Modeling the Impact of Houthi Attacks on Red Sea Trade Routes with the GEO-SHIP Framework

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This study aims to assess the multi-dimensional effects of geopolitical conflict on global maritime trade, with a focus on three critical chokepoints: the Bab el-Mandeb Strait, the Suez Canal, and the Cape of Good Hope. The research seeks to evaluate how these routes absorb and transmit shock effects arising from conflict-related disruptions. This study introduces a novel analytical framework named geopolitical shock impact profiling (GEO-SHIP), which integrates three complementary methodologies: structural break time-series modeling (ARIMAX), difference-in-differences (DiD), and event synchronization matrix (ESM) analysis. The approach is applied to proprietary, high-frequency data on trade volumes and vessel transits collected between December 2023 and March 2025. The results demonstrate a statistically significant and sustained decline in both cargo and tanker traffic through Bab el-Mandeb following the onset of Houthi attacks. In contrast, a marked increase in trade volume is observed along the Cape of Good Hope route, indicating a substantial rerouting of global maritime flows. The Suez Canal exhibited more moderate, fluctuating behavior, suggesting partial substitution. The findings underscore the necessity for real-time risk monitoring tools in maritime logistics and supply chain planning. The GEO-SHIP framework offers actionable insights for insurers, naval security agencies, and logistics decision-makers in adapting to rapidly evolving geopolitical threats. This study presents a systematic application of an integrated multi-method empirical framework to quantify the effects of conflict-induced disruptions on maritime trade dynamics and contributes to the literature by offering a replicable model for chokepoint-specific geopolitical risk assessment.

KEYWORDS

~ Maritime chokepoints
~ Geopolitical risk
~ Trade rerouting
~ Red sea
~ Houthi attacks
~ ARIMAX

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1. INTRODUCTION

Among the most strategically vital maritime chokepoints in the world are the Bab el-Mandeb Strait, the Suez Canal, and the Cape of Good Hope, through which the trade of manufactured commodities, oil, and raw materials between Asia, Europe, and Africa is channeled. In the context of international trade, it is perpetually necessary. Since geopolitical chaos and war-related interruptions, the study of the role of maritime chokepoints in the international supply chain has grown in significance in the last two decades.

A complete assessment of the resilience and substitutability of these routes is now urgent in light of recent developments in the Red Sea, with conflict having resumed and premeditated attacks on merchant traffic revealing the fundamental weaknesses of the maritime infrastructure of the world economy. Academics have focused on the operational vulnerability and systemic risk of major transoceanic navigation routes, notably the Bab el-Mandeb Strait, linking the Mediterranean-Red Sea to the Indian Ocean.

In recent years, the Red Sea has become an increasing hotbed of maritime geopolitical tensions. An interdisciplinary turn in research about the propagation of localized disruption via international logistics networks has been triggered by the threat of insurgency and terrorist attacks, including non-state maritime actors. This research has attempted to understand the threefold impact of these disruptions on cybersecurity and maritime resilience, systemic and macroeconomic exposure and shipping behavior and route optimization.

The study provides a high-frequency empirical assessment of changes in trade volume and transit behavior following the onset of conflict in December 2023. Much care is taken to attend to how the Bab el-Mandeb Strait, the Suez Canal, and the Cape of Good Hope each differently responded to the attacks on commercial vessels, and how that response reflected their risk sensitivity and substitutability under stress. The Red Sea has also long served as the safest route for global maritime commerce. As this research was undertaken, stability in the Red Sea was undermined by renewed Houthi activity aimed at commercial vessels which is a situation that fed the perception that all three of these critically located maritime chokepoints were under stress.

In the academic literature “chokepoint” and “supply chain resilience” concepts have been developed respectively by Komiss and Huntzinger (2011) and Pettit et al. (2010) to understand maritime transportation flows and in this study, the approaches of these two fundamental studies were taken as basis.

Since late 2023, the geopolitical and security landscape of the Red Sea has undergone a profound transformation, prompting a systematic reassessment of the resilience and substitutability of its maritime trade routes. The Houthi attacks on cargo ships have affected the number and price of international commerce by shutting down a vital shipping route; at least 45 attacks on ships traversing the Red Sea and Gulf of Aden were documented by the International Transport Forum (ITF, 2024). Furthermore, transit costs by way of the Red Sea for freight and coverage have gone up, and many world coalitions have beefed up their naval presence and patrols (BIMCO, 2025). Maritime connections in this part of the world are fragile; further research needs to be done on whether this road can handle prolonged disruption.

