show Spearman correlations >0.5 in LPI trends. Darker nodes indicate higher node degrees. Panel B: Relationship between LPI node degree and average LPI rates (2007–2022). Panel C: Association between LPI betweenness centrality and node degree, with a linear fit.

To investigate whether a nation's logistics improvements or policy shifts resemble those of multiple nations over time, betweenness centrality was analysed. There is a positive correlation between node degree and betweenness centrality (Figure 2C), but this trend is relatively weak (r = 0.378). Large differences in betweenness centrality are attributed to differences in economic and political partners, consistency in infrastructure and tracking, and sector focuses. For example, Estonia, with an LPI node degree of 32 and the highest betweenness centrality of 0.048, has trade structures that span over multiple economic unions (Dept IMFE, 2023). With a similar LPI node degree of 27, Egypt has a much lower betweenness of 0.00084, greatly deviating from the best fit line, indicating that it does not connect diverse nodes within the network.

2.3 Integrative Analysis of LPI and MFNWA graphs

To investigate relationships between nations' logistics systems and MFNWA tariff patterns, we compared LPI and MFNWA networks. Moreover, we investigated relationships between MFNWA tariffs and LPI with trade volume per capita as well as GDPPC. There is a strong negative correlation between average MFNWA tariff rate and average LPI score (Figure 3A, r=-0.666).

Figure 3. Integrated MFN–LPI Analysis



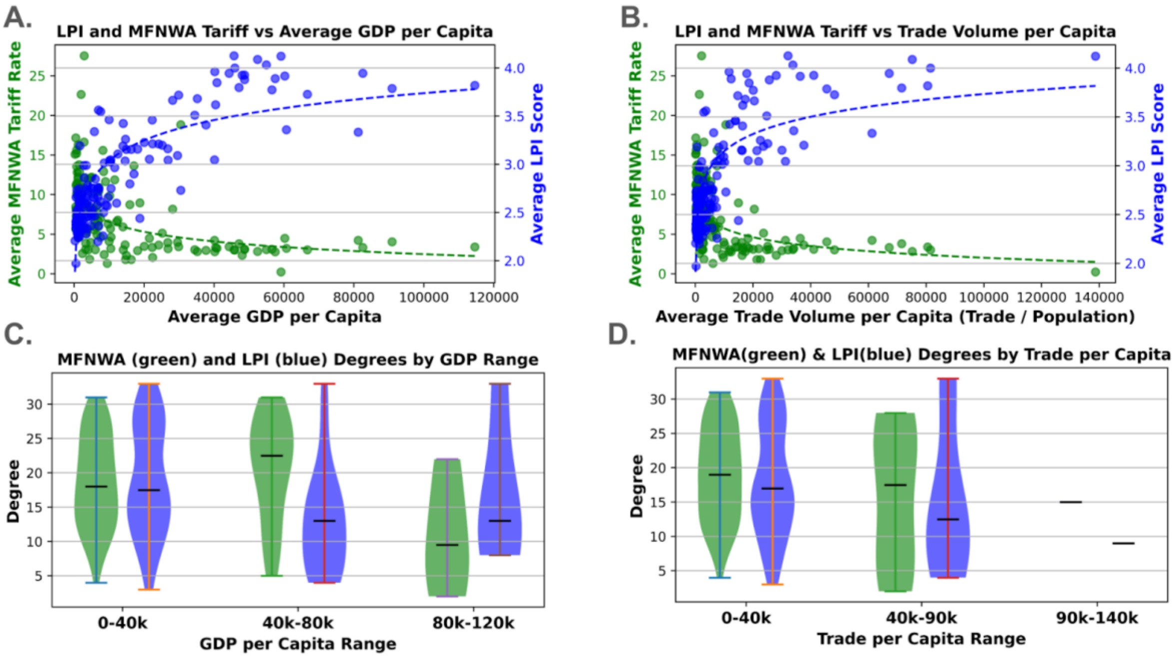
Note: *Panel A:* Relationship between average MFN tariff rates and average LPI scores (2007–2022), aggregated across all product categories, with a fitted linear trend. *Panel B:* Association between LPI node degree and MFN node degree, illustrating structural linkages between trade connectivity and logistics performance.

Thus, the nations with lower MFNWA tariffs often exhibit higher LPI scores. For example, Singapore has the lowest MFNWA value of 0.23% and the second highest LPI rate of 4.12 while Angola has a very high MFNWA tariff rate of 8.84%, and the lowest LPI score of 2.28. MFNWA degree and LPI degree are not correlated (Figure 3B, r=0.085), indicating that nations responding to or involved in global tariff burden trends are not necessarily the ones aligned with global logistics trends. For example, Spain and Greece, two EU members, both have relatively high MFNWA degrees of 29 and 27. Yet, Spain has a much higher LPI degree of 31 compared to Greece's 11. Furthermore, Rwanda and Niger, both of which are members of the African Continental Free Trade Area (AfCFTA 2023), have similar MFNWA degrees of 12 and 13 respectively. This similarity in MFNWA degree is not seen in LPI degree with Rwanda having a much higher LPI degree of 26 compared to Niger's 14. Rwanda and Niger's low degrees may be attributed to the insufficient number of qualified African Continental Free Trade Area nations in our study.

