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Determining Growth Drivers in Container Shipping: A Causality Analysis Between Container Throughput and Liner Shipping Connectivity

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ABSTRACT

Container transportation, facilitated by the development of standardized containers, has revolutionized global trade by increasing efficiency, reducing costs, and enhancing the competitive power of countries. The Liner Shipping Connectivity Index (LSCI) plays a crucial role in measuring the supply side of container transportation, influencing strategic decisions regarding infrastructure investments and policy development to boost global trade integration. Our study aimed to determine whether container throughput drives LSCI or vice versa, using panel data analysis to inform strategic decisions in maritime trade, investment priorities, and policy development. We conduct our analysis using a unique data set covers the years between 2008 and 2021 and consists of 85 countries and 1190 observations. The results obtained revealed that there is a two-way interaction between Container Throughput and LSCI variables, the effects of the variables are positive and reflected after 1 period, and the impact of changes in LSCI on Container Throughput is higher than the opposite situation. This shows that there is a positive feedback loop between the variables and that improvement in any one of them returns as improvement to itself after a certain period.

INTRODUCTION

Container transportation has significantly impacted global trade with the development of standardized containers (Knox et al., 2014). First, standardization has made loading and unloading activities, as well as the transfer of goods between different transportation modes, easier and faster. This has led to increased efficiency and productivity, particularly in terms of time. Second, containers allow for the consolidation of many small parcels of cargo into a single container, which can be stacked efficiently. This reduces total transportation costs due to economies of scale and lower labor costs. Third, cargo transported in metal containers is well-protected, minimizing the impact of external factors and ensuring safe transit. Fourth, the standardization of containers facilitates easy transportation across various modes, such as road, sea, air, and rail. Fifth, by reducing costs, containerization minimizes environmental damage and enhances the competitive power of countries, while also contributing to the increase in trade volumes (Miller et al., 2023). Due to the numerous advantages of container transportation, it has experienced significant demand, leading to a 255% increase in the total global container ship capacity in 2023 compared to 2000 (Statista, 2024). During the same period, the number of containers handled at ports increased by approximately 273% (World Bank, 2024a), highlighting the rapid development of container transportation in a relatively short time, driven by the mentioned advantages. To fully benefit from the advantages of container shipping, it is essential for container transportation to grow sustainably. This growth can be achieved in two macro ways: (i) supply-side growth, which involves the development of container transportation through affordable and accessible infrastructure, supported by the enhancement of infrastructure and transportation networks within the country; and (ii) demand-side growth, which is driven by the increased need for infrastructure and the expansion of container transportation as a result of growing transportation activities.

One of the most important indicators for measuring the supply side of container transportation in countries is the Liner Shipping Connectivity Index (LSCI). This index is formed by considering factors such as the number of weekly scheduled voyages in the country, deployed annual TEU capacity, the number of liner shipping services to and from the country, the largest deployed ship size servicing to and from the country, and the number of countries offering direct voyage services to the country (UNCTAD, 2024). Thus, an increase in any of these factors may indicate an improvement in liner shipping supply, and if this also stimulates demand, then supply-side growth can be observed. On the other hand, since container traffic at a country's ports is considered the demand side of the business, if an increase in demand leads to improvements in transportation infrastructure, then demand-side growth can be identified. Determining which type of growth prevails is crucial for stakeholders in container shipping because understanding this balance helps them plan investments, develop strategies, and respond effectively to market dynamics.

A higher connectivity network provides better access to global markets at lower costs and in shorter periods. Fast and secure shipping of export products to even very distant markets, as well as efficient supply of raw materials and semi-finished products for production, also provide competitive advantages for countries (Taşova, 2023). In countries, the efficient operation of each stage of the supply chain, from port infrastructure to warehousing, from hinterland transportation to container handling, can be seen as centers of attraction for other countries. Improving LSCI scores for developing or underdeveloped countries can increase the integration of these countries to world trade, attract more investments and increase their trade volumes (Notteboom et al., 2022). In addition, for policy makers, the LSCI score can play an important role in determining infrastructure investments related to maritime, identifying deficiencies and generating legislative regulations. Moreover, stronger integration means the arrival of larger ships and more frequent service, which will reduce transportation costs in the relevant country and provide a competitive advantage. The decrease in transportation costs per unit will also lead to a reduction in carbon emissions, offering significant environmental benefits.

