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Container port competitiveness amid disruptions: Insights from the European maritime network during the Red Sea crisis

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ABSTRACT

In November 2023, Houthi attacks on shipping routes passing through the Red Sea triggered changes in maritime networks and led to greater use of the Cape Route. This paper analyzes the impact of this rerouting on European port competitiveness during the first half of 2024, as the consequences of the event became apparent. The findings indicate a contraction of the network around major hubs by March, accompanied by an estimated increase in transport chain costs ranging from 3 % to 13 %, depending on the gateway and transshipment ports involved. Hub ports close to the Strait of Gibraltar reinforced their connectivity and experienced the smallest cost increases. In contrast, feeder ports, especially those in proximity to the Suez Canal, saw a decline in connectivity amid network reconfigurations. This research offers insights into the medium-term evolution of European maritime connectivity during periods of geopolitical instability and presents cost estimates that influence port choice processes.

1. Introduction

Recent global disruptions, including the COVID-19 pandemic, blockages in critical waterways, and geopolitical tensions, have exposed vulnerabilities in international supply chains and driven shifts in transportation networks (UNCTAD, 2024). Despite growing research on maritime connectivity changes induced by disruptions, it remains unclear whether the impacts of the Houthi-related Red Sea crisis are transient or will persist over time. Although the timing of this study is too early to assess the long-term impacts, it is possible to start disentangling the evolving patterns of the maritime network to obtain insights from medium-term trends on port connectivity and competitiveness. In this respect, recent academic editorials have emphasized the relevance of specialized research on maritime chokepoints and the implications of global disruptions for the continuity of supply chains (Haralambides, 2024; Notteboom et al., 2024).

Since November 2023, heightened risks of militia attacks have forced hundreds of vessels to reroute from the Suez Canal to the Cape of Good Hope. As a critical corridor in the global maritime network, the Suez Canal connects major European ports with those in East Asia and the Middle East. Consequently, disruptions in this route significantly impact international maritime trade between Asia and Europe, increasing voyage distance, transit times, and costs. Between January and March 2024, the UN Global Platform reported a 50 % rise in monthly voyage distance and time for cargo vessels compared to the June–September 2023 period (World Bank, 2024). In their editorial paper, Notteboom et al. (2024) note the need to measure the consequences of planned responses to this disruption, such as vessel rerouting, the use of alternative transport modes, and supply chain redesign. With the Red Sea crisis persisting, assessing its medium- and long-term effects on maritime transport connectivity and its associated costs becomes relevant for informing scholars, policymakers, and practitioners when considering such planned responses.

However, most existing studies concentrate on the impact of the Houthi-related Red Sea crisis on emissions, with limited attention given to its economic consequences. For instance, Pseftogkas et al. (2024) proposed a method for estimating the impact of rerouting on NOx emissions from vessels. During the first half of 2024, they reported a decline of 55 % and 15 % in the Red Sea and the Strait of Gibraltar, respectively, while observing a 40 % increase around the Cape of Good Hope. Furthermore, Peng et al. (2024) examined the European Union's emissions dataset, revealing heightened risks of carbon leakage under

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disrupted conditions, undermining the effectiveness of regional carbon pricing policies.

Regarding the impact on maritime connectivity, one precedent is the study of Yue et al. (2024) on the Ever Given incident, analyzing shipping routes from the top five maritime companies between November 2021 and January 2022. They report an 11 % decrease in network connectivity degree, a 10 % reduction in graph density, and a 3.5 % drop in the clustering coefficient. In this case, rerouting around the Cape of Good Hope led to a nearly 50 % increase in the well-to-tank carbon footprint. Similarly, Wan et al. (2023) found significant declines in network accessibility during the blockage, particularly for container and petrochemical routes.

Specifically on the connectivity implications of the Houthi-related Red Sea crisis, Yap and Yang (2024) provide insights into the short-term impacts, analyzing port call and shipping line data from October 2023 to February 2024. Their findings reveal that leading shipping alliances, such as the Ocean and 2M Alliances, maintained their service routes with minimal reductions in port calls, while THE Alliance experienced significant declines in weekly port calls and associated shipping capacity. The authors highlight the short-term impact on transshipment hubs in the Mediterranean and Red Sea. Ports such as Jeddah, Piraeus, and King Abdullah City, traditionally strong players in Asia-Europe and Asia-Mediterranean trade routes, lost prominence to Western Mediterranean ports like Tanger Med and Algeciras. These findings relate to the multiplex network analysis by Xu et al. (2024) on the global shipping network, showing that ports play multiple roles across different companies, with distinct connectivity strategies shaping regional dynamics.

Meanwhile, the Red Sea crisis persisted throughout 2024, creating significant uncertainty about the medium- and long-term consequences for container ports beyond throughput rankings, and leaving a knowledge gap regarding the evolution of maritime connectivity between Asia and Europe. Furthermore, there is very limited understanding of how such changes in connectivity are expected to impact maritime transport costs, potentially influencing port choices and the configuration of supply chains in Europe. In this context, the specific research questions this study aims to address are: 1) What is the medium-term evolution of container vessel connections between Asia and Europe? 2) How is this disruption expected to impact the cost-competitive positioning of Western Mediterranean ports serving hinterland regions in Europe?

The research utilizes network analysis to assess the evolution of European maritime connectivity from June 2023 to June 2024, leveraging Automated Identification System (AIS) data retrieved from Marine Traffic. Building on this connectivity analysis, a transport chain simulation model examines container shipping routes from Asia to European hinterlands, estimating the cost implications of these disruptions for the competitiveness of gateway and transshipment ports. Two Asia-Europe route scenarios are analyzed: first, a direct service to Genoa, Marseille, and Valencia or Barcelona; second, a transshipment service via Valencia or Tanger Med, followed by feeder services to Mediterranean ports. The study compares transport costs under normal Suez Canal operations versus rerouting via the Cape of Good Hope and evaluates the cost advantages between competing Western Mediterranean ports.

The primary contributions of this research lie in identifying the most impacted European ports in terms of connectivity during the first half of 2024, estimating the rise in transport costs, and their implications for port competitiveness. The paper discusses the policy implications of these findings for ensuring the continuity and resilience of European supply chains. By doing so, the paper provides insights into the evolving maritime network and its competitive landscape, contributing to the stream of research on resilient supply chain management in the face of growing uncertainty.

The paper is organized as follows: Section 2 builds a contextual framework of the Red Sea crisis. Section 3 explains the methodology followed and the data collected for the assessment. Section 4 presents the results, whose main implications are discussed in Section 5. Section 6 concludes the paper.

2. Contextual framework

Between December 2023 and March 2024, trade volumes passing through the Suez Canal decreased by approximately 50 % compared to historical averages, while vessel traffic around the Cape of Good Hope increased by a similar proportion (World Bank, 2024). This was the result of rerouting more than 650 container vessels following the Red Sea crisis, accounting for approximately 10 million TEUs (Clarksons, 2024). The rerouting activity peaked in January 2024 and stabilized by March, as illustrated in Fig. 1. This phenomenon, termed the “Great Rerouting,” has been recognized for its historical significance in reshaping global maritime transport (Rodrigue, 2024b).

By December 2024, the persistence of the Red Sea crisis and the uncertain geopolitical conditions in the Middle East maintained the elevated number of rerouted vessels. These disruptions have extended transit times significantly; the average time required to transport goods from Asia to Europe increased by 18 days during the third quarter of 2024 compared to the same period in 2023 (e2open, 2024).

Additionally, market responses to the crisis have been reflected in elevated container spot rates. The Drewry World Container Index peaked with a 170 % surge in January 2024, reaching approximately $4,000 to transport a 40-ft container from Asia to Europe. Although rates stabilized around $3,000 by April 2024, they remained well above the pre-crisis average of $2,000 (World Bank, 2024). Fig. 2 presents the specific case of spot rates from Shanghai to Europe. From a historical spot rate of around $1,000/TEU, prices notably increased after the COVID-19 pandemic and the Red Sea crisis. During the first half of 2024, rates rose to around $3,000 in January and reached a peak of $5,000 in June 2024 (Clarksons, 2024).

However, limited research has been conducted on the medium-term impacts on port connectivity, associated transport costs, and their implications for port competitiveness. Under normal conditions, shipping lines tend to be price takers. However, in the case of disruption, they can become price setters. The surge in prices is attributed to changes in spot rates and much of the capacity is secured under long-term contracts with fixed fares. When capacity is tight, spot rates surge, but the impacts on the actual costs of transport chain operations remain unclear. These costs likely vary depending on the maritime route and could confer a comparative advantage to certain ports, particularly in the Western Mediterranean, if the disruption persists over the medium to long term. Nevertheless, this aspect of port competitiveness remains understudied. The following section provides a detailed explanation of the data and methods used to examine it.

3. Data and methods

To evaluate the evolution of the European maritime network and its implications for the cost-competitive positioning of ports following the onset of militia attacks in the Red Sea, this study adopts a two-component analysis framework (Fig. 3). The first component involves a network analysis to estimate essential connectivity metrics, identify the most connected groups of ports (referred to as communities), and assess how the network structure evolved during the first half of 2024.

The second component builds on the insights from the network analysis to develop a transport model that simulates the cost impacts of transport routes serving Western European regions. The simulation model output is then used to estimate the comparative cost advantage of Mediterranean gateway and transshipment ports on these routes, relative to the baseline conditions before the disruption. The following sections provide a detailed explanation of each component.

3.1. Assessment of the network evolution

For the first component of the analysis framework, we collected monthly port call data of arrivals for top 15 European container ports in the first half of 2024 (PortEconomics, 2024) from Marine Traffic (2024)

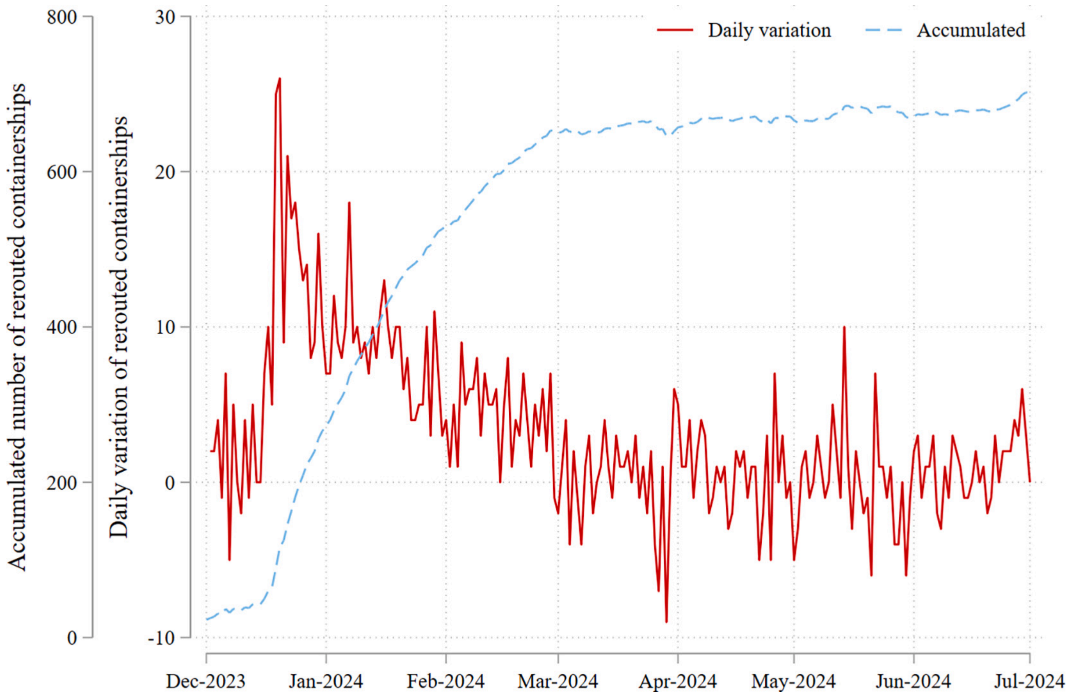


Fig. 1. Number of containerships rerouted from the Red Sea to the Cape of Good Hope.
Note: For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.
Source: Own elaboration with data from Clarksons (2024).