Figure 4A shows a strong logarithmic relationship between average MFNWA tariff rate and GDPPC (r = -0.574) and LPI score and GDPPC (r = 0.825). Furthermore, Figure 4B shows a strong logarithmic relationship between average MFNWA tariff rate and TVPC (r = -0.6) and LPI score and TVPC (r = 0.78). This suggests that nations with a combination of low average MFNWA tariff rates and high average LPI scores are wealthier and more involved in trade.

The MFNWA and LPI graph networks show complex interactions underlying global trade. In plots from Figure 4C and Figure 4D, we find that there is a large variation in MFNWA and LPI node degree for nations with low and medium GDPPC and TVPC. Assuming that node degree indicates a nation's level of collaboration in global trade, these nations with high node degrees in either the MFNWA or LPI networks might be involved in strategic alignment to support global trade, even if their levels of wealth and trade involvement may be lower. Compared to nations with lower and moderate GDPPC and TVPC, there are substantially fewer nations in the highest GDPPC and TVPC, so analysis of these baskets is less revealing.

Figure 4. Network–econometric integration of trade policy, logistics, and economic scale



Note: Panel A: Logarithmic relationship between average MFN tariff rates, LPI scores, and GDP per capita (GDPPC), capturing nonlinear scaling effects in trade policy and logistics performance. Panel B: Logarithmic relationship between average MFN tariff rates, LPI scores, and trade volume per capita (TVPC), reflecting network-mediated trade intensity. Panel C: Violin plots of MFNWA and LPI network node degrees across GDPPC groups, illustrating differences in structural centrality by income level. Panel D: Violin plots of MFNWA and LPI network node degrees across TVPC groups, highlighting how trade intensity relates to network embeddedness.

MFNWA node degree is higher than LPI node degree for medium GDPPC and TVPC nations. This could be because MFNWA is partially determined by nations, which is directly influenced by their trading needs and partners. While LPI trends might be influenced by partnerships with other nations, improving LPI scores requires large financial investments, a process that is more difficult for nations than tariff regulation or liberalization.

The heterogeneity in MFNWA and LPI node degree points to diverse strategic positioning; some intermediate economies are integrating into global value chains and aligning institutional and infrastructural systems, while others remain more insular or regionally focused, thereby reducing their visibility in global-scale correlational networks (Sposi et al., 2021; Cigna et al., 2022). Noticeably, the world's largest economy, the United States, shows an intermediate degree not only in the MFNWA correlation network but also in the LPI correlation network, indicating substantial logistical capability without close co-movement with many peers. Shifting focus, median MFNWA and LPI degrees are not correlated with GDPPC and TVPC in plots 4C and 4D. This suggests that synchronization of tariff or logistics trends does not have direct macroeconomic benefits.

Discussion and Conclusions

Graph theoretical network analysis is a powerful tool to investigate complex non-linear relationships between economies, trade partners, and the effect of globalization (Aller et al., 2015; Shepherd, 2016). The network analysis facilitates investigation of all the nations at the same time, taking into account direct and indirect relationships driving global trade.

Our results show that regional trade agreements and economic unions can strongly influence node degree in the MFNWA correlation network by promoting tariff and import composition harmonization among member states. Nations who increased preferential trade agreements (PTAs) with each other may also have retained high node degrees in the network as joint increases in PTAs tend to lead to simultaneous decreases in MFN rates (Kuenzel & Sharma, 2021). Furthermore, nations exhibiting similar trade structures and depending on similar industries as many other nations could have high node degrees in the network (Gonciarz & Verbeet, 2025), especially since this would result in similar import trends or pressures. Furthermore, we found that similar tariff burden patterns within regional trade blocs, such as the European Union, likely does not directly increase GDP or trade volume. However, it can enhance efficiency and policy stability. By aligning external tariffs, member nations reduce trade distortions and administrative complexity, prevent trade deflection, and strengthen collective bargaining power in global markets (Felbermayr et al., 2019).

Unlike node degree, betweenness centrality identifies nations that connect diverse economies. The United States maintains a low MFNWA degree and betweenness since it sets tariffs independently rather than via regional alignment, yet it remains a central player in the global economy through its massive market size, innovation capacity, and global production linkages [33,34]. Canada's high betweenness centrality and node degree indicate its important role in acting as a hub in the network, aligning itself with economic entities and creating otherwise non-existent pathways for international connections.