In our study, we aimed to determine whether container throughput drives LSCI or LSCI drives container throughput by using panel data analysis. The potential outcomes of this analysis are of great importance, as they can significantly influence strategic decisions in maritime trade, investment priorities, and policy development. Understanding whether Liner Shipping Connectivity Index (LSCI) drives container throughput or vice versa is crucial because it informs strategic decisions on where to focus investments and policies. If LSCI drives container throughput, enhancing connectivity infrastructure should be prioritized to boost trade volumes. Conversely, if container throughput drives LSCI, stimulating trade through economic policies may lead to improved connectivity. This distinction is essential for effectively allocating resources and ensuring sustainable growth in maritime trade. Our results indicate a mutual feedback relationship between Liner Shipping Connectivity Index (LSCI) and container throughput; however, improvements in LSCI have a more substantial impact on driving container throughput. Therefore, policies should prioritize enhancing connectivity infrastructure, as this will not only directly boost container throughput but also generate a reinforcing cycle that further strengthens the overall efficiency and competitiveness of the maritime transportation network.

The theoretical framework and literature related to our research are reviewed in the second section. The data set and method we used in the research are introduced in the third section. The findings obtained from the panel data analysis are presented in the fourth section, and evaluations and discussions are made in the last section.

Theoretical Framework and The Related Literature

The LSCI serves as a key indicator of global container shipping connectivity. A higher LSCI value signifies enhanced access to more competitive, cost-effective, and frequent transportation services. Additionally, the LSCI reflects a country's degree of integration into the global trading system. Consequently, a higher LSCI suggests greater involvement in international trade and deeper integration into the global freight transport network (Notteboom et al., 2022). Theoretically, LSCI can be viewed as a variable that both influences and is influenced by the volume of international trade, highlighting its dual role as both a driver and a reflection of a country's trade dynamics.

Although the LSCI literature is still emerging, the number of studies exploring the topic from various perspectives is steadily growing. While the LSCI is known to comprise five core components as outlined in reports, other factors may also statistically influence this index. For instance, in the study by Jouili (2019), LSCI was treated as an independent variable, and the impact of logistics performance, container transit times, container transport costs, gross domestic product, and containers per capita on the index was examined across a sample of 100 countries. The regression model revealed that logistics performance, container transport costs, GDP, and containers per capita positively affect the LSCI, whereas container transit time has a negative impact. The LSCI is influenced by logistics performance and, in turn, can also impact it, as a higher LSCI often indicates cheaper, faster, and more efficient transportation. In this context, Chen & Hasan (2023) analyzed the effects of LSCI and the Global Competitiveness Index on logistics performance across 29 countries. The study found that increases in LSCI have a significant accelerating effect on logistics performance and contribute to greater competitiveness.

Assuming that an increase in LSCI will naturally stimulate trade, the study conducted by Şeker (2020) on European Union countries and Türkiye found a positive relationship between LSCI and the countries' exports, establishing that the index is a driving factor for export growth. A similar study was conducted by Canbay (2024) for BRICS-T countries using causality analysis. The findings revealed a bidirectional causality relationship between LSCI and trade volume for Brazil, indicating a feedback loop between the two. In contrast, for Türkiye, the analysis showed a unidirectional causality from LSCI to trade volume, positioning LSCI as a driving force for trade in the country. Since maritime transport has a derived demand structure, increased trade will naturally lead to higher container traffic in ports. In this context, Reza et al. (2015) analyzed port traffic in six Southeast Asian countries using regression analysis, focusing on the components of the LSCI rather than the index itself. Their study revealed that among the components, only ship size had a significant positive effect on port traffic. In a study from a similar perspective, Atacan et al. (2022) conducted a regression analysis in Türkiye to examine the effects of changes in LSCI on international trade, specifically focusing on export and import container traffic in ports. The findings revealed that an increase in LSCI resulted in a proportional increase in both import and export container traffic. In addition to its impact on trade, the LSCI also indirectly influences economic growth, as increased trade and container traffic contribute to heightened economic activity. In a study conducted by Del Rosal & Moura (2022), the effect of the Liner Shipping Connectivity Index (LSCI) on containerized and non-containerized cargo in trade flows between EU and non-EU countries was examined. Their findings showed that an increase in the LSCI had a positive effect on containerized exports, while it had a negative effect on non-containerized exports. Ayesu et al. (2022) studied the effect of LSCI on economic growth in 28 African countries, using the index as an indicator of port efficiency. The results demonstrated that the LSCI has a significant and accelerating effect on economic growth, playing a complementary role to port throughput.