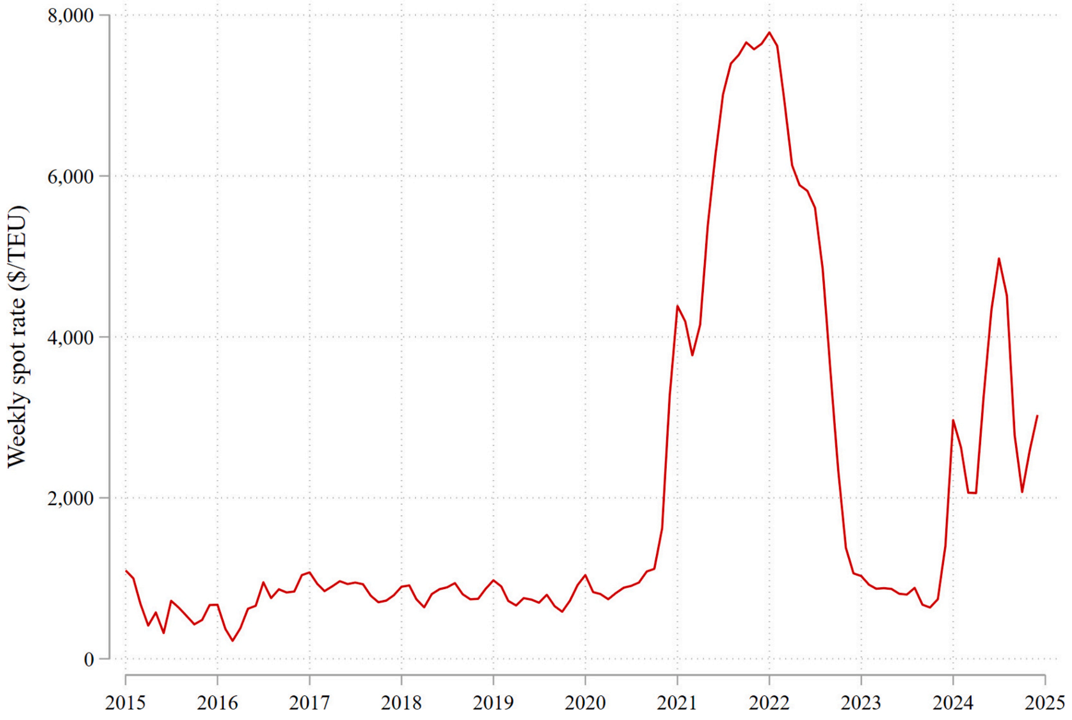


Fig. 2. Historical spot rates Shanghai-Europe.
Notes: The last observed value is the first week of December 2024.
Source: Own elaboration with data from Clarksons (2024).

(Fig. 4). This dataset provides information for each port call, including the vessel identifier, timestamp, and origin port. It details all voyages of large container vessels connecting Asia to these European ports during the study period.

Data were collected for four months selected based on their relevance to the timeline of rerouting events, as outlined in the contextual framework. June 2023 serves as the baseline month, representing the maritime network before disruptions arising from the Red Sea crisis. January 2024 corresponds to a significant increase in rerouted vessels navigating the Cape of Good Hope. By March 2024, the number

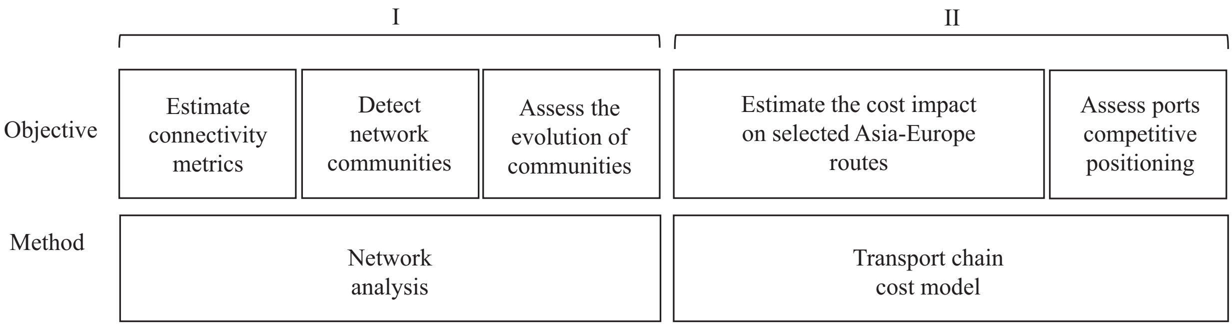


Fig. 3. Analysis framework.

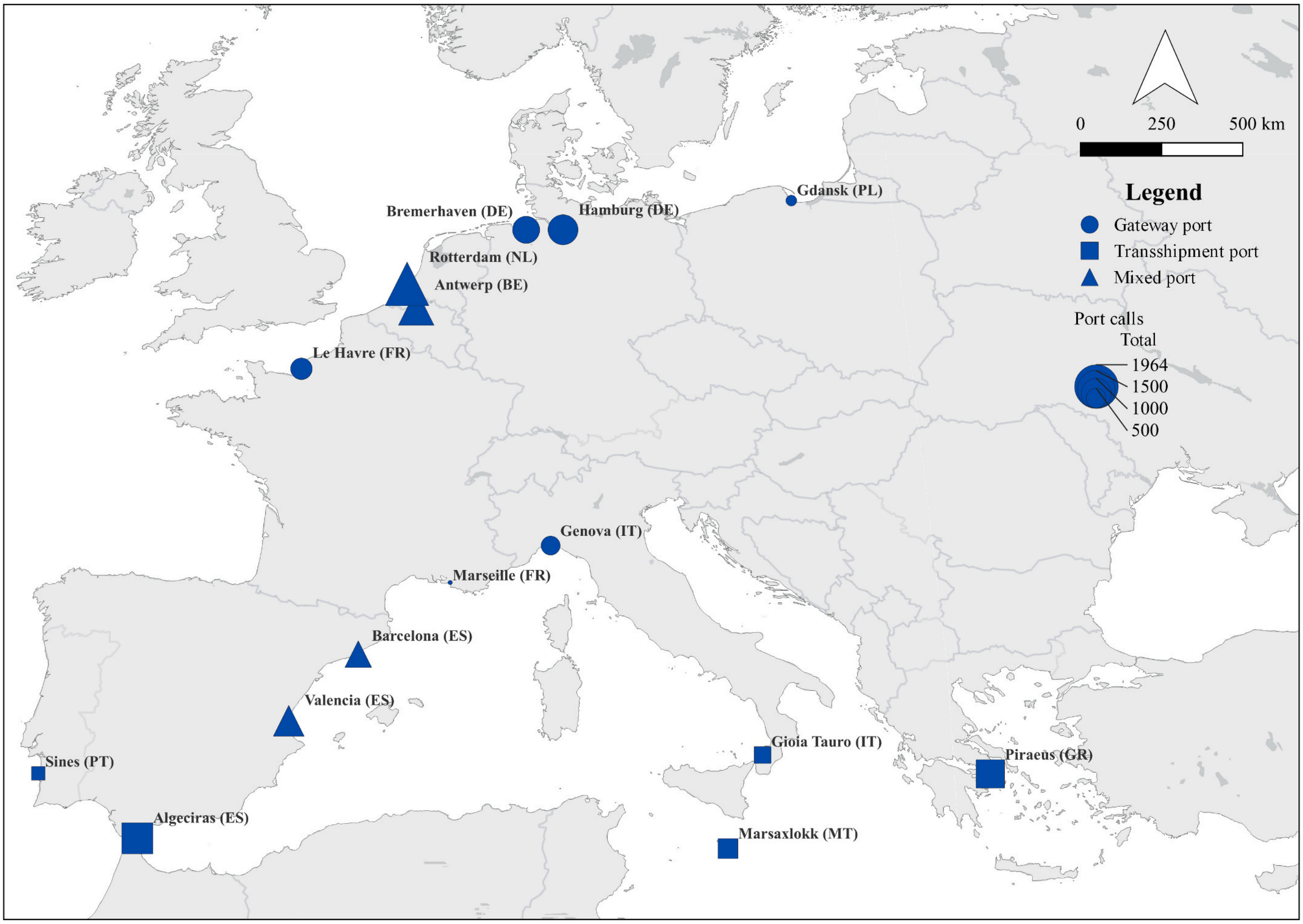


Fig. 4. Ports in the study.
Note: Total port calls during the four-month period of the study.
Rotterdam accounts for Maasvlakte and Waalhaven. Antwerp does not include Zeebrugge.

of rerouted vessels had stabilized, capturing the cumulative level of rerouting activity. Finally, June 2024 provides a year-over-year (YoY) comparison with the baseline month of June 2023, offering insights into medium-term impacts on maritime connectivity.

Among the 15 ports in the study, Rotterdam recorded the highest number of port calls, with 1964, while the remaining ports reported fewer than 1,500 calls. Several ports exhibited similar call volumes, such as Algeciras, Valencia, and Hamburg, with more than 1,000 each; and Piraeus, Bremerhaven, and Barcelona, with an average of 856. In contrast, port call volumes in the rest of the ports ranged from 573 in Le Havre to 143 in Marseille.

Considering ports of origin, the resulting network consists of 314 connected nodes. It is a directed network, meaning that a connection is established when at least one vessel makes a port call at one of these ports, without requiring a reciprocal voyage in the opposite direction. The weight of each connection is determined by the number of vessels in that specific maritime route. To study the changes in maritime connectivity, a set of metrics was estimated on this network, as summarized in Table 1.

The analysis begins by examining basic degree centrality, distinguishing between the number of incoming connections (In-Degree, Eq. 1.1) and outgoing connections (Out-Degree, Eq. 1.2). These metrics

Table 1
Connectivity metrics.