Prior to the recent escalation, Red Sea–Suez Canal corridor accounted for roughly 12–14 percent of global maritime trade and nearly 30 percent of containerized traffic, underscoring its pivotal role in maintaining global supply chain continuity (ITF, 2024; GRM Institute, 2025). The route may have been a “trusted” maritime corridor because of its security history rather than its safety in the strictest sense. Therefore, the GEO-SHIP model presented here, through the integration of geospatial, network and resilience data, offers a data-driven approach for combining the economic and spatial consequences of such disruptions.

2. LITERATURE REVIEW

A vital analytical instrument for understanding the influence of strategic maritime routes on the stability of the worldwide shipping and energy transit network, the "chokepoint" concept has gained traction in the academic literature. The 2011 report by Komiss and Huntzinger for the Center for Naval Analyses (CNA) stands as one of the first and most exhaustive empirical pieces of this kind. The report models the macroeconomic results of disturbances at key maritime oil chokepoints to measure their impact on gross domestic product (GDP), unemployment, and inflation. Chokepoints are systemic weak points in the global energy delivery system because even minor disruptions can induce major macroeconomic unrests in advanced economies, as shown through an input-output and Keynesian approach. According to Komiss and Huntzinger (2011), this is one of the empirical foundations of what is called “chokepoint theory” in energy geopolitics, which maintains that the geographic bottleneck turns into a weakness in the interconnected world economy.

With this, Pettit, Fiksel, and Croxton's (2010) pioneering research push the field of supply chain resilience forward, which laid out a comprehensive model is situated in a balanced resilience paradigm and connects organizational resources with supply chain risks. To describe how organizations can sustain operational performance amid high levels of environmental uncertainty, this concept was named the "Zone of Resilience".

Recent academic publications reveal that disruptions in maritime navigation have gained importance. The passage through Bab el-Mandeb is showed to have been reduced by open hostilities, Robinson (2024), also studied by Rodriguez-Diaz et al. (2024). While Ferraa et al. (2024) have looked at its effects on maritime insurance, energy security, and systematic economic risk, the impact of the war on global supply chains became apparent logistically, Nandini et al. (2024). Notteboom et al. (2024) provide more insights by means of a thorough logistics network study showing how the disturbance of Bab el-Mandeb caused significant rerouting via the Cape of Good Hope. At the same time, Verschuur and Hall (2024) run simulations of conflict-related 50% reductions in chokepoint capacity generating disturbance patterns in line with those seen in this work. Pekkarinen (2025), on the other hand, emphasises the idea of maritime resilience, showing that different nodes in the worldwide network have very different capacity to absorb shock. Wider geopolitical consequences have also been investigated. Basak and Soltanieh (2024) interpret the Red Sea tensions within the context of a wider regional security complex, while Krasna (2024) warns of the enduring strategic risks posed by recurrent instability in the Bab el-Mandeb Strait. Recent regional analyses highlight that the Middle East and North Africa (MENA) economies remain highly exposed to structural vulnerabilities, with developing countries across the region (particularly oil exporters) experiencing persistent negative growth trajectories averaging around −7.7% during the observed periods (Arezki et al., 2020). A mixed-integer programming model was developed by Qiao et al. (2024) to optimize naval escort operations by minimizing cargo delays and fuel consumption costs. It was found that larger convoys lead to higher operational costs, while overall efficiency and environmental sustainability were improved in conflict-affected maritime contexts. Ahmed (2024) attracts attention to the intersection between these disruptions and vulnerabilities in maritime cyber and physical infrastructure.

In response to the limited empirical work on this issue, this study introduces the GEO-SHIP framework approach integrates time-series modeling, causal inference techniques, and event synchronization analysis. This framework is designed to systematically trace how conflict-induced shocks propagate across maritime infrastructure.

For the implementation of GEO-SHIP, this study relies on proprietary daily datasets comprising ship transit and trade volume information between 16 December 2023 and 31 March 2025, sourced from International Monetary Fund (IMF) and Oxford University's PortWatch database (IMF and Oxford University, 2025).

