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Smart & Resilient Logistics Corridors Future Gateway to the Green Trade

A MULTIDIMENSIONAL ASSESSMENT OF FRANCE'S VULNERABILITY TO MARITIME TRADE

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ABSTRACT

Recent disruptions, including the COVID-19 pandemic, security incidents in the Red Sea, and water shortages in the Panama Canal have revealed how dependent are countries and industries on maritime shipping routes. Yet systematic, data-driven assessments of national vulnerability to maritime disruptions remain limited. This study develops a multidimensional conceptual and empirical framework for assessing maritime trade vulnerability. It distinguishes three complementary dimensions captured by a Logistics Exposure Index (LEI), a Commercial Exposure Index (CEI), and a Cost-Value Sensitivity Index (CVSI) respectively. These indicators are integrated into a composite Maritime Supply-Chain Vulnerability Index (MSCVI) which summarizes the structural fragility of a country to maritime trade networks. Using a dataset for France comprising information on more than 826,790 trade flows for 93 products from 2016 to 2021, the analysis reveals that maritime vulnerability is widespread but uneven: roughly half of the 93 products imported and exported fall within high or critical vulnerability categories. Manufactured goods, ores, works of art, and live animals show particularly elevated risk due to overlapping exposure channels.

1. INTRODUCTION

Maritime transport underpins approximately 80 per cent of global trade, making it a central component of international commerce and economic interdependence (UNCTAD, 2024). Consequently, large-scale disruptions in maritime networks can generate cascading effects across global supply chains. In recent years, extreme weather, global pandemics and geopolitical risks have shed light on the critical role of port congestions and chokepoints in global supply chains (Arvis et al., 2024; Kiyota, 2022; Steinbach, 2022, UNCTAD 2025). A key driver of this vulnerability lies in the spatial concentration of maritime trade along a limited number of shipping routes and at vulnerable chokepoints such as ports and canals. This vulnerability can then easily translate into a sovereign risk, as exposure to external shocks can threaten a nation's trade continuity and strategic autonomy.

However, the extent to which a given country or a specific industry dependent on and is vulnerable to maritime transport is generally unknown. In this article, we develop a framework that provides a transparent and replicable basis for assessing maritime supply chain vulnerability, thereby supporting the identification of structural weaknesses. Using detailed UNCTAD-World Bank trade data Hub, the framework is applied to France as a case study, for which we estimate sectoral indicators of logistical and commercial dependency and then, cost-to-value vulnerability. These dimensions are subsequently

integrated into a composite Maritime Supply-Chain Vulnerability Index (MSCVI), which provides a comprehensive, product-level measure of structural vulnerability to maritime transport disruptions.

Our main finding is that vulnerability to maritime transport is multidimensional, heterogeneous, and structurally embedded. Vulnerability do not arise from a single source but from the interaction of distinct dependency and exposure mechanisms, logistical, commercial, and cost-related. The results indicate that vulnerability is widespread in incidence but concentrated in intensity: more than half of the 93 analyzed products fall within the high or critical vulnerability categories. This pattern indicates that France's vulnerability is not solely driven by exceptional shocks but rather reflects enduring structural features of its trade specialization and its position within global maritime networks.

The remainder of this paper is structured as follows: Section 2 provides a literature review of the main sources of vulnerability to maritime transportation. Section 3 presents our methodology and indicators for assessing the vulnerability of a country to maritime trade. Section 4 discusses the dataset we will use to assess France's vulnerability to maritime trade and some preliminary statistics. Section 5 discusses our results and provides our conclusions.

2. LITERATURE REVIEW, RESEARCH GAP AND CONTRIBUTIONS

The analysis of supply chain vulnerabilities has evolved from traditional supply chain risk management to more sophisticated multi-dimensional frameworks. Christopher and Peck (2004) seminal work on vulnerability provides a comprehensive conceptual framework that intersects five vulnerability dimensions: Complexity, Concentration, Connectivity, Control, and Cohesion, with four primary risk categories: supply-side, demand-side, environmental, and network risks. This framework proves particularly relevant to assess countries' vulnerability to maritime applications, where four interrelated sources of vulnerability exist: supply-side operational risks, geopolitical and demand-side risks, environmental risks, and network-structure risks.