Metric	Definition	Formulation	Equation
In-degree (k_i^{in})	The number of links a node *i* receives from other nodes *j* at moment *t*. It refers to the number of maritime connections destined for a given port.	$k_i^{in}(t) = \sum_{j=1}^{N(t)} a_{ji}(t)$	(1.1)
Out-degree (k_i^{out})	The number of links a node *i* sends to other nodes *j* in moment *t*. It is the number of maritime connections originating at a given port.	$k_i^{out}(t) = \sum_{j=1}^{N(t)} a_{ij}(t)$	(1.2)
Degree (k_i^T)	The sum of in and out degrees.	$k_i^T(t) = k_i^{in}(t) + k_i^{out}(t)$	(1.3)
Network diameter (*ND*)	The longest of all the shortest paths between any two nodes in the maritime network. It reflects the maximum number of intermediate port calls needed to connect two ports via the most efficient route.	$ND = max_{i,j\in V}\, d(i,j)$	(1.4)
Av. Path length (*APL*)	The average of the shortest path lengths between all pairs of nodes. It presents the average number of port calls needed to connect two ports in the network.	$APL = \frac{1}{N(N-1)} \sum_{I,J\in V} d(ij)$	(1.5)
Graph density (*GD*)	The proportion of connections (*m*) in the network compared to the maximum possible.	$GD = \frac{m}{n(n-1)}$	(1.6)

Source: Adaptation from Ducruet et al. (2023), Calatayud et al. (2017), and Wang et al. (2011).

are further analyzed by incorporating weights based on the number of vessels making port calls, also referred as Weighted In-Degree and Weighted Out-Degree metrics. Then, overall network interconnectedness is assessed through three metrics: First, the network diameter (Eq. 1.4) accounts for network efficiency by indicating the shortest path with the highest number of required connections to be completed. Second, the average path length (Eq. 1.5) accounts for network distance by considering the number of calls between all pairs of ports in the network. Lastly, network density is calculated to measure the proportion of existing connections relative to the maximum possible connections in the network (Eq. 1.6).

In addition to these metrics, modularity is estimated to identify communities of ports within the network, utilizing the Leiden algorithm for community detection and visualization (Traag et al., 2019). We prefer the Leiden algorithm as it outperforms the Louvain method (Traag et al., 2019), which in turn outperforms most other algorithms (Mukerjee, 2021). Leiden takes a step back in each iteration to prevent the formation of disconnected communities, a known issue for the Louvain method (Traag et al., 2019). While not yet common in analyzing maritime networks, the algorithm has been frequently applied in regional economics (Verhetsel et al., 2022) and mobility research (e.g., Gibbs et al., 2020). Empirically, 1000 runs proved to yield stable results (Thomas et al., 2017), which is applied to identify the communities of ports. These calculations are performed in R, using the leindenbase package (Ewing, 2024), and the visualization is done in Gephi (Bastian et al., 2009).

The community detection provides insights into the network's most connected components and their evolution over time. The modularity formulation for the weighted graph is presented in Eq. (2), where ϑ represents the total number of connections in the network, A_{ij} denotes the presence of a connection between nodes *i* and *j*, k_i^{in} and k_i^{out} represent the number of incoming and outgoing connections to and from node *i*, respectively (i.e., In-Degree and Out-Degree), *c* refers to the community to which nodes *i* or *j* belong, and the δ -function $\delta(c_i, c_j)$ equals 1 if $c_i = c_j$ and 0 otherwise.

Connectivity metrics for each critical month (January, March, and June 2024) are visually compared to the baseline month of June 2023 to illustrate the evolution of the maritime network. This procedure allows analyzing the evolution of connections and their communities. The analysis identifies the most impacted ports and captures the establishment or elimination of connections between ports. A final YoY comparison for June 2024 highlights medium-term changes in the network.

$$Q_d = \frac{1}{\vartheta}\sum_{ij}\left[A_{ij} - \frac{k_i^{in}k_j^{out}}{\vartheta}\right]\delta(c_i, c_j) \tag{2}$$

3.2. Transport chain cost model

The second component of the analysis framework focuses on simulating various scenarios to evaluate the cost-competitive positioning of ports, incorporating the variations in the maritime network analyzed in the previous sub-section. This simulation model calculates the total costs associated with transporting goods from a specific hinterland of origin to a destination hinterland within a defined transport loop (Fig. 5). The methodology is based on the approach originally developed by van Hassel et al. (2016) and aims to identify the transport chain with the lowest overall cost. This analysis considers costs across the maritime segment, port operations fees, and hinterland transport modes.

Building on the contextual framework outlined in Section 2, the disruption is mainly impacting maritime transport, making the generalized cost of the maritime segment the critical component for comparison within the transport chain. This cost, expressed in €/TEU, is estimated for a vessel *v* traveling from a port of origin *i* to a port of destination *j*, as summarized in Eq. (3).

$$GC_{vij} = \frac{OC_{vij} + VC_{vij} + CapC_{vij}}{N_{TEU}} + VoT^{*}T_{ij} \tag{3}$$

The simulation incorporates direct maritime costs, including operational costs (*OC*), voyage costs (*VC*), and capital costs (*CapC*). Additionally, it accounts for the total maritime time between ports (*T*). This is converted into monetary terms by considering the value of time (*VoT*), which is set equal to the opportunity cost during transport. The detailed components of the transport chain simulation model for vessel *j* on a given transport loop *k* are presented in Eqs. (3.1)–(3.3), and the notation is summarized in Table 2.

The estimation of these components follows the methodology established by van Hassel et al. (2016), incorporating updated values for 2022 provided by Pruyn and van Hassel (2022) and van Hassel et al. (2022). The first component, the operational cost of a ship of size j (OC_j), consists of five elements, all originally sourced from Drewry (2005) and indexed to 2012 (Eq. (3.1)): crew (CC_j), insurance (IN_j), consumables (CON_j), repair and maintenance (RM_j), and management and administration (MA_j). These costs are calculated based on the ship's size and expressed as a cost per hour. $DIST_k$ represents the total distance sailed (in nautical miles) for a given loop *k*, and V_j is the speed of ship *j* in knots.

$$OC_j = \frac{(CC_j + IN_j + CON_j + RM_j + MA_j)}{V_j}{}^{*}DIST_k \tag{3.1}$$

The second component, the voyage costs for a ship of size *j* (VC_j), is calculated based on Eq. (3.2) and includes fuel (FC_j), lubricants (LUB_j), canal dues (CD_j), and port dues of port *i* ($PD_{i,j}$). Fuel cost is determined by the price per tonne of fuel and the vessel's fuel consumption. The latter is calculated in the technical design model using resistance predictions (Holtrop and Mennen, 1978), propeller calculations based on the Wageningen B-series (Oosterveld and van Oossanen, 1975), and engine characteristics (Wärtsilä data). Lubricant costs are estimated using the same method. Canal dues for transiting the Suez Canal are based on officially published rates.

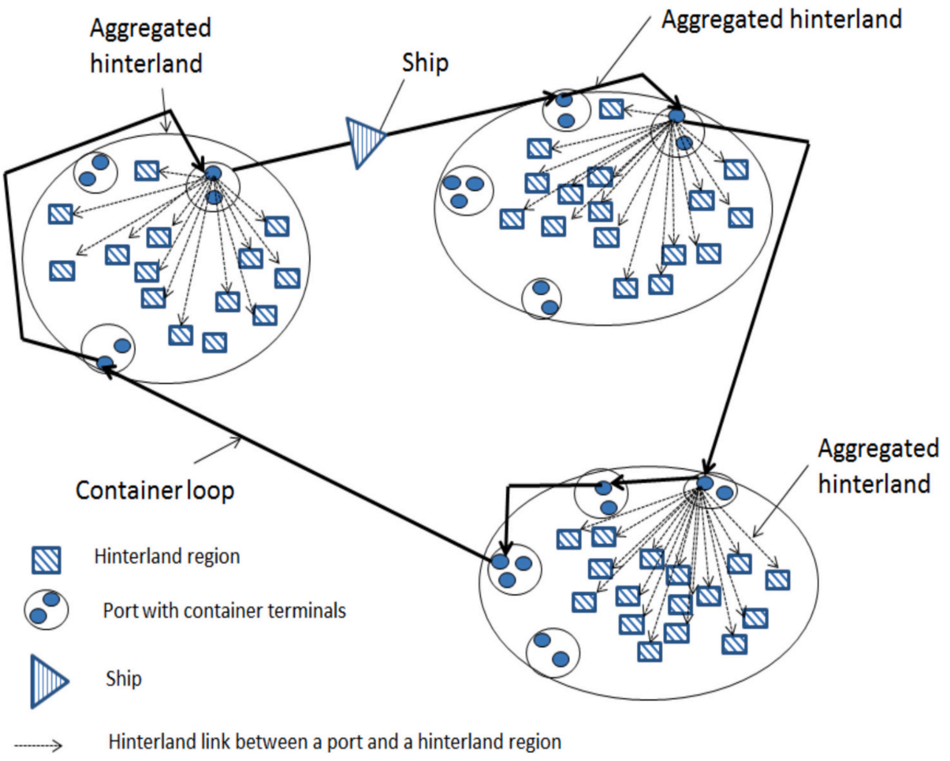


Fig. 5. Transport chain simulation loop.
Source: van Hassel et al. (2022)

Table 2
Notation of the transport chain simulation model.

Variable	Description	Unit
OC	Operational cost	€/hour
CC	Crew cost	€/hour
IN	Insurance	€/hour
CON	Consumables	€/hour
RM	Repair and maintenance	€/hour
MA	Management and administration	€/hour
DIST	Sailing distance	Nm
V	Speed	Knots
VC	Voyage cost	€/hour
FC	Fuel cost	€/hour
LUB	Lubricants cost	€/hour
CD	Canal dues	€
PD	Port dues	€
CapC	Capital costs	€
DEP	Depreciation	€
INTER	Interest cost	€
T	Time in loop	Days

Source: van Hassel et al. (2016).

$$VC_j = \left(FC_j + LUB_j\right)*\frac{DIST_k}{V_j} + CD_j + PD_{i,j} \tag{3.2}$$

The final component, the capital costs for a ship of size j ($CapC_j$), is determined by Eq. (3.3), where $INTER_j$ represents the interest cost and DEP_j the depreciation of ship j. T_k denotes the total time, in days, that a ship spends on the selected loop k. This includes both sailing time at speed V_j and the total port time across all ports. To calculate depreciation and interest, the ship's purchase price must be known. Mulligan (2008) proposed a simple yet effective model for estimating the newbuilding cost of a container ship based on its size (dead weight tonnage).

$$CapC_j = \left(DEP_j + INTER_j\right)*\frac{T_k}{365} \tag{3.3}$$

This simulation model enables the identification of the most cost-effective alternative for completing a given transport chain, including the port-hinterland segment. To illustrate the differentiated impacts of reaching European hinterlands from Mediterranean ports, the analysis adopts the Nomenclature of Territorial Units for Statistics (NUTS) classification, used by the European Union for statistical and administrative purposes. The second level (NUTS-2) represents basic regions and is commonly preferred for regional policy analysis (Eurostat, 2024).

Within this evaluation framework, this research focuses on two case studies to estimate the expected cost increases when vessels are rerouted via the Cape of Good Hope and the resulting implications for the comparative advantage of competing gateway and transshipment West Mediterranean ports. The scenarios will be simulated based on insights obtained from the network analysis in Section 3.1 and aim to illustrate how a global disruption can significantly impact gateway and transshipment port hierarchies. This analysis considers Singapore, one of the world's busiest transshipment hubs which serves as a major port for EU-bound cargo from China and Southeast Asia, with special relevance during the Red Sea crisis (Rodrigue, 2024a).

The first case study focuses on gateway ports by examining a direct call structure, typical for premium services with fast transit times. The second case study considers a transshipment in Europe, reflecting a hub-and-spoke strategy commonly used for cost optimization. These case studies also represent current shipping routes from Asia to Europe, particularly those operated by the world's third-largest container shipping company, CMA CGM, under the Mediterranean Club Express 2 service (CMA CGM, 2024).