Since container shipping operates regularly on a schedule, and follows specific routes, changes in a country's LSCI can also impact the LSCI values of neighboring countries. Additionally, certain strategically located countries are striving to attract major shipping lines, aiming to capitalize on the advantages of being a transshipment hub. In this context, it is expected that successful countries may either diverge from others or converge with similarly successful nations. A study by Açık & Atacan (2023) explored this dynamic using unit root tests, focusing on Türkiye and its neighboring countries. The results indicated that the dominant roles of Egypt and Greece in the region are likely to persist. In addition, bilateral trade agreements, economic and political unions, and memberships in common organizations between countries typically lead to increased trade, which can drive higher demand and result in the convergence of transport network connectivity. In this context, Açık (2021) analyzed whether the LSCI values of EU countries have converged using the unit root method. The findings indicated that the differences in the capacities of EU countries' transport networks have diminished, signifying a convergence in their connectivity. That is, international unions and memberships play a crucial role in enhancing trade relations, leading to increased demand and the convergence of transport network connectivity among member countries

Liner shipping operates on specific routes, so the volume and frequency of voyages between countries tend to change gradually. To measure the connectivity between countries more accurately, a variation of the LSCI, known as the Liner Shipping Bilateral Connectivity Index (LSBCI), was developed. In a study conducted by Fugazza & Hoffmann (2017) for 138 countries, the impact of this variable on international trade was examined, revealing that connectivity between countries, as measured by the LSBCI, is more effective in explaining international trade flows than traditional distance-based models. Using a similar approach, Del Rosal (2023) employed the LSBCI as a weighting tool in a gravity model and found that LSBCI significantly impacted trade in the leading regions and trade routes of the global manufactured goods market. However, the analysis revealed that this effect varied from region to region, indicating that the influence of LSBCI on trade was asymmetric. It is reasonable to consider transportation costs using a distance-based approach, as stronger bilateral connectivity between countries may lead to lower transportation costs.

Maritime transport has a derived demand structure, meaning any factor that impacts product demand also affects maritime transport. Consequently, economic shocks can naturally influence the service delivery policies of shipowners and, therefore, the LSCI. In a study conducted by Akpa (2022), which examined LSCI values for G7, BRICS, and MINT countries to determine whether these effects are permanent or temporary, it was found that G7 countries recovered more quickly from economic shocks. This quicker recovery was attributed to the fact that the G7 group consists of advanced economies.

Since the LSCI variable measures connectivity, a higher LSCI does not necessarily translate into a higher trade volume. The efficient use of the service capacity provided to enhance the network is crucial. In this context, Nadarajan et al. (2023) conducted a study on seaport network efficiency, using LSCI as an output variable. The analysis, supported by various methods, led to the suggestion of a more effective efficiency measurement methodology. As demonstrated, the Liner Shipping Connectivity Index (LSCI) is a crucial indicator for measuring a country's connectivity to the international container transportation network and, by extension, to global trade. Ongoing research is focused on enhancing the accuracy and representation of this index by diversifying its calculation methods and weighting processes (Mishra et al., 2021).

Understanding the direction of the relationship between Liner Shipping Connectivity Index (LSCI) and container throughput not only illuminates the dynamics of maritime transportation but also plays a critical role in the strategic decisions of policymakers, port authorities, and businesses. In terms of strategic planning and investment, if LSCI drives container throughput, it suggests that prioritizing factors that enhance connectivity—such as providing more frequent services, accommodating larger ships, and increasing infrastructure investments—should be the focus. Conversely, if container throughput drives LSCI, it implies that as trade volumes naturally grow, LSCI will improve. In this scenario, focusing on investments that facilitate trade and boost exports and imports would be more beneficial, with increased connectivity following as a secondary effect.

In terms of policy implementation, if LSCI drives container throughput, policymakers can focus on port infrastructure investments, negotiating more liner shipping routes, and expanding logistics networks to achieve growth through a stronger connectivity structure. On the other hand, if container throughput drives LSCI, connectivity can be increased by implementing policies such as economic growth-boosting, production-boosting trade agreements, and export incentives.