Supply-Side Vulnerabilities and maritime-centric disruptions encompass equipment failures, labor disputes and regulatory changes that directly impact port operations and shipping capacity. For instance, the literature extensively documents how port disruptions cascade through national economies, affecting both input deliveries for production and final goods distribution to end-users (Arnold et al., 2006; Wei et al., 2020; Cariou and Notteboom, 2023). Empirical evidence demonstrates the national vulnerability to port disruptions. For instance, Park et al.'s (2008) examination of the 2002 Los Angeles/Long Beach strike shows that economic losses concentrate in specific regions despite coast-wide disruptions. Rose and Wei's (2013) investigation of a hypothetical 90-day disruption at Texas ports demonstrates how proximity to alternative facilities can mitigate impacts, contrasting sharply with Wei et al.'s (2020) projection that a one-year disruption at Los Angeles/Long Beach would generate $569 billion in national GDP losses. In a recent assessment of Germany' vulnerability, Bodenschatz et al. (2025) showed for instance that around 90 per cent of German trade is channeled through maritime hubs that are often located near strategic chokepoints. Using satellite data for container shipping routes from Ganapati et al. (2024), the report shows that in 2023, approximately 9.8 percent of German imports passed through the Suez Canal, making it the most critical chokepoint. Other key chokepoints are also critical for German trade, such as the Strait of Malacca (8.7 percent of imports), the Strait of Bab El-Mandeb (9.4 percent of imports) or the Strait of Taiwan (7.1 percent). One key result is on the product-level heterogeneity of these dependencies. As an example,

roughly 97 percent of all German imports of crude oil or 30 percent of all German imports of printed circuits pass through the Suez Canal and 92 percent of all German imports of herbicide is reliant on the Strait of Taiwan. Similar reliance on maritime chokepoint was found in Balley and Wellesley (2017) when studying Global trade foods. They also highlight that some chokepoints will come under more pressures in the future, such as wheat exports from the Black Sea region that overly depend on the Turkish Straits.

Geopolitical and Demand-Side Risks such as armed conflicts, sanctions, and diplomatic tensions have also reshaped global trade patterns and challenge national supply security (Roscoe et al., 2022; Li et al., 2025). Modern geopolitical risk extends beyond traditional warfare to include trade disputes, economic sanctions, and diplomatic restrictions that can effectively weaponize maritime dependencies (Yang et al., 2025). Caldara and Iacoviello's (2022) quantification of geopolitical risk revealed how political tensions translate into measurable economic disruptions, affecting firm-level decisions on cash holdings and investment while increasing financial market volatility. The maritime sector is particularly sensitive due to the international nature of shipping routes and the concentration of critical chokepoints under specific national jurisdictions. Recent analyses of the Red Sea crisis (Yap and Yang, 2024; Yang et al., 2025) demonstrate how geopolitical tensions force carriers to adjust schedules, implement rerouting strategies, and skip ports entirely, fundamentally altering global shipping patterns. These adjustments impose significant costs on importing nations, particularly those with limited alternative routes.

Environmental Risks and Climate-Induced Vulnerabilities represent an increasingly critical dimension of maritime vulnerability, extending beyond immediate infrastructure damage to encompass operational disruptions that affect global supply chain reliability. Due to climate change, and in particular rising sea levels, physical damages and operational downtime may increase considerably (Verschuur and Beker 2025; Verschuur et al. 2023) For instance, historical analyses of hurricane impact also demonstrate lasting effects on trade patterns of Hurricane Matthew revealing how port-specific vulnerabilities depend on layout, traffic volume, and operational efficiency (Touzinsky et al. 2018). Friedt's (2021) longitudinal analysis of Hurricane Katrina's effects shows how environmental disruptions can permanently alter trade flows, with rerouting effects persisting for eight years and fundamentally restructuring regional economic relationships. Redekar et al. (2025) also identifying how increasing frequency of extreme weather events, rising sea levels, and temperature fluctuations compound traditional supply chain vulnerabilities. These environmental transformations require nations to reassess their maritime dependencies and develop adaptive strategies.

Network Structure and Systemic Vulnerabilities have been stressed through network-based approaches that treat ports as nodes and shipping routes as edges, utilizing centrality measures to identify critical infrastructure (Rousset and Ducruet, 2020). Recent empirical applications have shown how specific disruptive events propagate through maritime systems. Feyrer's (2021) analysis of the Suez Canal closure (1967-1975) provides historical perspective on chokepoint vulnerabilities, while Rousset and Ducruet's (2020) examination of 9/11 impacts to reveal how security shocks undermine ports' positions within shipping networks. Contemporary studies of the Russia-Ukraine conflict (Xiao et al., 2024; Lyu et al. (2025) and Red Sea crisis provide high-frequency evidence of how carriers adjust to geopolitical threats through schedule modifications, rerouting, and port skipping strategies. These network-level analyses reveal how seemingly minor nodes can lead to high vulnerability scores due to their strategic location, while major hubs may demonstrate greater resilience through alternative routing options.