Nations in this study with a high MFNWA betweenness centrality, including Canada, share similar and compatible MFNWA tariff patterns to a wide range of trading partners. In an applied economics sense, this characteristic could be advantageous in international markets, facilitating increased access to diverse suppliers and allowing nations to import a broader variety of differentiated goods. Furthermore, a high MFNWA betweenness centrality may contribute to decreased policy-shock vulnerability. If one nation or economic union unpredictably changes their MFNWA tariff structure, high MFNWA betweenness centrality nations still have access to alternative trading partners. This leads to more resilient and consistent export baskets and import supply chains, where a nation is not dependent on selective markets and prone to trading disruptions.

Nations with high MFNWA node degrees tended to be involved in economic unions, while nations with high LPI trend similarity were consistent with their investment towards LPI dimensions, with this investment behaviour being more of a country-level decision than a result of regional agreements. LPI degrees can be impacted by their level of similarity to other nation's logistical structures (Kamrul et al., 2025), and their level of synchronization with other nations' macroeconomic indicators, including inflation and GDP growth trends (Jayalakshmi & Praveen, 2024; Ohakwe & Wu, 2025). Nations often collaborate by developing common best practices and by regional co-operation. It is also likely that the nations collaborate to improve their trade jointly. This implies that while degree captures how many peers a nation is similar to, betweenness highlights those economies that may link disparate trajectories, making them key players in the collaboration. One such nation that was highlighted in the LPI betweenness analysis is Estonia, which has an unique role in the global economy with its export driven economy, digital trade leadership, and integration with the EU (United States Department of State, 2023). Estonia's investment in logistics may be explained by its openness to foreign investment. Estonia's Customs Act permits the government to establish free trade zones (Arora & Brintrup, 2021, Aller et al., 2015).

When integrating the MFNWA and LPI correlation networks, we observed little correlation between MFNWA and LPI node degrees, suggesting that synchronization of tariff burdens and logistics improvement are influenced by different factors. So, while average MFNWA tariff rate and average LPI score are negatively correlated, trade liberalization decisions alone (i.e., actively lowering MFN rate or importing lower-duty goods) likely do not lead to consistent increases in logistics performance. Instead, direct fiscal policy decisions to increase investment towards logistics systems, especially infrastructure, would likely be effective in boosting overall logistics efficiency (Bentar et al., 2025; Azwardi et al., 2024). We find that wealthy and trade-involved nations are commonly trade-open and logistically efficient. This demonstrates that global trade powers can afford a more trade-liberal and logistically efficient economy because it benefits their economic structure.

The analysis of MFNWA and LPI degrees with GDPPC and TVPC also reveals that intermediate wealth and trade involvement nations have lower LPI degrees than MFNWA degrees. Although intermediate GDPPC and TVPC nations likely play an influential role in global trade with their ability to invest in logistics and supply chains, they seem to primarily involve themselves in global trade by aligning tariff burden and trade liberalization patterns.

Finally, it is important to acknowledge the limitations of this analysis. MFNWA tariffs are aggregated across products, masking sectoral differences that may drive unique patterns of correlation. Furthermore, MFNWA tariffs may not fully represent a nation's tariff policy as some imports face preferential rates under free-trade agreements instead. LPI combines both objective performance indicators and survey-based perceptions, which may introduce reporting biases. Future research could address these gaps by employing sector-specific MFNWA data, longitudinal analysis of LPI trends, and network-based approaches to quantify centrality and interdependence in trade–logistics structures.

Credit Authorship Contribution Statement

Kelkar, A contributed to the conceptualisation of the study, data collection and preparation, network modelling design, and the empirical analysis of the relationships between logistics performance indicators and tariff structures. He also drafted the initial version of the manuscript and conducted the visualisation of the network analysis results. Sienkowski, D. contributed to the methodological refinement, statistical validation of the analytical framework, and the interpretation of the findings within the broader context of international trade and logistics performance research. He further provided critical revisions of the manuscript for important intellectual content and participated in the final review and approval of the submitted version.

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Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement

The data that support the findings of this study were obtained from the World Bank Group and are available at https://wits.worldbank.org/CountryProfile/en/country/by-country/startyear/LTST/endyear/LTST/tradeFlow/Import/indicator/MFN-WGHTD-AVRG/partner/WLD/product/Total#; https://data.worldbank.org/indicator/TM.VAL.MRCH.CD.WT; https://data.worldbank.org/indicator/NY.GDP.PCAP.CD; https://data.worldbank.org/indicator/SP.POP.TOTL; https://data.worldbank.org/indicator/LP.LPI.OVRL.XQ.

Ethical Approval Statement

This study utilized secondary data from the World Bank, which is publicly available, aggregated, and anonymized. Therefore, ethical approval was not required.

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