In terms of resource allocation, understanding the direction of the relationship between LSCI and container throughput can help identify where to focus efforts. If LSCI is driving container throughput, resources should be allocated to infrastructure investments that enhance connectivity. Conversely, if container throughput is the driver, resource allocation can be focused on incentives that boost trade volume. Given that port and transportation infrastructure investments are costly and long-term, accurately determining which areas should be prioritized is of great importance for maximizing the effectiveness of these investments.

There may also be feedback loops between variables, where both LSCI drives container throughput and container throughput drives LSCI. If this interaction is positive, it can be defined as a virtuous cycle; if negative, it can be defined as a vicious cycle. In a positive feedback loop, an improvement in one area leads to an improvement in the other, generating a self-reinforcing cycle of growth and development. For example, an increase in LSCI due to better infrastructure, more frequent services, and larger ships will lead to higher container throughput, which in turn attracts more investment in connectivity. This mutual enhancement generates a cycle of continuous improvement. Similarly, when increased container throughput contributes to improving LSCI, the resulting connectivity boost will generate even more container traffic. Conversely, in a negative feedback loop, a decline in one area causes a decline in the other, leading to a downward spiral that is difficult to reverse.

MATERIAL AND METHODS

The data covers the years between 2008 and 2021 and consists of 85 countries and consists of 1190 observations. The selection of countries was made to maximize the number of observations and countries as much as possible, provided that the LSCI and Container Throughput variables existed together for the same years.

The included countries are Argentina, Australia, Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Congo, Costa Rica, Cote d'Ivoire, Croatia, Cyprus, Denmark, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong SAR, China, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea, Rep., Latvia, Lebanon, Lithuania, Malaysia, Malta, Mexico, Morocco, Myanmar, Namibia, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russian Federation, Saudi Arabia, Senegal, Singapore, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Thailand, Trinidad and Tobago, Tunisia, Türkiye, Ukraine, United Arab

Emirates, United Kingdom, United States, Uruguay, and Viet Nam in alphabetical order.

Two-axis representations of the Container Throughput and LSCI variables of the countries included in the research are presented in Appendix 3. According to the figures, the relationship between variables has a positive tendency in most countries. Panel correlation values were determined as 0.649 for raw data (t=29.44, p=0.00), 0.866 for logarithmic data (t=59.71, p=0.00) and 0.135 for first differenced logarithmic data (t=4.55, p=0.00). There is a positive and significant relationship between the variables, and they generally act together, but of course this analysis cannot provide any findings about which variable affects which.

Descriptive statistics for the whole panel dataset covering all countries are presented in Table 1. In addition, individual Container Throughput descriptive statistics of the countries are presented in Appendix 1, and LSCI descriptive statistics are presented in Appendix 2.

The three countries with the highest annual average Container Throughput values are China (192,000,000), the USA (46,751,180) and Singapore (32,684,129), respectively, while the 3 countries with the lowest are Nicaragua (126,508.6), El Salvador (194,055.9) and Bulgaria (201,058.1). Since China and the USA are the two largest economies in the world, naturally the traffic in their ports occurs in the largest amounts. Singapore, on the other hand, reaches large volumes due to its role as a transshipment port due to its geographical advantage rather than a huge economic size.

The three countries with the highest average LSCI values are China (141.45), Singapore (100.44) and South Korea (94.51), respectively, while the three countries with the lowest average LSCI values are Myanmar (7.46), Bulgaria (7.83) and Barbados (7.97). In the LSCI variable, the USA could not enter the top 3 because the formation of transportation networks depends not only on the country's own demand but also on the demands of surrounding countries. Other countries, in addition to their own demands, enjoy the advantages of being located on the main container shipping route.

As the globalizing world and countries' intense commercial, political and economic relations increase the interaction between them, any change in a country can be quickly transferred to other countries (Nazlioglu et al., 2011). This situation causes especially economic variables to move together among cross section units (Das, 2019). It is defined as cross-sectional dependence in econometrics, and this causes the results to be inconsistent and biased (Bai and Kao, 2006). Therefore, when analyzing panel data, it is of great importance to determine whether there is such a dependency in the dataset and, if so, to choose appropriate methods. In this regard, to test possible cross-sectional dependencies in our dataset we have used LM test by Breusch-Pagan (1980), scaled LM and CD LM tests by Pesaran (2004), and bias-corrected scaled LM test by Baltagi et al. (2012). Although the use of these tests varies depending on the T and N status in the data set, we chose to apply all 4 tests to our data set to increase the consistency of the results. In our study, determining cross-sectional dependence is of great importance because, according to the findings, it will be determined which unit root tests and which causality test should be preferred.