Although recent studies have significantly advanced our understanding of maritime risks and vulnerability, existing studies have assumed that the impact of maritime-related vulnerability is similar for all products, given that 80% of international trade is imported via maritime transport. However, there is still a research gap as the share of imports transported by sea is insufficient to fully consider countries' vulnerability. Firstly, vulnerability can be expressed through alternative metrics, such as import value or transport costs as a percentage of import or export commodity prices. Secondly, although a large proportion of trade is carried out by sea, the existence of alternative maritime sourcing means that a country may not be automatically vulnerable to a specific disruption. In practical terms, this means that, for example, although countries A and B might both rely on maritime transport for 80% of their imports, the fact that country A imports from 10 different countries while country B imports from a single source leads to different conclusions in terms of vulnerability to maritime transport.

We address these limitations in developing a multidimensional conceptual and empirical framework that links maritime dependency, exposure, and vulnerability within a unified analytical structure. It makes three principal contributions. *Our methodological contribution* is to introduce a transparent and replicable measurement approach based on harmonized trade and transport data, enabling comparative assessment of maritime dependency and exposure and their aggregation into a composite vulnerability index at the product level. *Our empirical contribution* is in applying our method to France, using a large data on import and export flows between 2016 and 2021 and for 93 different products. We provide the first product-level mapping of maritime trade vulnerability for a major economy, revealing structural patterns of dependency and exposure and identifying priority areas for targeted resilience strategies.

3. CONCEPTUAL FRAMEWORK AND INDICATORS

Conceptually, we extend Christopher and Peck's (2004) model of supply-chain vulnerability, in adding three structural dimensions: concentration (through partner-dependence measures), connectivity/dependency (through maritime reliance), and control (reflected indirectly through exposure measures that reveal the limits of diversification and adaptive capacity). Figure 1 presents the conceptual logic of our approach. The dependency layer quantifies the extent to which a country's trade depends on maritime route and on maritime trading partners (e.g., maritime share and partner concentration). The exposure layer identifies three sources of exposures that can be logistical exposure, commercial exposure, and cost-value related exposure. The vulnerability layer aggregates these exposures into a composite measure reflecting the overall structural fragility of the trade system. This three- tier design moves beyond event-based assessments toward a systemic representation of maritime risk, emphasizing how dependency channels into exposure and culminates in vulnerability.

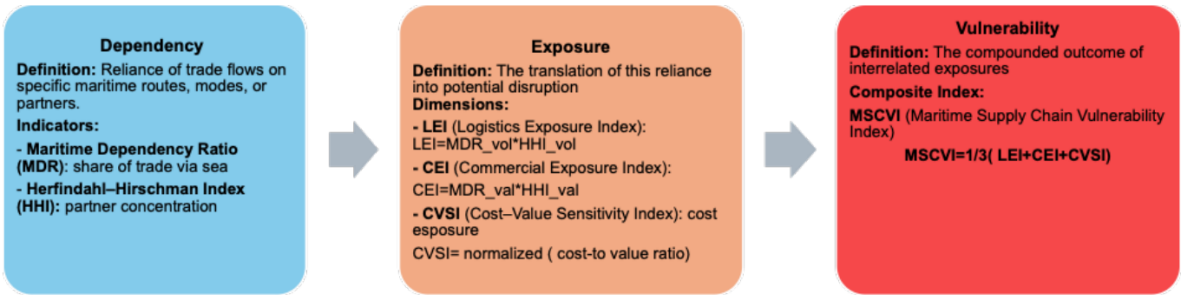

Figure 1: Conceptual framework linking maritime dependency, exposure, and vulnerability. Source: Authors.

Our framework thus offers a unified structure for assessing how dependency translates into exposure and, in turn, into vulnerability across products and sectors. Low index values denote diversified and resilient configurations with limited reliance on specific maritime corridors or partners, while high values identify sectors where concentrated flows and elevated cost sensitivity jointly heighten the potential for disruption. Our methodological approach then translates into measurable indicators on dependency, exposure and vulnerability.

Dependency indicators relate to maritime dependency and market concentration are captured through two complementary indicators. The first indicator relates to the Maritime Dependency Ratio (MDR) which corresponds to the share of maritime trade out of total trade, total import and total exports such that MDR = $\frac{Trade_{maritime}}{Trade_{Total}}$. It is calculated separately by volume (MDRvol) and value (MDRval) to differentiate between physical shipment dependency and commercial dependency. The second indicator is the degree of concentration amongst partners either for import or export which is assessed in using a standard measure, the Herfindahl-Hirschman Index (HHI), such that HHI = $j\sum(s_{ij})^2$, where s_{ij} is the share of partner j in the total trade of product i. High values indicate concentrated trade flows and limited diversification; low values reflect broader partner networks. When HHI equal to 1, it means that one trading partner represents 100% of trade. These two initial indicators are then used to construct the multidimensional exposure indices described below.