Specifically, the first case study involves a 15,000 TEU vessel departing from the Port of Singapore with scheduled calls at three Mediterranean ports: Genoa, Marseille, and Valencia. The final destinations include hinterland regions in Spain, Portugal, France, and Italy. This case study models a direct route to the Mediterranean ports without any transshipment operations. Generalized transport chain costs are estimated for two scenarios: the vessel passing through the Suez Canal under normal conditions and the vessel being rerouted via the Cape of

Good Hope under disruptive conditions (Fig. 6a). To further examine a localized competitive setting in the Strait of Gibraltar, the analysis will consider a competing gateway port, Barcelona, as an alternative to calling at Valencia to service hinterland regions in the Iberian Peninsula.

In contrast, the second case study examines a transshipment scenario involving a larger 24,000 TEU vessel departing from the Port of Singapore. This vessel sails around the Cape of Good Hope (Fig. 6b) and concludes its voyage at the Port of Antwerp. In this case, the larger vessel conducts a transshipment operation at Valencia, where cargo is transferred to smaller feeder vessels of 3,600 TEU for reaching Marseille and Genoa, as illustrated by the purple trajectory in Fig. 6b. As a typical alternative to transshipping in Valencia, the analysis will consider conducting this operation in one of the main competing ports: Port of Tanger Med (Morocco). Regardless of transshipment port chosen, the final voyage segment for the larger vessel to Antwerp remains the same, as shown by the blue line in the figure.

4. Results

4.1. Overall network evolution

European ports underwent diverse connectivity variations between June 2023 and June 2024. While the average number of port connections decreased by 4.6 %, it was accompanied by a 12.0 % reduction in the frequency of traffic within those connections, as measured by the number of vessels making port calls of arrival (i.e., Average Weighted Degree, Table 3). This result suggests less existent and less frequent services between ports. This is the logical outcome of the rerouting through the Cape Route and the associated rationalization of port calls. Additionally, while the network's diameter remained unchanged, the average path length slightly decreased by 1.5 %, and the graph density by 16.7 %. This means that the overall dimension of the network remained unaltered, which is intuitive since no ports closed operations, but the configuration of the connections evolved during the Red Sea crisis until June 2024.

Beyond the averages, the impact of the disruption on connectivity has exhibited significant heterogeneity across ports. During this YoY period, the most notable positive changes were recorded in the Ports of Valencia (ES) and Sines (PT), with an 18.5 % increase in connections, followed by Algeciras (ES, 17.9 %), Rotterdam (NL, 14.1 %), Hamburg (DE, 8.3 %), Gioia Tauro (IT, 4.8 %), Barcelona (ES, 4.5 %), and Bremerhaven (DE, 4.3 %). Conversely, connections declined in Antwerp (BE, −1.7 %), Genoa (IT, −3.8 %), Marseille (FR, −7.1 %), Piraeus (GR, −8.6 %), Marsaxlokk (MT, −8.9 %), and Gdansk (PL, −31.6 %). The absolute changes are illustrated in Fig. 7, and the complete table of percentual variations is presented in Appendix A.

A similar pattern is observed when examining the weight of these connections. In this disruptive context, most major ports reported negative variations, with two prominent exceptions: Valencia (8.4 %) and Algeciras (8.2 %). In contrast, significant declines were observed in Genoa (−29.9 %), Gdansk (−22.6 %), and Marsaxlokk (−14.1 %). These results underscore the uneven connectivity shifts across nodes within the maritime network. Intuitively, ports located closer to the Strait of Gibraltar benefited in terms of connectivity for both metrics, while those in the Hamburg-Le Havre range exhibited mixed variations (e.g., Antwerp and Rotterdam), and ports near the Suez Canal experienced declines. Notably, the contrasting change in connectivity between ports like Gioia Tauro and Marsaxlokk suggests that, beyond geographical factors, shipping lines may adjust their strategies based on gateway and transshipment competing ports within the maritime network, as supported by the literature reviewed (Xu et al., 2024; Yap and Yang, 2024).

Focusing on individual origin-destination connections, Fig. 7 highlights that many smaller connections observed in June 2023 (in dark orange) were absent in June 2024 (in blue). Instead, connections between the busiest ports displayed higher weights. This pattern is particularly evident for ports on the Iberian Peninsula, Genoa, and Piraeus, suggesting a possible contraction of connectivity toward the largest Mediterranean ports. Moreover, it can be noted that the connectivity degree with Southeast Asia and North America either decreased or remained relatively stable in most ports, while ports in Southern Africa and Brazil showed moderate improvements.

To explore this pattern further and avoid overlapping nodes in the visualization due to scale and geographical proximity (e.g., Algeciras vs. Tanger Med), the network layout is analyzed and presented in Fig. 8. The four-months period modularity score of 0.42 indicates a defined community structure, although these communities are subject to redefinition. When estimating the modularity score month by month, it varies from 0.42 to 0.45. In other words, the nodes in the network (i.e., ports) may reestablish connections that bring them closer to different communities. Such dynamic highlights the evolving nature of the network's structure, which is expected to be influenced by disruptions and changing connectivity trends.

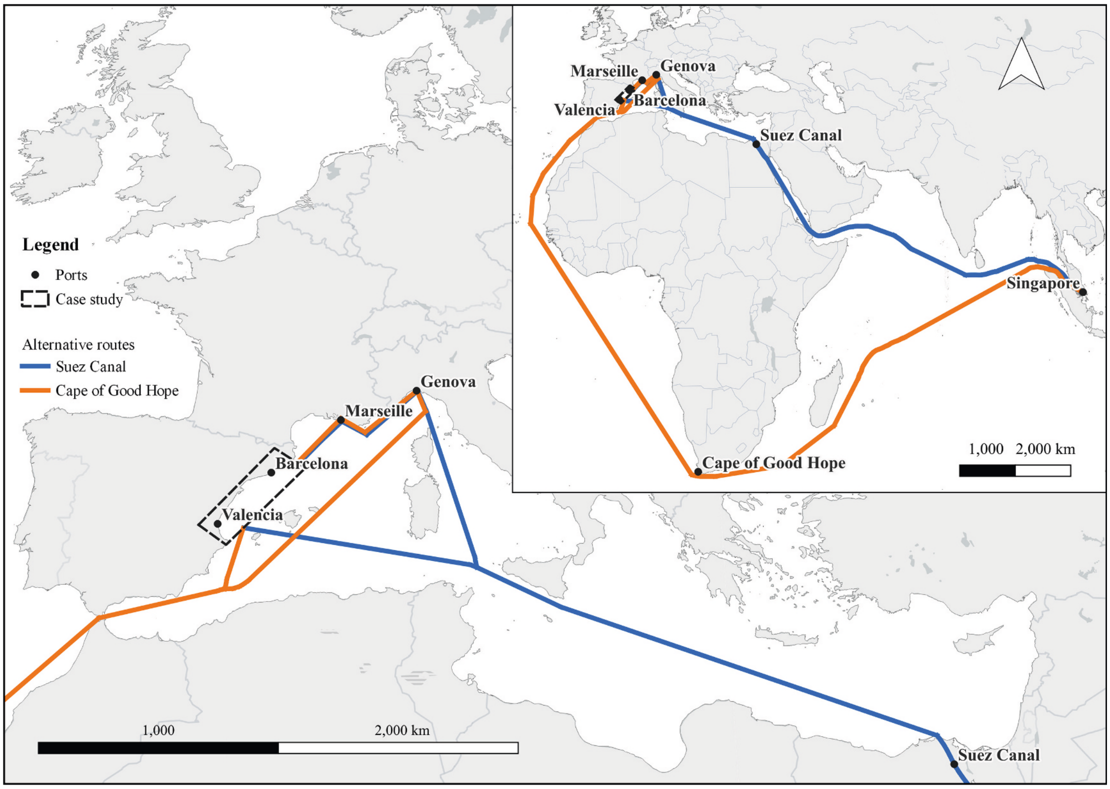
Taking this into account, the Leiden algorithm was employed to identify the consistent communities of ports within the network, represented by distinct colors in Fig. 8. The largest community, shown in purple, corresponds to the so-called Hamburg-Le Havre range and accounts for approximately 40.4 % of all ports. In contrast, ports in the Mediterranean Sea are divided into two communities, reflecting their geographical positioning relative to the Suez Canal and the Strait of Gibraltar. The orange community, situated closer to the Strait of Gibraltar, comprises 31.9 % of the ports, with Valencia serving as the primary maritime hub according to weighted degree, followed by Algeciras, Barcelona, and the gateway ports of Marseille and Genoa. Meanwhile, the green community, positioned nearer to the Suez Canal, includes 27.7 % of the ports, with the highest weighted degree concentrated in Piraeus, Marsaxlokk, and Gioia Tauro. For the remainder of the paper, these communities will be referred to as the Western and Eastern Mediterranean, respectively.

The analysis by time intervals allowed tracking the evolution of the network. From June 2023 to January 2024 (Figs. 9), shifts in connectivity were observed both between and within network communities. Between communities, Eastern Mediterranean ports experienced a decline in connectivity, with the average number of connections decreasing by 5.3 %. In contrast, the Western Mediterranean and the Hamburg-La Havre communities showed increases of 6.3 % and 2.6 %, respectively. Notably, many of the connectivity losses in the Eastern Mediterranean community occurred in peripheral connections, suggesting a decline in connectivity for smaller ports.

Within communities, variations were primarily observed in the weight of connections (i.e., the number of vessels) during this interval, revealing disparities between the hubs and spokes of the network. In the Western Mediterranean reductions in vessel numbers were observed in Genoa (−15.7 %) and Sines (−13.4 %), while significant increases occurred in Algeciras (6.5 %), Valencia (6.1 %), and Barcelona (10.4 %). In the Hamburg-Le Havre community, connectivity declined across most of the hub ports, with Gdansk experiencing the most significant reduction (−25.0 %). Within the Eastern Mediterranean community, Marsaxlokk recorded a substantial decline in vessel numbers (−21.5 %), followed by Gioia Tauro (−18.2 %). Piraeus, however, experienced a relatively smaller reduction in vessel traffic (−4.5 %). Such patterns can be influenced by multiple factors since the beginning of the rerouting, including vessels size, service frequency, and the strategic behavior of shipping lines. Such factors will be discussed in greater detail in the following section of the paper.