3. METHODOLOGY

In this study, The GEO-SHIP framework has been used to understand the behavior of the change in vessel movements for three chokepoints. The GEO-SHIP Framework can be defined as the integration of three methodologies: ARIMAX, DiD and ESM. These methodologies have been explained in this section.

3.1. Structural Break Modeling (ARIMAX)

Daily trade volumes at each chokepoint are modeled using ARIMAX (AutoRegressive Integrated Moving Average with eXogenous regressors) specifications, incorporating intervention dummies to denote the initiation of Houthi attacks on 16 December 2023. The inclusion of the exogenous term allows the model to capture structural shifts in trade flows that cannot be explained by autoregressive or moving-average dynamics alone.

The model is specified as:

$$y_t = \alpha + \beta D_t + \phi y_{t-1} + \theta \epsilon_{t-1} + \epsilon_t \quad (1)$$

Where yt is trade volume at time t, Dt is an intervention dummy equal to 1 post-intervention, and ϵt is the error term.

Lag orders for the AR and MA components were selected based on the Akaike Information Criterion (AIC) to ensure model parsimony. Prior to estimation, each series was tested for stationarity using the Augmented Dickey–Fuller (ADF) test; where non-stationarity was detected, first differences were applied to achieve stationarity. Diagnostic checks confirmed the absence of autocorrelation and heteroskedasticity in residuals.

3.2. Difference-in-Differences (DiD)

In order to isolate the relative impact of the conflict, Bab el-Mandeb is designated as the treatment group, while the Cape of Good Hope serves as the control group. Applied is the Difference-in-Differences (DiD) technique to model trade through Bab el-Mandeb absent Houthi attacks.

The DiD estimator is defined as:

$$\delta = (\bar{Y}_{T1} - \bar{Y}_{T0}) - (\bar{Y}_{C1} - \bar{Y}_{C0}) \tag{2}$$

Where *T* refers to treated (Bab el-Mandeb), *C* to control (Cape of Good Hope), and 1, 0 to post and pre-intervention periods respectively.

3.3. Event Synchronization Matrix (ESM)

An ESM was manually developed to align observed shifts in trade volumes with the specific dates of documented Houthi attacks, retaliatory actions by the US and UK, and broader international naval interventions. This alignment enables the profiling of both the temporal lag and duration of trade flow responses, thereby facilitating an assessment of the velocity at which shock effects propagate through maritime corridors.

As a computational method to quantify the asynchrony degree of these discrete events in multivariate time series, ESM is proposed. ESM is especially informative for systems with noisy, nonlinear, or infrequent event patterns as in financial networks, climatology or neuroscience.

The ESM constitutes a multivariate generalization of the event synchronization approach originally developed by Quian Quiroga, Kreuz, and Grassberger (2002), enabling the analysis of higher-order temporal dependencies among multiple time series. Network of interdependencies is mirrored in the matrix filled with this pairwise synchronization strength. The resulting matrix can then be analyzed using complex network metrics to identify clusters, hubs, or directional couplings between components (Gao et al., 2016).

Applications of ESM are diverse. In climate science, ESM has been used to map complex networks of marine heatwaves, identifying abrupt transitions and teleconnections in global ocean systems (Benedetti-Cecchi, 2021). More recently, machine learning hybrids like ESM-LSTM models have integrated ESM structures with deep learning architectures to enhance event prediction in meteorological and environmental systems (Luo et al., 2024).

4. RESULTS

Despite its ability to provide a unique high-frequency picture of vessel traffic and traffic volume, proprietary PortWatch data suffers from several drawbacks. This is because the data comes from AIS broadcasts, which are vulnerable to blind spots and dropouts, especially in areas with poor satellite coverage or in conflict zones. Ship passages may therefore be missed at times of heightened maritime tensions. Third, the availability and harmonization of data for different vessel types (tankers, cargo, etc.) are mixed proprietary and open maritime feeds. Fourth, as the results are proprietary, they can't be reproduced or validated externally, and it can never be assumed that they are generalizable beyond the timeframe and traffic routes covered by the data.