Building on the dependency indicators, three indices quantify the ***exposure dimensions***, defined as follows.

- ***Logistics Exposure Index (LEI)*** = MDRvol × HHIvol: captures logistical exposure in physical (volume) terms, resulting from maritime dependency and partner concentration.
- ***Commercial Exposure Index (CEI)*** = MDRval × HHIval. captures commercial exposure in economic (value) terms, resulting from maritime dependency and partner concentration.
- ***Cost-to-Value Sensitivity Index (CVSI)*** = Transport Expenditure / FOB value , this index captures relative cost exposure, showing how freight costs compare to product value and is normalized from 0 to 1.

Finally, the ***Maritime Supply Chain Vulnerability Index (MSCVI)*** integrates the indices of logistical, commercial, and cost-related exposure, captured respectively by LEI, CEI, and CVSI, into a unified indicator of structural vulnerability. This composite index assumes equal weighting among them, on the grounds that each represents a distinct yet equally relevant mechanism of vulnerability.

- ***Maritime Supply Chain Vulnerability Index (MSCVI)*** = ⅓ x (LEI + CEI + CSI).

To facilitate the interpretation of results, the global MSCVI scores were grouped into four qualitative categories reflecting increasing degrees of vulnerability.

MSCVI Range	*Vulnerability Level*	*Description*
MSCVI < 0.2	Low	Diversified trade structure with limited vulnerability
0.2 ≤ MSCVI < 0.4	Moderate	Dependency is evident in one dimension (selective and manageable)
0.4 ≤ MSCVI < 0.6	High	Significant dependency may arise from supply-chain bottlenecks or cost shocks
MSCVI ≥ 0.6	Critical	Severe, multi-dimensional vulnerability i.e. systemic exposure

4. DATASET AND PRELIMINARY FINDINGS

The dataset we used is publicly available from UNCTAD data Hub[c]. It records international trade, in values and volumes, alongside the transport expenditure and transport work incurred for its transport, by pair of trading partners, commodity and mode of transport, annually, from 2016 to 2021. The dataset Trade-and-Transport dataset has been developed jointly by UNCTAD and the World Bank. It uses as main sources UN Comtrade and a transport network model based on geographic information systems developed by Equitable Maritime Consulting (Halim et al., 2018). The Trade-and-Transport dataset is a methodologically enhanced and extended version of the Global Transport Costs Dataset for International Trade (Hoffmeister, et al. 2022). The dataset displays the trade and related transport from 237 economies of origin to 170 economies of destination. These data are broken down by commodity group at the level of headings (4-digit codes) of the Harmonized System classification (2017 revision) and by mode of transport, differentiating between air, sea, rail, road, and others. Statistics are provided for each product-trade on the FOB value (in USD), volume (in kg), unit value (USD/kg), Transport expenditure (CIF - FOB value in USD), transport work in vlaue (in 1000 USD/km), transport work in volume (in 1000 USD/ton), ad-valorem freight rate (Transport Expenditure/FOB value in USD) and Per-unit freight (US$/kg). We only selected data on France's imports and exports.

In total, there are 2,037,680 bilateral flows (across all modes of transport), of which 1,211,562 are exports (59.5%) and 826,118 are imports (40.6%). Of these flows, 40.6% are maritime, comprising 59.9% exports and 40.1% imports. The average annual import volume is 186 million tons, while the export volume is 74 million tons. The top 3 maritime products exported in volume are Iron and Steel (approximatively 15 million per year), Mineral fuels (also 15 million) and Beverages and spirits (4.5 million). For imports, the top 3 products are Mineral fuels (approximatively 108 million per year), Iron and Steel (10.3 million) and Ore (9.5 million). In value, Vehicles (29 billion USD per year), Nuclear reactor (16.3 billion) and Beverages and spirits (13 billion) are the top 3 exported products. Mineral fuel (46.6 billion USD), Vehicles (40 billion USD per year), Nuclear reactor (20 billion) are the top 3 imported products.