While the use of first-generation unit root tests is sufficient when there is no cross-sectional dependence, second generation unit root tests must be preferred in cases where there is cross-sectional dependence (Söderbom, 2015). Since the findings obtained from the tests indicate a strong cross-sectional dependence, we preferred the Bootstrap-IPS test (Smith et al., 2004), which is one of the second-generation unit root tests. This method is an improvement of the IPS (Im, Pesaran, Shin) test developed by Im et al. (2003). In the IPS test, the augmented Dickey-Fuller test is applied to individual series and then the average of individual statistics is used. However, since this method assumes that the cross-sections are independent, it is inadequate in cases of dependency. For this reason, the Bootstrap-IPS test was developed and the dependency between units was considered. Since this test is a unit root test, the null hypothesis indicates the existence of a unit root.

Table 1. Descriptive statistics of the panel dataset

	CONTAINER	LSCI	DCONT	DLSCI
Mean	7626350	38.87799	0.040452	0.030600
Median	2114758	32.38717	0.040296	0.017699
Maximum	263000000	171.1775	2.591990	1.193361
Minimum	59471	4.582467	-0.843134	-1.161193
Std. Dev.	22187850	27.03486	0.145356	0.134375
Skewness	8.096327	1.257344	4.776400	0.701652
Kurtosis	77.18312	4.715268	92.77086	26.56703
Jarque-Bera	285864.7	459.4295	375242.5	25662.44
Probability	0.000000	0.000000	0.000000	0.000000
Observations	1190	1190	1105	1105

Note: Source: World Bank (2024a, 2024b), UNCTAD (2024)

Panel data analysis, by combining cross-sectional and time series data, enhances variability and the amount of information available, leading to more reliable and efficient forecasts. Meanwhile, panel causality analyses allow for the identification of root causes by examining the relationships between variables, enabling policymakers to focus on these underlying causes in their implementations. We concluded that a panel causality test is the most appropriate method to examine the relationship between countries' LSCI and container throughput. This approach allows us to identify potential demand-led, supply-led, or feedback loop relationships, thereby providing a decision support mechanism to determine which policy actions should be prioritized.

To apply the causal relationship between variables, we employed Granger non-causality test proposed by Juodis et al. (2021). The reasons for choosing this method are; (i) it can be used in multivariate systems, (ii) it is strong against both homogeneous and heterogeneous alternatives, (iii) it can be used in the cases of cross-sectional dependence and cross-sectional heteroscedasticity. This method also works well when there are a large number of cross-sections and a relatively medium time dimension (Xiao et al., 2023).

RESULTS AND DISCUSSION

In panel time series data analysis, it is of great importance whether the series contain cross-sectional dependence or not. Unit root and causality tests must be selected according to the structure of the series. For this reason, first, various cross-sectional dependency tests were conducted on the series. Then, based on the results, it was decided which unit root and causality tests would be used. In the analyses, logarithms of the series were taken and the analyzes were carried out on the relevant data type.

Cross-Section Dependence and Heterogeneity Tests

The presence of cross-sectional dependence in panel data sets may be due to some reasons. When there is a horizontal cross-section, a shock occurring in one of the countries spreads to other countries and affects them as well. The reasons for this may be the global economic system, the economic policies of neighboring countries, cultural factors, network effect, geographical proximity, common economic integration or similarities in management systems.

Cross-Section Dependence Tests was performed by using EViews and results were presented at Table 2. We have applied Breusch-Pagan LM (Breusch-Pagan, 1980) (Small N-Large T), Pesaran scaled LM (Pesaran, 2004) (Large N-Large T), Bias-corrected scaled LM (Baltagi et al., 2012) (Large N-Large T), Pesaran CD (Pesaran, 2004) (Smal T-Large N, Large T-Large N). Considering our panel data set consisting of 85 countries (N) for 14 years (T), Pesaran CD test is the most appropriate one. The null hypotheses of these tests indicate the absence of cross-sectional dependence in the data set. According to the results obtained, the hypothesis that there is no cross-sectional was rejected by all tests for both variables. The results show that there is cross-sectional dependence in both the Container variable and the LSCI variable and that the change or shock in one country spreads to other countries.