Some trends became more pronounced during the second interval of analysis, spanning January to March 2024. As illustrated in Fig. 9, the weight of connections further increased around the primary network hubs, particularly within the Western Mediterranean community. On the other hand, the Eastern Mediterranean community experienced mixed variations, though the Port of Piraeus maintained a relatively steady decrease of just 1.2 %. During this period, the Port of Valencia and Algeciras saw substantial increases in connectivity, at 13.2 % and

(a) Direct connection from Asia to gateway Mediterranean ports



(b) Transshipment operation with feeder vessels

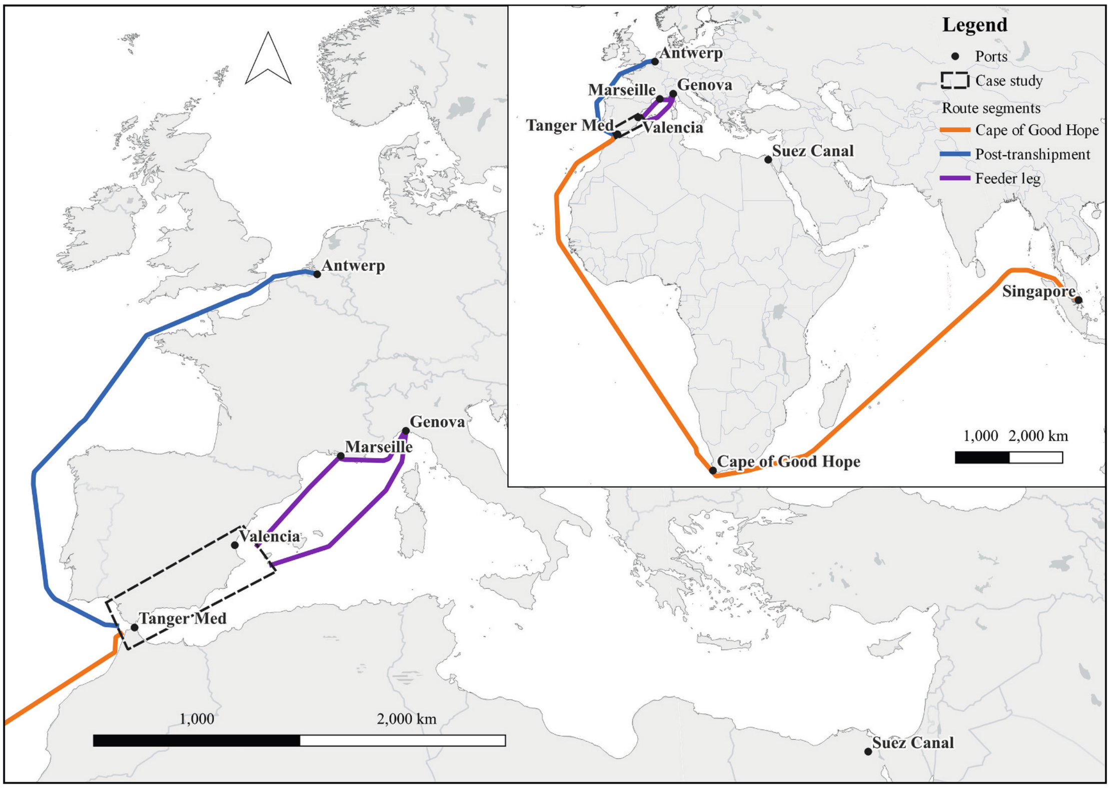


Fig. 6. Case studies.

Table 3
Connectivity metrics Jun 23 vs. Jun 24.

Metrix/Year (June)	2023	2024	Δ%
Av. Degree	2.605	2.485	−4.6 %
Av. W. Degree	13.814	12.159	−12.0 %
Avg. Path Length	2.253	2.220	−1.5 %
Network diameter	4	4	0.0 %
Graph density	0.012	0.010	−16.7%

Note: Metrics are calculated based on all ports in the network reporting at least one connection per month.

2.6 %, respectively. In contrast, several other major ports in the network, such as Barcelona, Marseille, and Sines, reported declines. A similar trend, albeit less pronounced, was observed in the Hamburg-Le Havre community, where the Ports of Hamburg, Rotterdam, and Antwerp experienced notable gains of 12.2 %, 8.42 %, and 5.7 %, respectively.

The final interval, from March to June 2024, revealed signs of evolution toward a more normalized setting, though significant differences remained compared to the pre-crisis baseline. Connectivity in the Eastern Mediterranean improved, with the Port of Gioia Tauro showing positive changes while others stabilized. This seems to be a short term pattern, as transshipment hubs of the region were recovering the connectivity level. Conversely, the Western Mediterranean community experienced pronounced declines in connectivity, particularly in Valencia and Barcelona. Similarly, the Hamburg-Le Havre reported an overall decrease in connectivity, with noticeable changes affecting its main hubs.

4.2. *Simulated cost impact on competing Western Mediterranean ports*

Moving on to the second and last component of the analysis framework, we estimate how these changes in the network evolution may influence transport costs. As a key route for Asia–Europe maritime trade, any blockage in the Suez Canal and subsequent rerouting would lead to delayed arrivals and increased costs at major Mediterranean hubs due to longer journeys via the Cape of Good Hope. However, these effects are also expected to be heterogeneous, depending on a port's spatial and network positioning.

The case studies focus on the Western Mediterranean community, which reports the largest variations in connectivity. More specifically, this sub-section examines the implications for Valencia, Barcelona, Algeciras, Genova, and Marseille. Fig. 10 shows the network's connectivity between June 2023 and 2024, highlighting dense links between major hub ports and smaller feeder ports, with the largest overall gains observed in Valencia and Algeciras, and losses for Barcelona and Genoa. These observed connectivity patterns are compared with the results from the cost impact simulations, which distinguish between gateway ports (Barcelona, Genoa, Marseille, and Valencia) and transshipment ports (Algeciras and Valencia) by considering two specific maritime services. Given its central role and dual gateway-transshipment function, Valencia is used as the reference port in both cases.

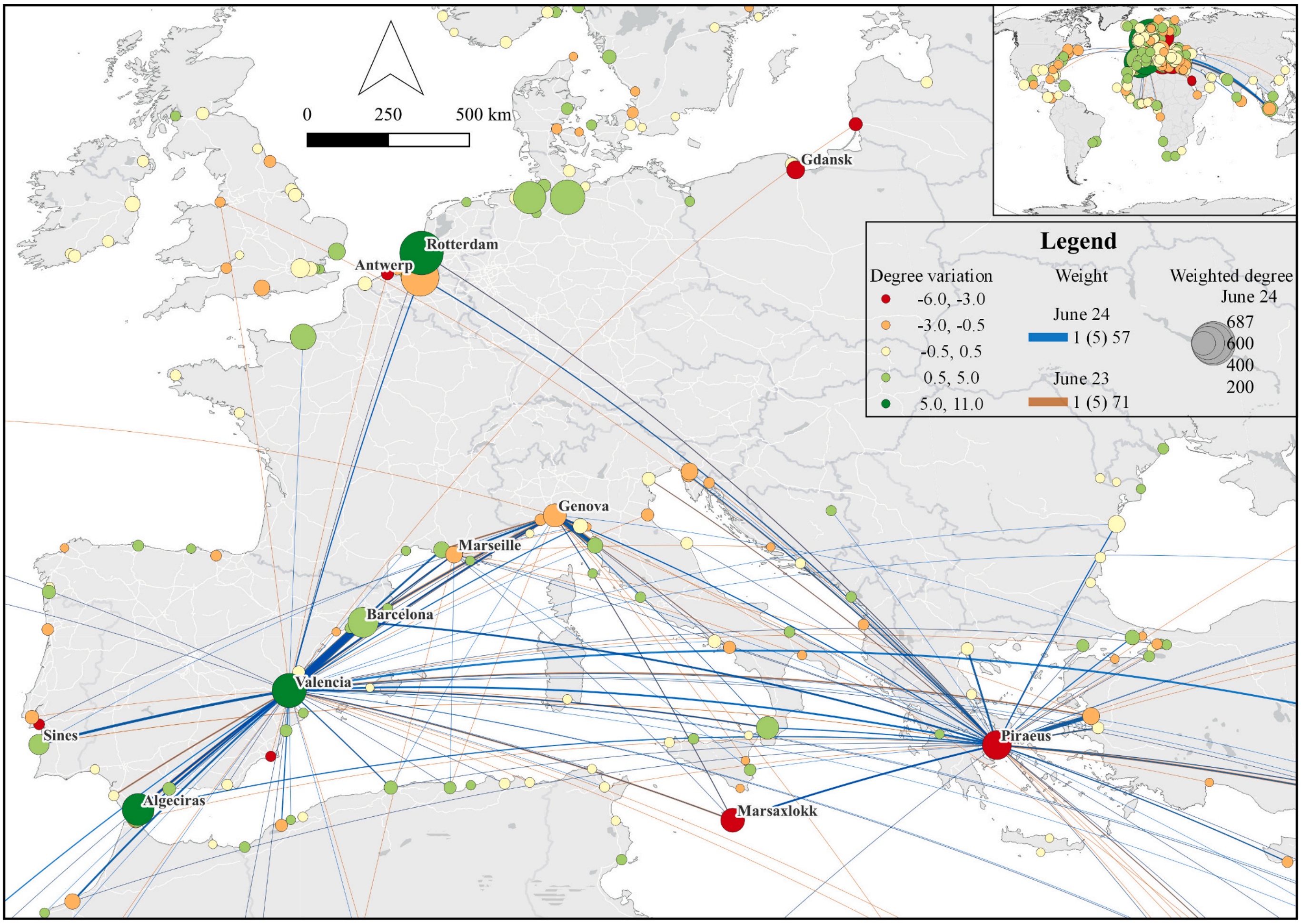


Fig. 7. Evolution of individual connections in busiest Mediterranean ports.
Notes: For ease of visualization, links are filtered for Valencia, Marseille, Genoa, and Piraeus.
Overlapping ports are rendered by priority according to weighted degree.

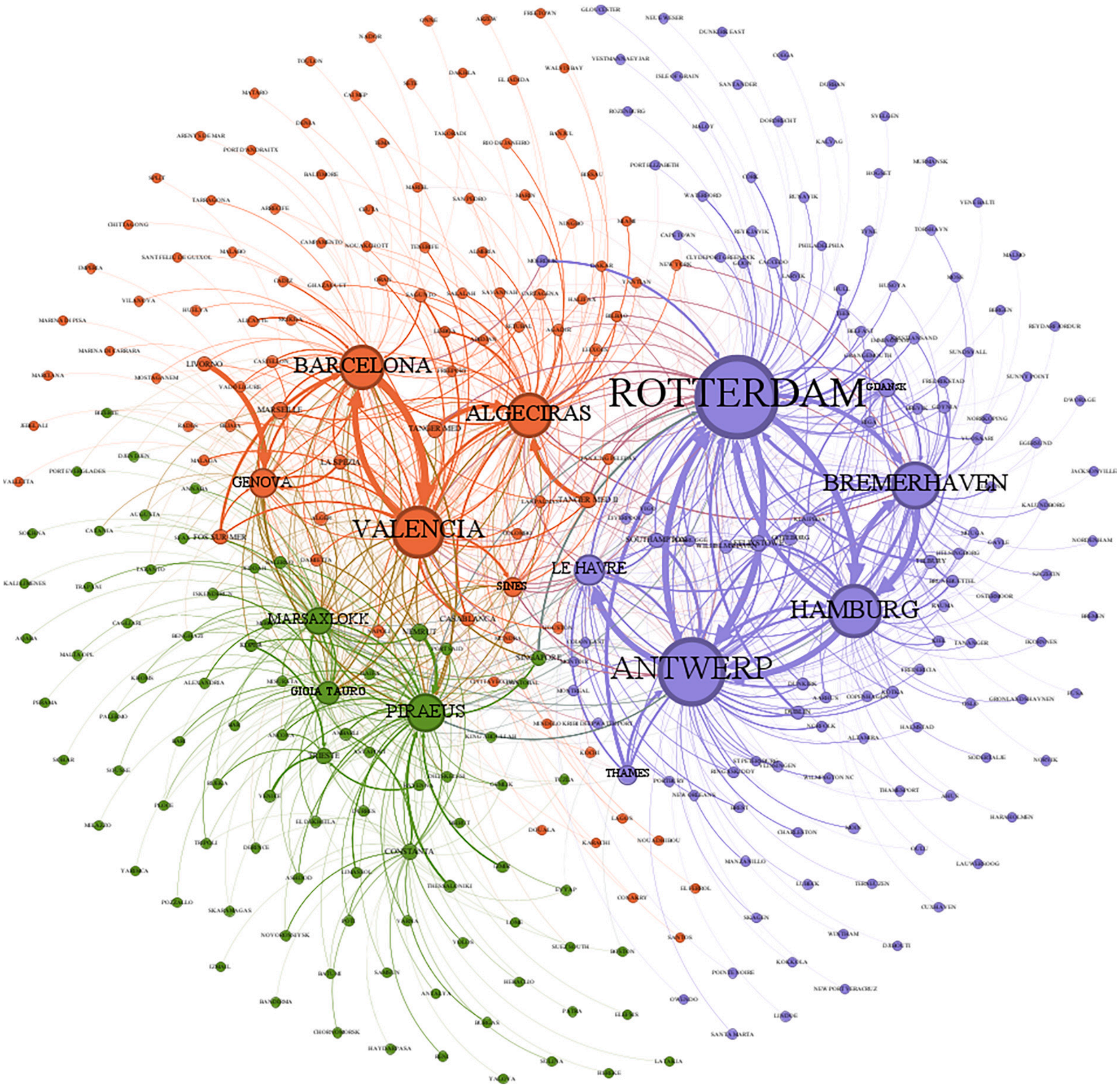


Fig. 8. Network communities (June 2023–2024).
Legend: Node size according to total weighted degree. Colors identify distinct network communities. The purple community comprises 40.4 % of ports, followed by the orange (31.9 %), and the green community (27.7 %).