We first used the statistics from UNCTAD data hub to generate a Maritime Dependency Ratio (MDR), which corresponds to the share of maritime trade out of total trade, total import and total exports (See Figure 2). A first pattern is the dominance of maritime transport, particularly for imports. In volume terms, 64.94% of imports are carried by sea, compared with 48.89% of exports. In value terms, maritime dependency is lower but remains significant, with both imports and exports close to 42%. A second pattern is the importance of road transport, which accounts for 36.41% of export volumes and 26.59% of import volumes. In value terms, the dependency on road is even greater (27.83% exports; 35.64% imports), reflecting the strong role of intra-European trade, confirmed by (Figure 4). A third observation is that rail and air transport play a marginal role in volume terms (<15%), but air is disproportionately important for value. Air dependency accounts for 21.01% of export values and 14.56% of import values, underscoring its role in high-value, low-weight sectors.

[c] https://unctadstat.unctad.org/datacentre/dataviewer/US.TransportCosts

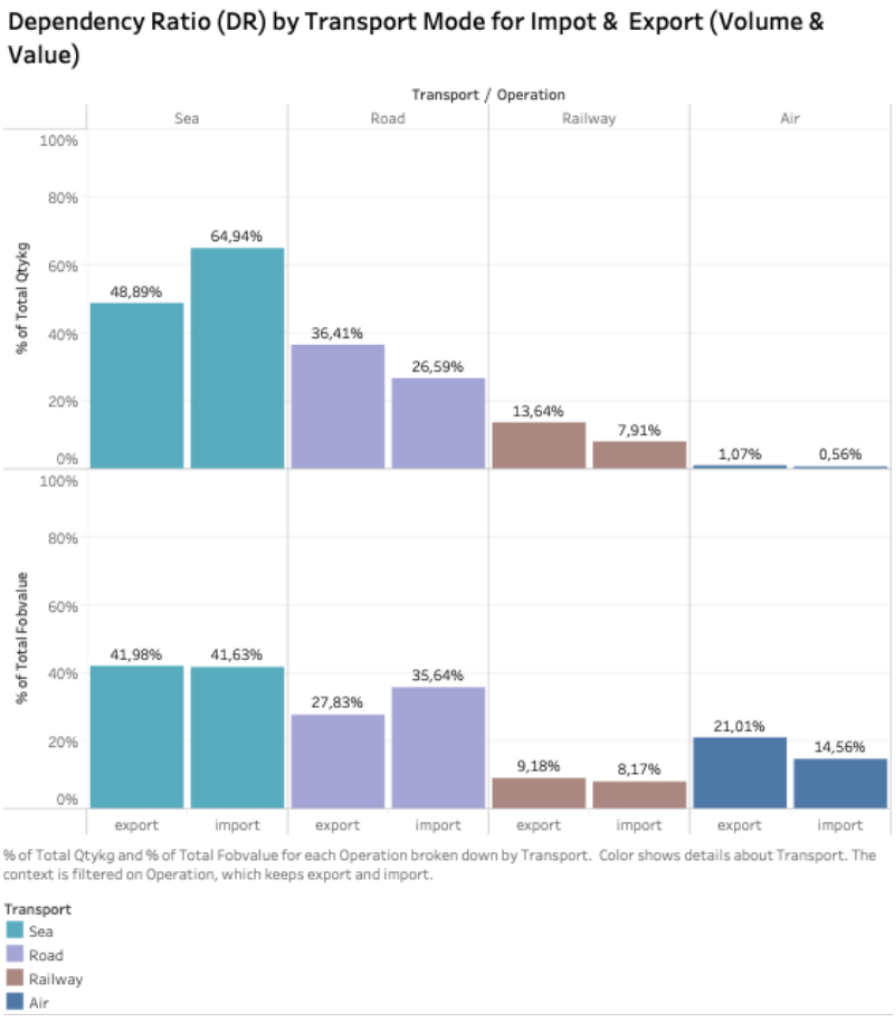

Figure 2: France's Maritime Dependency Ratio, by mode of transport (2016-2021)

5. EXPOSURE AND VULNERABILITY ASSESSMENT

To assess the degree of logistical and commercial exposure, we combined the Logistics Exposure Index (LEI) and the Commercial Exposure Index (CEI) to provide a comprehensive framework for assessing France's trade exposure. Figure 3 presents our estimates for French imports' LEI and for CEI. It shows for instance that Umbrellas are the most exposed products imported by France and are subject to high logistic and commercial exposure. This is explained by a large share of maritime transport in both volume (79.28%) and value (70.8%), combined with a high concentration in a single country of origin, China, which accounts for 59.7% of import volumes and 61.6% of import values.