In econometric terms, these results indicate that second-generation tests should be preferred instead of first-generation unit root tests and that methods that take cross sectional dependence into account in panel causality tests should be preferred.

Unit Root Tests

Since cross-sectional dependency was detected in our container throughput and LSCI variables, second-generation unit root tests should be preferred instead of first-generation unit root tests. In this direction, we preferred the Bootstrap-IPS test (Smith et al., 2004), which is an improvement of the IPS (Im, Pesaran, Shin) test developed by Im et al. (2003). The Bootstrap-IPS test was applied to the Container and LSCI variables in both Constant and Constant & Trend versions, and the results were presented in Table 3. The null hypothesis of the relevant test indicates the existence of unit root in the panel variable. According to the results, the null hypothesis could not be rejected at the level for both variables. When the first differences of the variables are taken, the null hypothesis is rejected, in other words, the series become stationary.

Since the series had to be stationary in the causality analysis that takes cross-sectional dependency into account, the analyzes were continued by using the first differences of both variables.

Panel Causality Tests

To determine the direction of the relationship between variables, we employed Granger non-causality test proposed by Juodis et al. (2021). This method is a robust causality analysis that takes into account both cross-sectional dependence and cross-sectional heteroskedasticity. Stata software was used to implement the relevant test. The null and alternative hypotheses of the test were developed as follows (Equations 1-2):

Since the data set frequency is annual, the maximum lag is determined as 2. Additionally, a value of 100 was chosen for bootstrap by using seed for randomness. To talk about significant causality, the null hypothesis must be rejected. The test results regarding whether the LSCI variable is the Granger cause of the Container variable are presented in Table 4. According to the results obtained, the optimum lag was determined as 1 and the null hypothesis was rejected. The coefficient of LSCI variable with 1 lag is 0.139. That is, the LSCI variable is the Granger cause of the Container variable.

The null and alternative hypotheses developed regarding whether the container variable is the Granger cause of the LSCI variable were developed as follows (Equations 3-4):

$$H_0: lsci\ does\ not\ Granger - cause\ container\ throughput \quad (1)$$

$$H_1: lsci\ does\ Granger - cause\ container\ throughput\ for\ at\ least\ 1\ panelvar \quad (2)$$

$$H_0: container\ throughput\ does\ not\ Granger - cause\ lsci \quad (3)$$

$$H_1: container\ throughput\ does\ Granger - cause\ lsci\ for\ at\ least\ 1\ panelvar \quad (4)$$

Table 2. Cross-section dependence and homogeneity tests

	Container		LSCI	
Test	**Statistic**	**Prob.**	**Statistic**	**Prob.**
Breusch-Pagan LM	25594.20	0.00	21784.28	0.00
Pesaran scaled LM	260.6460	0.00	215.5574	0.00
Bias-corrected scaled LM	257.3768	0.00	212.2882	0.00
Pesaran CD	117.6746	0.00	111.4335	0.00
d.f.	3570		3570	
Delta Tilde	5.86	0.00	7.87	0.00
Delta Tilde Adjusted	6.61	0.00	8.88	0.00

Table 3. Bootstrap IPS unit root test results

		Container		LSCI	
	Test	**Constant**	**Constant & Trend**	**Constant**	**Constant & Trend**
Level	t-bar statistics	-1.66	-2.37	-1.58	-2.34
	p-value	0.26	0.17	0.31	0.20
First Difference	t-bar statistics	-4.16	-4.55	-4.30	-4.37
	p-value	0.00	0.00	0.00	0.00

Note: 1000 bootstrap replication, block size 50, maximum lag 2.

Table 4. Results for the panel causality test for model 1

	Coefficient	**Std. Error**	**z**	$P > \|z\|$
$lsci_{(-1)}$	0.1396	0.0548	2.55	0.011
JKS Non-Causality Result	**HPJ Walt Test**	6.4876	**P-Value**	0.0109

Table 5. Results for the panel causality test for model 2

	Coefficient	**Std. Error**	**z**	$P > \|z\|$
$container\_throughput_{(-1)}$	0.1049	0.0473	2.22	0.027
JKS Non-Causality Result	**HPJ Walt Test**	4.9091	**P-Value**	0.0267

The results of the test applied to determine whether the container variable is the cause of the LSCI variable are presented in Table 5. According to the results obtained for optimum 1 lag, the null hypothesis was rejected, and a significant result was obtained. The coefficient of Container Throughput variable with 1 lag is 0.105. That is, the Container Throughput variable is the Granger cause of the LSCI variable. This situation reveals the presence of a positive feedback loop between the variables, where an increase in one variable triggers an increase in the other, which in turn amplifies the initial variable, generating a reinforcing cycle.