4.2.1. *Impact on gateway ports*

The results from the first case study, which focuses on a connection originating at Singapore, indicate that transport costs are estimated to increase by at least 2.9 % (56 €/TEU) for a vessel with a capacity of 15,000 TEUs when making a direct port call at Valencia after being rerouted around the Cape of Good Hope relative to the no disruption scenario of using the Suez Canal. Intuitively, the hinterlands of the Iberian Peninsula are expected to experience the smallest cost increases, whereas the most significant rises are anticipated for those in Italy and the Alpine region due to additional sailing costs and time required. These variables directly influence operational, voyage, and capital costs. For instance, the distance from Singapore to Genoa increases by approximately 3,500 nautical miles, over 40 % longer than the Suez Canal route. At an average sailing speed of 16–18 knots, this translates into an additional 8–10 days at sea, though actual transit times may vary due to factors such as port congestion, weather conditions, or bunkering delays. Consequently, the results indicate that cost can increase by 6.1 % (132 €/TEU) when calling at Genoa. This result is coherent with the variations on the weighted degree noted in Fig. 10.

Looking closer at the Iberian Peninsula can further illustrate the competitive patterns that emerge between gateway ports in Europe following a connectivity disruption in the Red Sea. To do so, the simulation is made to estimate the cost implications for major hub ports, considering a route around the Cape of Good Hope. This analysis focused on Spain’s largest gateway ports, Valencia and Barcelona, which showed significant variations in the network analysis, estimating the costs of reaching hinterland regions (NUTS-2) in the Iberian Peninsula. Figure 11 presents a cost comparison for a sub-scenario where the Port of Barcelona is selected for a direct port call instead of the reference port, Valencia. The results indicate that Barcelona is more competitive than Valencia only in northern Spain, with its relative advantage reaching a maximum in Catalunya.

Intuitively, the results indicate that the Port of Valencia retains a competitive advantage in serving several central hinterland regions of Spain, including ES51 (Comunidad Valenciana), ES30 (Comunidad de Madrid), ES42 (Castilla–La Mancha), and ES62 (Región de Murcia). Two insights emerge from this analysis. First, while geographic proximity to inland regions is a primary factor in determining port competitiveness,

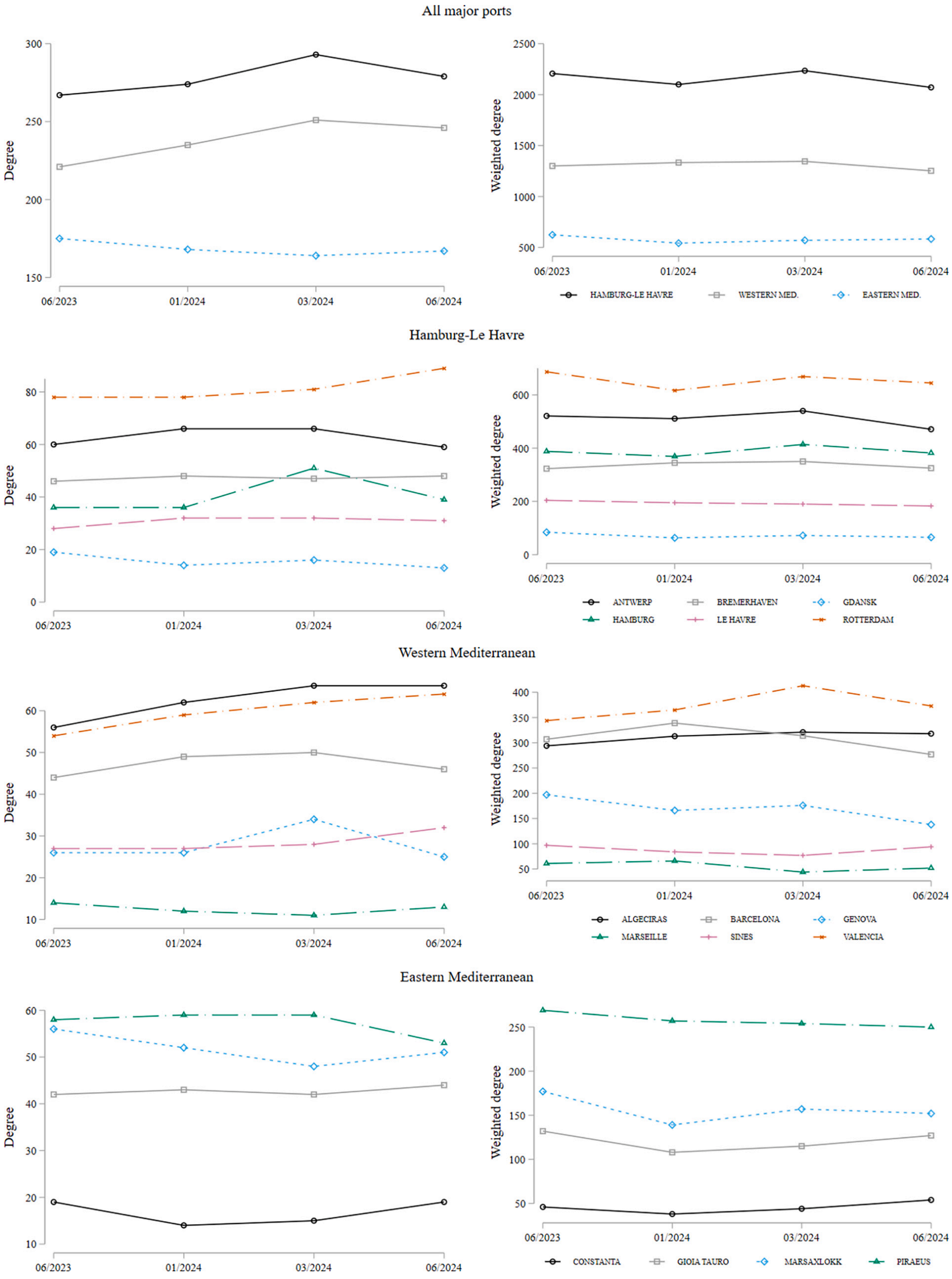


Fig. 9. Evolution of connectivity in port communities June 2023 – 2024.

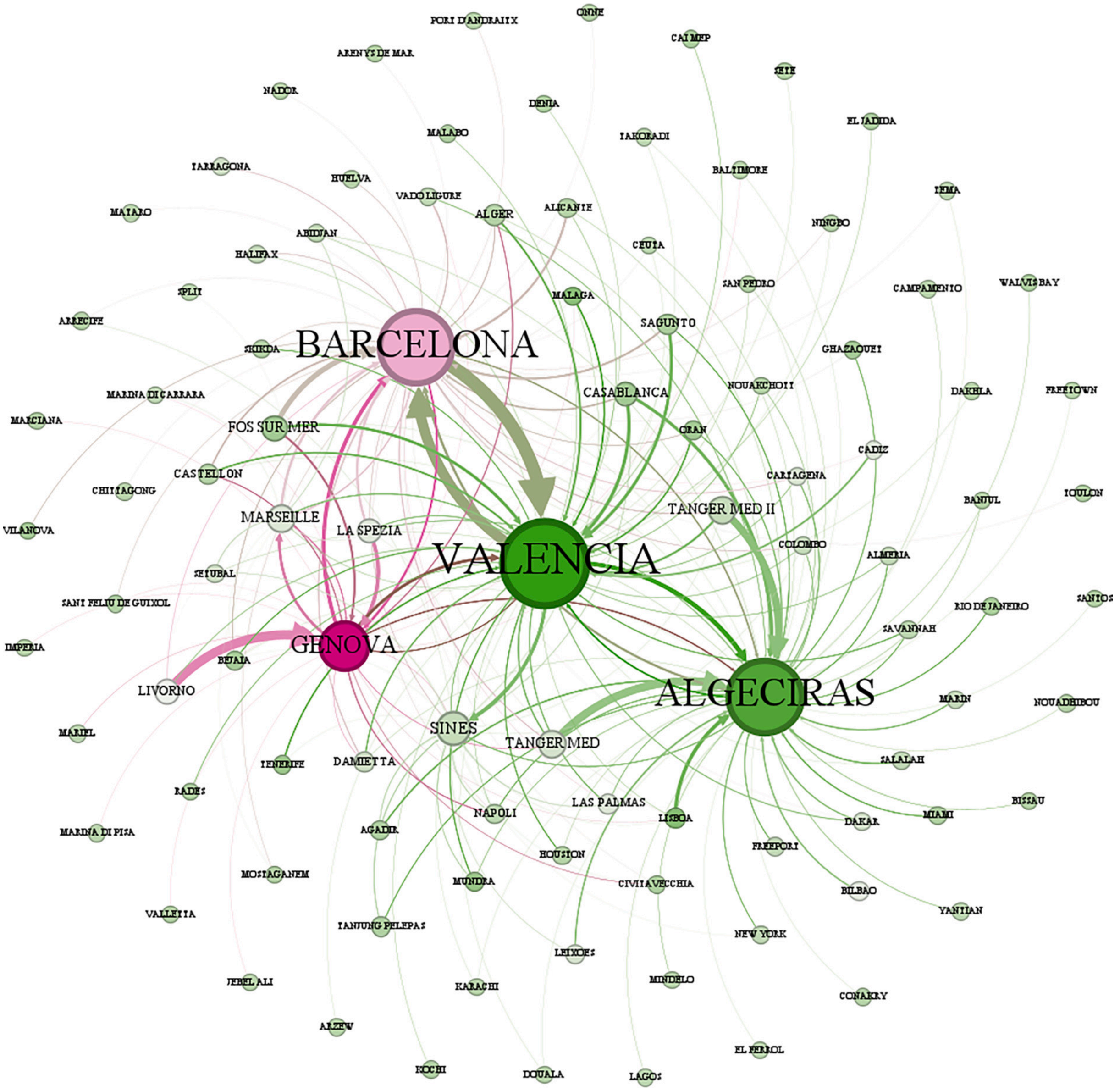


Fig. 10. Community of Western Mediterranean ports (June 2023–2024).
Legend: Color coding according to weighted degree variation Jun 2024 vs. 2023, with green intensity representing a positive variation and purple intensity a negative variation. Node size according to total weighted degree.

the quality of inland transport connectivity also plays a role. This is the case of the Madrid region, as shown in Fig. 11. Although Madrid is farther from Barcelona than from Valencia, the hinterland rail and road connectivity from both ports makes it a more contested region compared to the regions of Castilla-La Mancha and Murcia, which appear in dark red in Fig. 11**.** In line with the findings of Garcia-Alonso et al. (2019) on Spanish contested port hinterlands, this helps explain why Barcelona's relative cost disadvantage is less pronounced than Valencia's when serving Madrid.