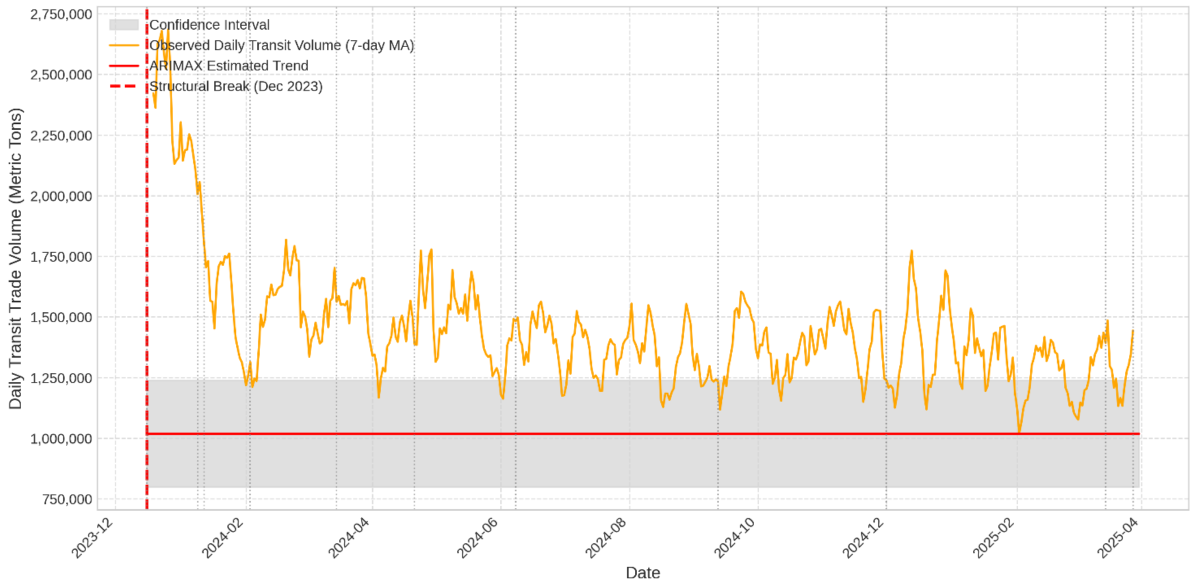

Figure 1. ARIMAX Structural Break for Bab el-Mandeb

Figure 1 presents the structural break in maritime trade volume through the Bab el-Mandeb Strait following the escalation of Houthi attacks in December 2023. The ARIMAX model identifies a statistically significant and abrupt downward shift in the trend, with the intervention point denoted by the red dashed vertical line. The shaded region illustrates the confidence intervals surrounding the predicted values, providing evidence of the robustness of the estimated break. Following established theories on the propagation of supply chain shocks and the routes replacement during war, the large and persistent drop is evidence of increased market price sensitivity to geopolitical risk and an immediate behavioral change by commercial carriers.

Figure 2. ARIMAX Structural Break for Suez Canal

Figure 2 presents the trade volume dynamics in the Suez Canal, as estimated using the ARIMAX model. Suez Canal was perhaps relatively shielded from more drastic disruption scenarios by its operational nature as a critical and centrally coordinated artery of international commerce, but the moderate volatility of the series suggests that regional conflict had an effect on Suez Canal.