To classify products according to their exposure level, two thresholds were defined, one for maritime dependency (MDR) and another for partner concentration (HHI). These thresholds were implemented dynamically within the analytical tool (Tableau), allowing sensitivity testing by adjusting the cut-off values in real time. This approach led to the identification of three exposure groups: high exposure (above both thresholds), moderate exposure (above one threshold), and low exposure (below both thresholds). When setting both the maritime dependency (MDR) and partner concentration (HHI). thresholds at 20%, the results indicate that 13 products (13.98% of the total 93) fall within the high logistical exposure category, as measured in terms of volume. Under the

same threshold conditions, 23 products (24.73%) are classified as having high commercial exposure, as measured in terms of value.

Our analysis reveals important differences between logistical and commercial exposure. A first pattern is observed for logistics-driven products, where exposure is primarily linked to physical shipment volumes. For example, Vegetable textile fibers; paper yarn and woven fabrics of paper yarn (Prod. 53, import flows) exhibits high logistical exposure (LEI = 8.81%), driven by a maritime dependency ratio of 34.12% and a partner concentration index of 25.81%. A second pattern concerns commercial-driven products, where exposure is primarily reflected in economic rather than physical terms. Textiles, made-up articles; sets; worn clothing (Prod. 63, import flows) illustrates this case. While the product shows only moderate logistical exposure (LEI = 10.31%), it records high commercial exposure (CEI = 12.69%). This demonstrates that some products may not be physically significant in shipment volumes but remain economically critical in value terms.

Finally, a third group of products exhibits dual exposure, scoring high on both indices. Feathers and down; prepared articles thereof (Prod. 67, import flows) provide a clear example. With a maritime dependency ratio (MDRvol) of 77.22% and a partner concentration index (HHIvol) of 46.30% in volume terms, it records a high logistical exposure index (LEI = 35.75%). At the same time, its commercial indicators also place it in the high commercial exposure category (CEI = 29.28%), driven by strong partner concentration (HHIval = 46.08%) and a high value-based maritime dependency ratio (MDRval = 63.54%). Such products are simultaneously exposed in both logistical and economic dimensions and thus represent the most critical cases of dependency within France's import structure.

The analysis of the Cost-Value Sensitivity Index (CVSI) for import flows reveals marked heterogeneity across products and confirms that cost-value sensitivity is specific rather than systemic. For import, only a limited subset of products exhibits high-cost sensitivity, where maritime transport expenses account for a substantial portion of total trade value. The top four categories are Live animals (Prod. 01), Nickel and articles thereof (Prod. 75), Metals; n.e.c., cermets and articles thereof (Prod. 81), and Musical instruments; parts and accessories of such articles (Prod. 92). For these products, even modest increases in maritime freight rates could significantly erode profit margins or make imports economically unviable. A second group of goods shows moderate cost-value sensitivity, including vegetable plaiting materials (Prod. 14), cork and articles of cork (Prod. 45), furskins and artificial fur; manufactures thereof (Prod. 43), and Works of art; collectors' pieces and antiques (Prod. 97). Although these products are less extreme, they remain exposed to logistics cost pressures that can constrain competitiveness in periods of high freight volatility.

By contrast, a large share of products (75 products, 80.65% of the total 93) cluster near the lower end of the index (CVSI < 3%), indicating that for most import flows, maritime transport costs remain marginal relative to trade value. This asymmetry demonstrates that cost sensitivity is not a general feature of France's imports, but rather a selective source of exposure concentrated in a limited number of product groups. Export flow shows similar overall patterns, though with some differences in sectoral rankings, reflecting the composition of France's trade basket.

Finally, we compute the Maritime Supply Chain Vulnerability Index (MSCVI) that combines the Logistics Exposure Index (LEI), the Commercial Exposure Index (CEI), and the Cost-Value Sensitivity Index (CVSI) into a single composite measure. The distribution of MSCVI values across import products (Figure 5) reveals a strongly right-skewed pattern. A limited group of categories, 9 products, representing 9.68% of the total sample of 93,

exhibit critical vulnerability levels (MSCVI ≥ 0.6). These include "Umbrellas, sun umbrellas, walking-sticks, seat sticks, whips, riding crops; and parts thereof (Prod. 66)", "Works of art; collectors' pieces and antiques (Prod. 97)", "Feathers and down, prepared; and articles made of feather or of down; artificial flowers; articles of human hair (Prod. 67)", "Manufactures of straw, esparto or other plaiting materials; basketware and wickerwork (Prod. 46)" and "Live animals (Prod. 01)". For export products (Figure 12), a smaller subset, 3 products (3.23%), also display critical vulnerability (MSCVI ≥ 0.6). These include "Works of art; collectors' pieces and antiques (Prod. 97)", "Live animals (Prod. 01)" and "Vegetable textile fibres; paper yarn and woven fabrics of paper yarn (Prod. 53)". These products combine strong maritime reliance with highly concentrated partner structures, often reinforced by elevated cost-value sensitivity, making them particularly exposed to disruptions in maritime transport systems.