Second, since hinterland connectivity within the Iberian Peninsula remains unaffected by the Red Sea disruption, there is little reason to expect a significant shift in inland distribution patterns, despite increased maritime transport costs due to rerouting via the Cape of Good Hope. In fact, the results confirm that Valencia continues to hold a strategic advantage in serving Spain's economically dynamic regions, most notably the region comprising Madrid. This cost advantage reinforces Valencia's role as a major gateway port, in line with the connectivity patterns observed during the second interval of the network analysis (January to March 2024), when Valencia experienced a notable increase in direct port calls compared to other ports in its community.

4.2.2. Impact on transshipment ports

Nonetheless, it is very likely that such an increase in connectivity is associated with transshipment cargo rather than influencing hinterland flows. The second case study further examines the competitive positioning of transshipment ports. This case study evaluates a scenario in which transshipment operations are conducted using a larger 24,000 TEU vessel, with Mediterranean ports subsequently served by a feeder vessel with a capacity of 3,600 TEU. The results, presented in Fig. 12, indicate that using the Port of Valencia as the transshipment hub provides a cost advantage of up to 13.0 % (€454 per TEU) relative to Tanger Med for connections with the ports of Marseille and Genoa, in reaching hinterland regions in Southeastern France, Northern Italy, and the Alpine region.

Considering that in both cases the vessel passes by the Cape of Good Hope instead of crossing the Suez Canal, the results suggest that the cost

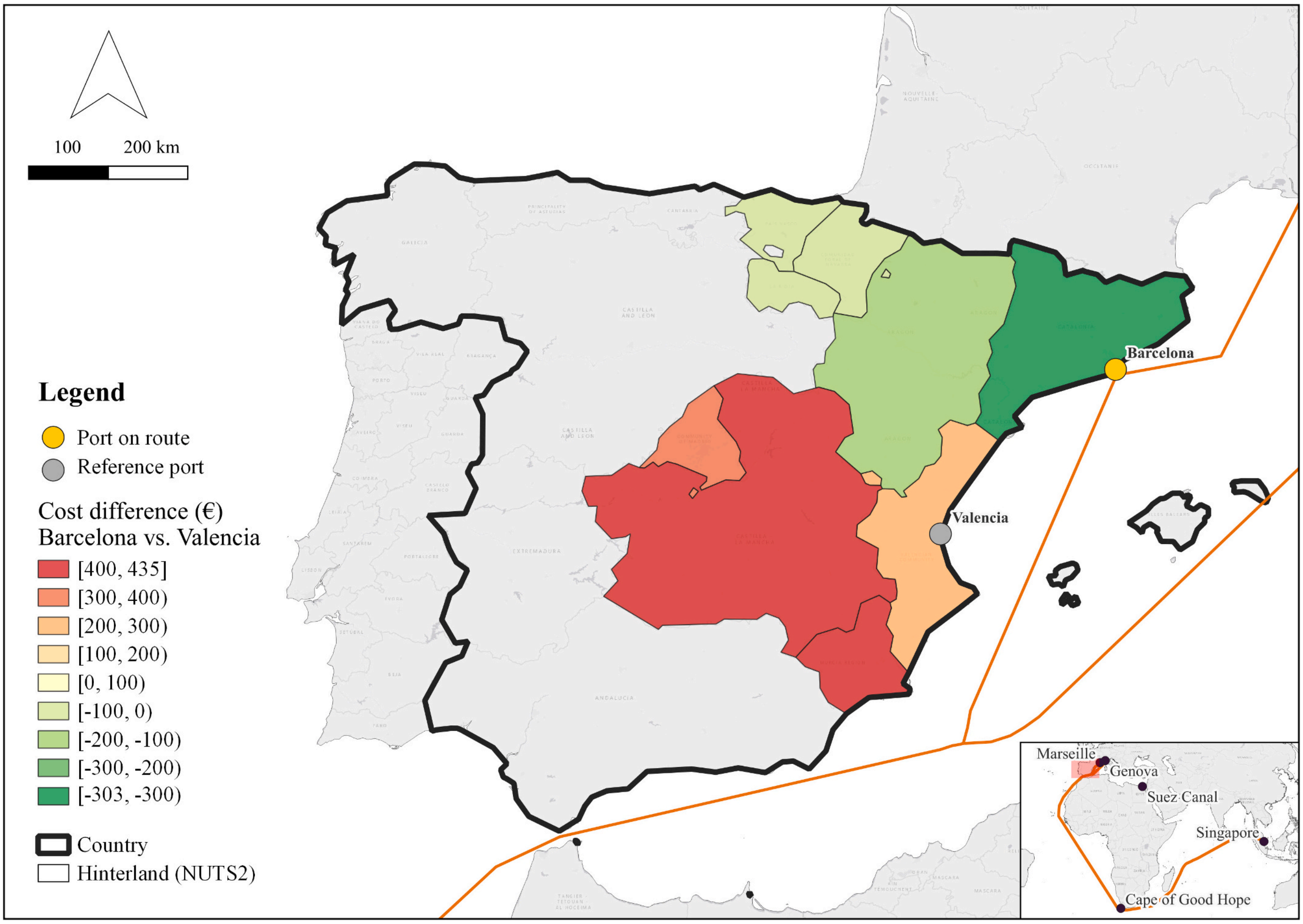


Fig. 11. Cost comparative advantage of Port of Barcelona vs. Port of Valencia.

advantage observed is primarily driven by differences in the port call costs and subsequent feeder legs (purple segment in Fig. 12), rather than the mainline vessel's route. In the case examined, the mainline vessel departs from Singapore, rounds the Cape of Good Hope, and continues on to the North Sea after transshipment occurs in Valencia or Tanger Med. This means that the overall distance and cost for the mainline segment remain relatively similar across both options. Regarding the decisive factors, the results align with the study by Arvis et al. (2019), suggesting that Valencia holds a more favorable position in this respect, offering shorter feeder distances, more frequent services, and better integration into the regional logistics network. These factors translate into lower feeder leg costs and greater connectivity advantages that ultimately drive the cost differences highlighted in the figure. Other factors that could be explaining the comparative advantage of Valencia are further discussed in the following section.

5. Discussion

This study builds on Yap and Yang (2024) Structure–Conduct–Performance (SCP) framework by introducing a spatial-network perspective. While their work emphasizes how shipping lines adjusted service deployment in response to the Red Sea disruption, we explored how these strategic choices have been reflected in port hierarchies across Europe's maritime network. Using modularity and connectivity metrics, this study showed that the crisis reinforced the dominance of Western Mediterranean ports like Valencia and Algeciras, while rendering Eastern Mediterranean ports such as Marsaxlokk and Piraeus increasingly peripheral. The subsequent cost simulations quantify the economic impact of these network changes, confirming that increasing centrality can lead to lower transport costs, relative to competing routes, due to greater service capabilities, taking into account both maritime and hinterland connectivity. This not only supports the argument that maritime container networks are highly dynamic but also shows that strategic shifts in port roles have measurable economic consequences. By linking network dynamics with cost structures, this study contributes to the literature on maritime connectivity, port competitiveness, and resilience during global shocks.

Regarding spatial dynamics, the results of this study underscore the importance of geographical positioning in shaping the comparative advantage of ports within the European maritime network, as evidenced by the connectivity shifts observed between port communities since the onset of the Red Sea crisis. Proximity to strategic chokepoints such as the Suez Canal and the Strait of Gibraltar plays a fundamental role in explaining the evolving structure of the network. Specifically, the findings reveal a clear link between a port's location and the extent of connectivity changes during the disruption, with more pronounced negative effects experienced by ports in the Eastern Mediterranean. While this outcome was anticipated, given the increasing peripherality of Eastern ports relative to their Western counterparts, the results offer deeper insights into how such network reconfigurations can impact transport costs within port communities.

Particularly, intracommunity dynamics reveal that the crisis's impact within port clusters follows a hub-and-spoke logic. During the first phase of the analysis (June 2023–January 2024), major hub ports within each community showed greater resilience, and some even experienced gains in connectivity. By the second phase (January–March

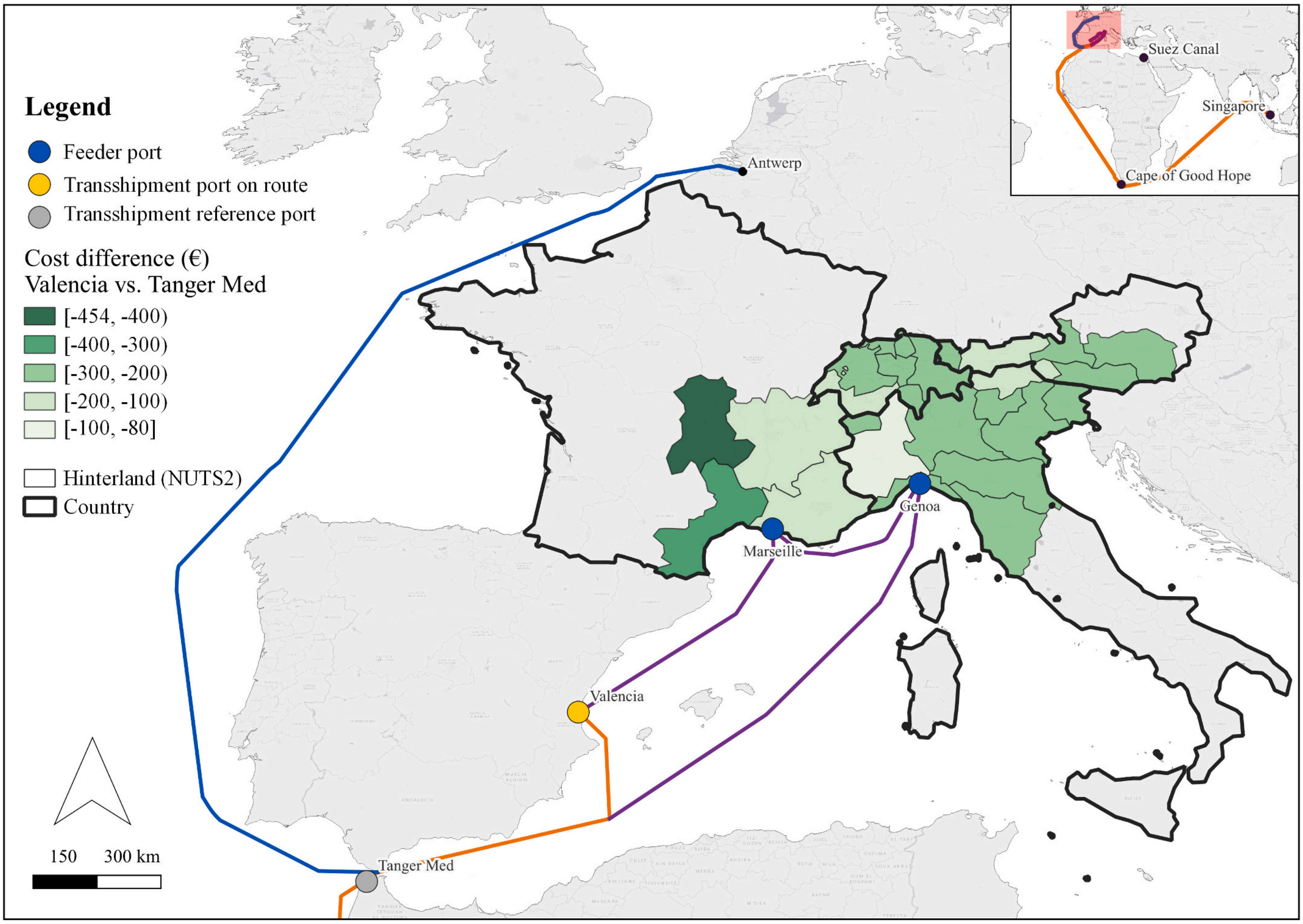


Fig. 12. Transshipment at Port of Valencia vs. Tanger Med.