In our research, we examined the relationship between LSCI variables and Container Throughputs of countries with 1190 observations consisting of 85 countries and a 14-year period. Our main motivation in this research is to determine whether supply-side growth or demand-side growth is more effective in global container shipping. Based on the results obtained, it is aimed to present policy recommendations for the development of global trade.

Since we first conducted our analyzes with the panel data set, we applied the Cross-Sectional Dependency test to both variables and determined that there was dependence in both variables. If we evaluate the situation in terms of LSCI, the presence of cross-sectional dependence indicates that the LSCI value in a country is not independent from any other country. If a country increases its infrastructure and connectivity, neighboring countries and trading partner countries may experience an increase in their LSCI variables. Because this may lead to the development of routes, an increase in the frequency of ship service or the inclusion of larger ships on the route. The reason is that it is the demands of all countries on a certain route that determine the capacity in liner shipping. Similarly, the situation in countries where the LSCI value decreases for any reason may affect the demand on the route and cause a decrease or increase of LSCI values in other countries. A decrease in the connectivity of a neighboring country may also cause ships to shift to the relevant country and achieve higher connectivity. In addition, the establishment of new ports in any country is a factor that directly affects the LSCI values of other countries. Similarly, disruptions in a country's supply chains may reduce the connectivity of some ports and increase the connectivity of others. In this respect, it is inevitable to have cross-sectional dependence in the LSCI variable as a shock in any country can easily spread to other countries

If we examine the cross-section dependency situation in terms of Container Throughput, it can be said that it is caused by many factors, as in the case of LSCI. When container traffic in a country's ports increases for any reason, this naturally causes an increase in the countries where it carries out commercial activities and is used as a transshipment port. Additionally, when ports in a country increase their capacity or efficiency, this may cause them to steal cargo from other countries. Agreements facilitating trade between countries also stand out as an important factor affecting both regional and route-based container traffic. As mentioned about LSCI, disruptions in the global supply chain have a role in dependence and interaction between countries, as they can cause the decline originating from one country to be reflected negatively or positively in other countries. All these and similar situations cause the change in a country's container traffic for any reason to be reflected in the traffic of other countries and pose inter-country dependency.

Due to the cross-sectional dependence in the series, methods that are robust to this situation have been chosen in the selection of both panel unit root tests and panel causality tests. The applied unit root tests indicated the existence of unit root in both LSCI and Container Throughput variables. While the existence of a unit root indicates that shocks have permanent effects, this can be due to many reasons. If countries make significant infrastructure investments in their ports, this generates a permanent impact on port traffic and LSCI values. In addition, if trade-facilitating agreements and policies are implemented between countries, this also induce a permanent effect. Similarly, global events that negatively affect the global supply chain and economic activities may have permanent effects on the values of countries, such as COVID 19 and Russia-Ukraine War. As a result, the variables were purified from the unit root effect by taking their first differences and causality analysis was applied with stationary series.

The results obtained from the panel Granger causality analyzes can be evaluated in different dimensions in terms of significance, coefficient and lag. In terms of significance, there are significant causal relationships both from Container throughput to the LSCI variable and from the LSCI variable to the Container Throughput variable. This shows that both variables affect each other and that a change in one variable causes a change in the other, meaning there is a two-way flow of information.

In terms of coefficient, the coefficients of the independent variables are positive in both causality equations. This indicates that the change in the LSCI variable causes an increase in Container Throughput in subsequent periods, and the changes in Container Throughput cause an increase in the LSCI variable in subsequent periods. Considering the coefficient size, the coefficient of the independent LSCI variable in the first model (0.1396) is higher than the coefficient of the independent Container Throughput variable in the second model (0.1049). This shows that improvements in infrastructure and transportation networks generate more demand, and the increase in demand also causes more transport infrastructure services to be provided in the relevant countries, but the impact in the first case is higher.