Figure 3: French Logistics and Commercial exposure Indices for French Imports

A broader group of 43 import products (46.24% of the total) fall within the high vulnerability range (0.4 ≤ MSCVI < 0.6). Representative examples include "Articles of leather; saddlery and harness; travel goods, handbags and similar containers; articles of

animal gut (other than silk-worm gut) (Prod. 42)", "Clocks and watches and parts thereof (Prod. 91)", and "Photographic or cinematographic goods (Prod. 37)". For exports, a similar share of 43 products (46.24%) also falls within the high vulnerability range (0.4 ≤ MSCVI < 0.6), including "Furskins and artificial fur; manufactures thereof (Prod. 43)", "Oil seeds and oleaginous fruits (Prod. 12)" and "Zinc and articles thereof (Prod. 79)". This pattern highlights the MSCVI's ability to detect partial yet significant weaknesses within France's trade structure. Meanwhile, a significant share of import flows (41 products, 44.09%) and export flows (47 products, 50.54%) fall within the moderate vulnerability range (MSCVI < 0.4).

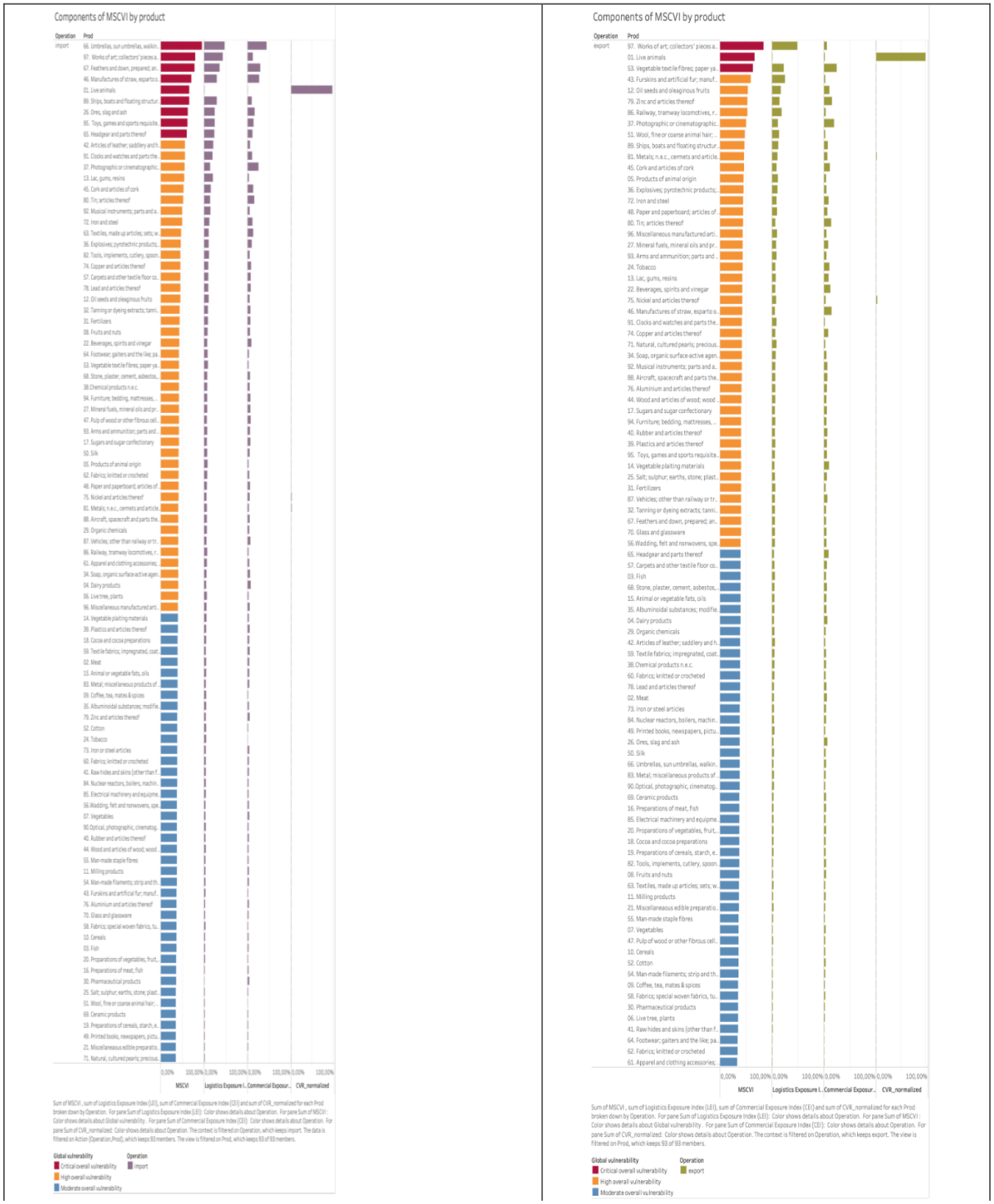

Figure 4: Components of MSCVI by products

6. CONCLUSIONS

The analysis demonstrates that France's maritime trade vulnerability is multidimensional, heterogeneous, and structurally embedded. Vulnerability arises not from a single source but from the interaction of distinct dependency and exposure mechanisms, logistical, commercial, and cost-related. At the dependency level, France's international trade remains predominantly maritime, yet the degree of reliance varies substantially across products and between imports and exports. This structural dependency forms the foundation upon which exposure develops. At the exposure level, the Logistics Exposure Index (LEI) and the Commercial Exposure Index (CEI) reveal three distinctive profiles:

1. Logistics-driven products, characterized by strong maritime reliance and concentrated shipping partners in volume terms.
2. Commercial-driven products, where exposure is primarily economic, stemming from concentration in high-value trade flows.
3. Dual-exposure products, which combine both physical and economic dependencies and therefore represent structurally fragile nodes in the trade network.

The inclusion of the Cost-Value Sensitivity Index (CVSI) introduces a third analytical dimension, capturing how freight-cost intensity amplifies exposure for selected products such as metals, live animals, and works of art. This cost channel adds crucial economic realism to the assessment, showing that even moderate logistical dependencies can become critical when paired with high transport-cost sensitivity. Integrating these three exposure dimensions, the MSCVI provides a synthetic view of structural vulnerability. Results indicate that vulnerability is widespread in incidence but concentrated in intensity: More than half of the 93 analyzed products (52 products, 55.9% of the total, in import flows; and 46 products, 49.5% of the total, in export flows) fall within the high or critical vulnerability categories.