2024), maritime traffic became increasingly concentrated in hub ports, such as Valencia and Piraeus, while some feeder and smaller ports, including Marsaxlokk and Barcelona, saw their connectivity deteriorate. Then, the two case studies assessed showed how these changes ca be reflected in transport costs variations. Ports that gained connectivity with increased service frequency and more direct connections are also likely to have lower average cost per TEU relative to other competing ports. Conversely, smaller ports faced higher expected costs due to declining service frequency and greater reliance on feeder services.

The second case study showed the extent to which cost disparities can influence transshipment competing connections. Ports that reinforced their hub status within the communities can strengthen their competitive advantage relative to competing alternatives, despite longer mainline distances via the Cape of Good Hope. This can largely be explained due to central network positioning, being strategic to reach other ports in the community with shorter maritime routes, cutting sailing times and fuel costs. These findings highlight the notion that transport costs are influenced not just by geography, but also by the structural function a port fulfills in the network, i.e., whether it is a hub or feeder node.

Several additional factors can contribute to the cost advantages observed for the port of Valencia. As an EU port, it can benefit from regulatory harmonization and customs simplifications, avoiding the delays and barriers encountered at non-EU ports like Tanger Med. Operational efficiency and integration with inland transport networks to main economic centers (e.g., Madrid) remain among its main advantages, as previously noted by Arvis et al. (2019) and Garcia-Alonso et al. (2019). Valencia's reliability and reduced transit times also make it an attractive choice for time-sensitive cargo, particularly for reaching other European gateway ports (Martinez-Moya et al., 2024; Martínez-Moya and Feo-Valero, 2020). These combined advantages help explain the broad cost savings identified in the impact analysis.

Port throughput data published by Notteboom (PortEconomics, 2024) for the first half of 2024 aligns with the findings of this study. Both the connectivity metrics and observed TEU growth suggest gains for Valencia, Algeciras, and Sines. Meanwhile, Piraeus suffered significant throughput losses, consistent with reduced Suez Canal transits. Our network analysis suggests that volume changes could be linked to the observed 30.1 % year-on-year drop in the average capacity of vessels calling at this port by June 2024, as it became more peripheral in the EU maritime network relative to Western Mediterranean ports.

In a scenario where the Red Sea passage is normalized, the results here also suggest that the maritime network can show notable signs of recovery. By the third analysis interval (March–June 2024), a period marked by easing geopolitical tensions, the structure of the network began reverting to its pre-crisis configuration observed in June 2023. This signals a degree of resilience in European maritime connections, with the potential to rebound within a timeframe similar to the disruption period itself.

This study points to several avenues for future research. One question is whether the observed shifts in connectivity have accelerated the development or adoption of alternative transport routes. If the Red Sea crisis continues, rerouting via overland rail corridors (e.g., the China–Europe route) or Arctic Sea lanes may become increasingly attractive. Meersman et al. (2021) suggest that the viability of the China–Europe rail connection depends on factors such as transport costs, cargo characteristics, and trade imbalances. The recent interview study by Rentschler et al. (2025) reveals that beyond logistics, the Trans-Caspian Corridor functions as a geopolitical instrument, with China, Kazakhstan, the EU, and Turkey leveraging it to reshape regional influence and reduce dependence on maritime routes. Similarly, Pruyn and van Hassel (2022) argue that the Arctic route could become a competitive alternative for time-sensitive cargo, although its long-term potential hinges on overcoming environmental, geopolitical, and reliability challenges, as noted by Rovenskaya et al. (2024).

Building on the results presented here, future research can also examine how continued shifts in connectivity affect maritime emissions and environmental outcomes. Pseftogkas et al. (2024) provide clear evidence that rerouting via the Cape of Good Hope has led to a 55 % decrease in NO_2 emissions over the Red Sea and a 40 % increase off South Africa's coast, underscoring how rerouting not only changes traffic flows but redistributes emissions geographically. This resonates with our findings on the growing centrality of Western Mediterranean ports, which could be assessed not only for cost advantages but also for incurred externalities, such as higher traffic congestion and emissions.

For instance, considering the first week of June 2024, we observe a 2 % increase in the median time vessels spent at the 15 European ports of our study compared to the same week in 2023. When excluding Hamburg—an atypical case due to vessel arrival delays, construction works, and high yard utilization during May and June 2023 (Kuehne-Nagel, 2024)—the year-on-year increase in time spent was 11 %. Regarding changes in emissions, Bouman et al. (2017) offer a valuable review framework for measures dealing with the carbon footprint of shipping networks. Future research could integrate emissions-per-TEU indicators with evolving maritime routes to model how changes in network structure affect the carbon intensity of services, particularly in hub ports experiencing increased vessel calls, and provide insights for its mitigation.

Several limitations of this study must be acknowledged. First, while the simulation captures the total capacity of each port, it does not account for evolving capacity constraints at ports during the months of the disruption, which could influence competitive positioning and port choice under uncertain conditions. Second, the cost model relies on fixed parameters (e.g., value of time) and does not fully account for dynamic shifts in transport behavior or market conditions. Third, the analysis is limited to container flows, though similar methodologies could be extended to other segments such as bulk or RoRo. Fourth, our framework does not consider concurrent structural shifts, such as the EU's Emissions Trading System or Brexit, that could influence routing and port preferences. Lastly, the analysis does not project the evolution of connectivity metrics beyond June 2024, leaving room for further research to examine long-term impacts.

To address these limitations, future studies on maritime disruptions can enhance methodological precision, as suggested by Niérat (2022). Cost models should evolve beyond aggregate metrics and integrate detailed representations of hinterland dynamics, including pre- and post-haulage costs, transshipment handling, and spatial dispersion. Behavioral elements, such as the strategic choices of carriers, port authorities, and shippers, can be embedded to better reflect real-world decision-making under uncertainty. Additionally, scenario-based sensitivity analyses could improve robustness in the face of evolving geopolitical risks and market volatility. These refinements would generate more accurate estimates of port competitiveness and provide further guidance for policymakers and infrastructure planners navigating future crises in global maritime trade.

6. Conclusions

This paper examined how the Red Sea crisis altered the European maritime network and reshaped port competitiveness, with a particular focus on Western Mediterranean ports. By combining network analysis with transport chain cost simulations, it assessed medium-term impacts of rerouting via the Cape of Good Hope during the first half of 2024.

The findings indicate a 4.6 % reduction in the average number of maritime connections and a 12 % decline in average service frequency across Europe, with Eastern Mediterranean ports such as Marsaxlokk and Piraeus experiencing the sharpest connectivity losses. In contrast, Western Mediterranean ports, particularly Valencia and Algeciras, gained prominence as major hubs, improving both their network centrality and their cost-competitive positioning. These results reinforce the notion that ports close to the Strait of Gibraltar benefited from the network reconfigurations, while those reliant on the Suez Canal became increasingly peripheral.

From a cost perspective, the study reveals that rerouting via the Cape of Good Hope led to generalized expected increases in transport costs between 3 % and 13 %, depending on the port and service structure. Specifically, Genoa experienced the largest expected cost increases up to 6 % for specific direct Asia-Europe routes, reflecting both longer sailing distances and reduced service frequency. In the Iberian Peninsula, Valencia continued outperforming Barcelona in cost competitiveness across most inland regions, except for parts of northern Spain. In transshipment scenarios, Valencia also showed an advantage over Tanger Med, offering a 13 % cost differential for feeder services to Southeast France and Northern Italy, which could be partially attributed to its central positioning in the maritime network relative to competing routes.

These results complement and extend the short-term observations of recent studies, which documented early strategic shifts by major shipping alliances in response to the crisis. While previous research focused on service deployment, this study quantifies the economic outcomes of those strategic choices, confirming that enhanced port connectivity can lead to tangible cost advantages over competing alternatives. Similarly, whereas existing literature focused on the environmental risks of rerouting, such as increased emissions and carbon leakage, our findings emphasize the economic trade-offs, highlighting how specific Western Mediterranean ports gained competitive ground in connectivity and relative cost efficiency, factors that can influence long-term port choice decisions.

This paper contributes to the literature on maritime connectivity by empirically linking network shifts with transport cost dynamics, offering a multidimensional view of port competitiveness during a sustained disruption. It also highlights the importance of considering both network structure and spatial cost differentials when planning resilient supply chains amid a highly uncertain global context.

CRediT authorship contribution statement

Felipe Bedoya-Maya: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Joris Beckers:** Methodology, Validation, Writing – review & editing, Visualization, Supervision. **Jeroen Cant:** Conceptualization, Methodology, Validation, Writing – review & editing, Visualization, Supervision. **Julián Martínez-Moya:** Validation, Resources, Writing – review & editing, Supervision, Funding acquisition. **Edwin van Hassel:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Thierry Vanelslander:** Conceptualization, Validation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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Appendix A. Appendix

A.1. Year-over-year connectivity variations in June 2024

Region	Port	Change (%)	
		Degree	Weighted Degree
Western Mediterranean	Algeciras (ES)†	17.9	8.2
	Barcelona (ES)*†	4.5	−9.8
	Genoa (IT)*	−3.8	−29.9
	Marseille (FR)*	−7.1	−14.8
	Sines (PT)†	18.5	−3.1
	Valencia (ES)*†	18.5	8.4
Eastern Mediterranean	Gioia Tauro (IT)†	4.8	−3.8
	Marsaxlokk (MT)†	−8.9	−14.1
	Piraeus (GR)†	−8.6	−7.1
Hamburg-Le Havre	Antwerp (BE)*†	−1.7	−9.6
	Bremerhaven (DE)*	4.3	0.6
	Gdansk (PL)*	−31.6	−22.6
	Hamburg (DE)*	8.3	−1.5
	Le Havre (FR)*	10.7	−10.3
	Rotterdam (NL)*†	14.1	−6.1

Note: (*) Gateway port, (†) Transshipment port, (*†) Mixed port.

Data availability

The authors do not have permission to share data.

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