When considering the issue in terms of lag, the optimum lag for both models was determined as 1. This shows that in both models, the change in the independent variable has an effect on the dependent variable in the following period. The change in LSCI value in the current period increases the Container Throughput in the next period and vice versa.

The two-way interaction between variables can be evaluated as an increase in one variable causing an increase in the other variable and then reflecting positively on itself, in other words, a positive feedback loop. Growth in one variable stimulates growth in the other variable. While there is a two-way relationship between Liner Shipping Connectivity Index (LSCI) and container throughput, the impact of LSCI on container throughput (with a coefficient of 0.1396) is slightly stronger than the impact of container throughput on LSCI (with a coefficient of 0.1049). This suggests that improvements in LSCI have a more pronounced effect on increasing container throughput than the reverse, highlighting the importance of connectivity enhancements in driving trade volumes.

When analyzing the studies in the literature, the positive effect of container throughput on LSCI is confirmed through the variable "container per capita" (Jouili, 2019). Similarly, the positive effect of LSCI is validated through variables such as exports (Şeker, 2020), trade volume (Canbay, 2014; Fugazza & Hoffmann, 2017), container throughput (Reza et al., 2015; Atacan et al., 2022; Del Rosal & Moura, 2022), and economic growth (Ayesu et al., 2022). While there is no single study that employs a methodology capable of detecting a positive feedback loop relationship in the same manner as ours, all these studies collectively support this finding. While existing studies confirm individual relationships between variables like LSCI, container throughput, and trade volume, our research uniquely contributes to the literature by employing a methodology capable of detecting a positive feedback loop between these variables. This comprehensive approach allows us to reveal the cyclical nature of these relationships, which has not been addressed in previous studies. By uncovering this feedback loop, our work provides deeper insights into the dynamic interactions within container transportation and global trade. Our findings highlight the need to focus not only on infrastructure investments to improve transport connectivity but also on implementing trade-enhancing policies. Moreover, this finding aligns closely with Myrdal's (1957) theory of cumulative causation, which posits that economic processes are self-reinforcing, leading to cycles of development or underdevelopment. In this context, an increase in one variable, such as LSCI, can trigger positive changes in other areas, like container throughput, generating a feedback loop that amplifies growth. Myrdal (1957) argued that such processes are cumulative, meaning that initial changes tend to set off a chain reaction of further changes in the same direction, thereby enhancing the overall economic effect.

The annual nature of the data used in the study stood out as an important limitation of the study, making it impossible to apply short-term dynamic analysis. LSCI is published quarterly, if container throughput can be obtained at a more frequent frequency such as quarterly, more dynamic analyzes can be applied in future research. In addition, by clustering countries according to their profiles, it can be determined whether the relationship differs according to country groups. Future studies should expand on our investigation of the relationship between the Liner Shipping Connectivity Index (LSCI) and container port throughput by incorporating additional performance metrics such as the Maritime Transport Efficiency Index (MTEI), Logistics Performance Index (LPI), and Container Port Performance Index (CPPI). Analyzing these indices in conjunction with the LSCI could provide a more comprehensive understanding of the factors influencing maritime logistics efficiency and offer valuable insights for improving port performance and connectivity.

CONCLUSION

This study makes a groundbreaking contribution to the literature as the first to identify and analyze the cyclical relationship between LSCI and container throughput, shedding light on the dynamic interplay of these variables. Our findings reveal a two-way positive feedback loop, where advancements in one area stimulate growth in the other, emphasizing the deeply interconnected nature of transportation networks and trade volumes. Moreover, the stronger influence of LSCI on container throughput underscores the critical importance of infrastructure and connectivity enhancements in driving global trade. In alignment with the cumulative causation theory, this study demonstrates that initial improvements in connectivity can set off self-reinforcing cycles of growth, promoting economic development and trade efficiency. By establishing this novel feedback loop, our research offers a unique perspective and lays the foundation for future studies in the field.

Compliance with Ethical Standards

Authors' Contributions

AD: Writing – original draft, Investigation, Formal Analysis.

AA: Conceptualization, Supervision, Writing – review & editing.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data that support the findings of this study are available from the corresponding author on request.

Supplementary Materials

Supplementary data to this article can be found online at https://doi.org/10.61326/actanatsci.v5i2.287.

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