From a policy perspective, decomposing the MSCVI into its constituent indices enables a diagnostic framework for targeted resilience strategies, rather than generalized interventions:

- Logistics-driven vulnerabilities call for diversification of shipping routes, investment in port and intermodal infrastructure, and contingency planning for chokepoint disruptions.
- Commercial-driven vulnerabilities require supplier diversification, trade-partner rebalancing, and strategic sourcing policies to reduce concentration risk.
- Cost-value-sensitive vulnerabilities demand freight-rate stabilization mechanisms, logistics-efficiency programs, or multimodal integration to mitigate cost shocks.
- Multidimensional vulnerabilities, where these factors overlap, require integrated responses combining transport, trade, and financial instruments, as they represent the most structurally fragile points in the system.

Beyond targeted policy intervention, the MSCVI framework advances the understanding of maritime vulnerability by linking dependency (the structural reliance on maritime networks), exposure (the translation of this reliance into potential disruption), and vulnerability (the compounded outcome of interrelated exposures). Methodologically, it translates these dimensions into harmonized trade and transport indicators that allow cross-product comparison and evidence-based prioritization. Empirically, it identifies the sectors and product groups where overlapping exposure channels generate the greatest systemic risk. Applied to France's trade between 2016 and 2021, the analysis demonstrates that maritime vulnerability is not uniform but highly differentiated across sectors and products.

While France's overall trade structure remains resilient, a substantial share of its import and export portfolio exhibits high or critical vulnerability scores. These vulnerabilities arise from the combined effects of logistical dependence on maritime transport, concentration of trading partners, and cost sensitivity to freight-rate volatility. This pattern indicates that vulnerability is not driven solely by exceptional shocks but reflects enduring structural features of France's trade configuration and its position within global maritime networks. Our analysis, which relies solely on data from France as an example, is obviously subject to criticism and cannot be generalised to all countries/sectors. Another source of criticism stems from the equal weighting of LEI, CEI and CVSI, which does not reflect product-specific priorities. Our method could also be criticised because it covered the challenging period of the 2020s, which was affected by the global pandemic, but also because it does not include metrics on availability, time to market or transit time for alternative sources. This could lead us to reconsider how we assess a country's vulnerability to maritime trade.

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8. DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES:

During the preparation of this work, the author(s) used METIS and Chat-GPT (AI engines) in order to improve the readability of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as necessary and take(s) full responsibility for the content of the publication.