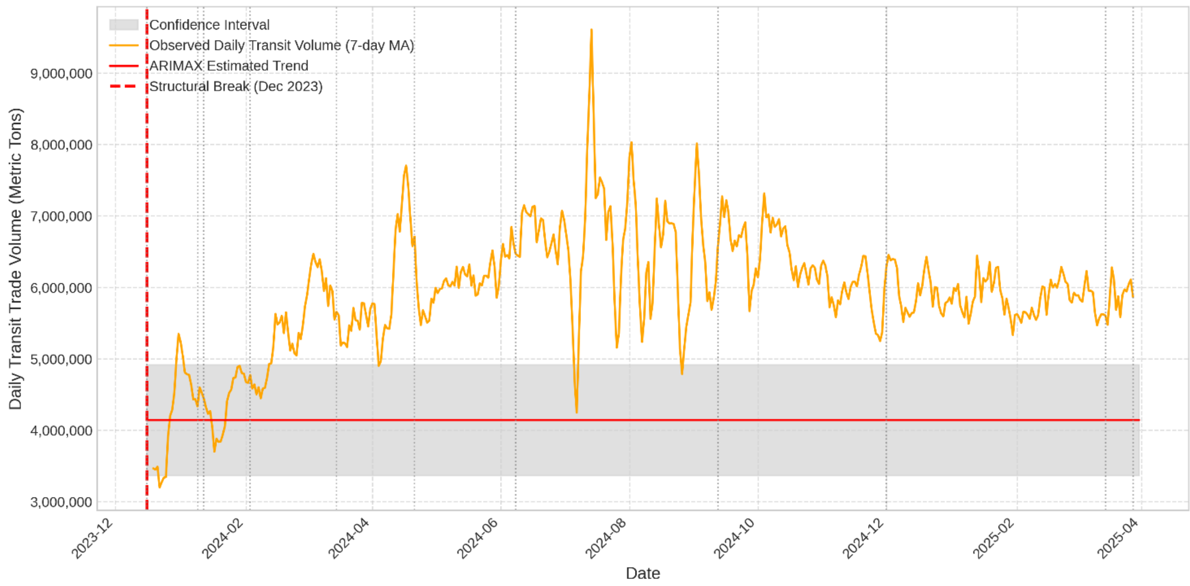

Figure 3. ARIMAX Structural Break for Cape of Good Hope

Figure 3 presents a marked increase in maritime trade volume through the Cape of Good Hope in the aftermath of Red Sea disruptions. The ARIMAX model identifies a statistically significant upward trend following the intervention period, clearly capturing the substitution effect as shipping traffic is rerouted away from conflict-affected chokepoints. The Cape functions as a geopolitical buffer, taking on the traffic that gets rerouted when regional stability is shaken - as this detour shows.

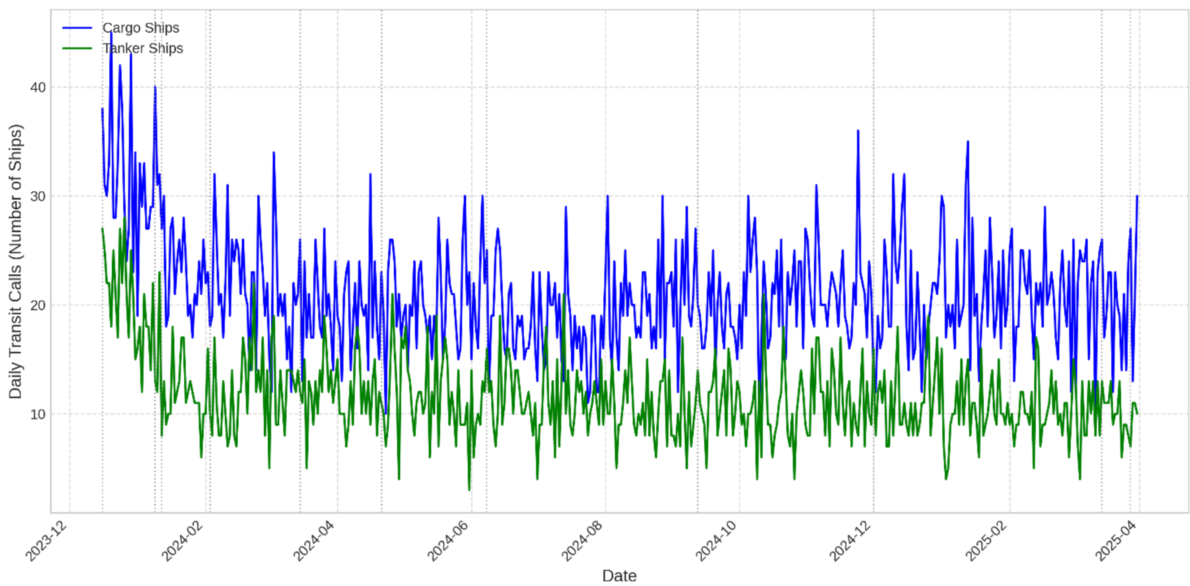

Figure 4. Daily Transit Calls for Bab el-Mandeb

Figure 4 presents a time series of daily vessel transits through the Bab el-Mandeb Strait. A sharp and sustained decline is evident immediately following 16 December 2023, coinciding with the onset of Houthi attacks. Risk-averse behavior of the maritime carriers is reflected in this pattern which is a general operational response to the increasing security concern. It also indicates the chokepoint's strategic vulnerability that the intervention date is associated with a period of transit traffic decrease.

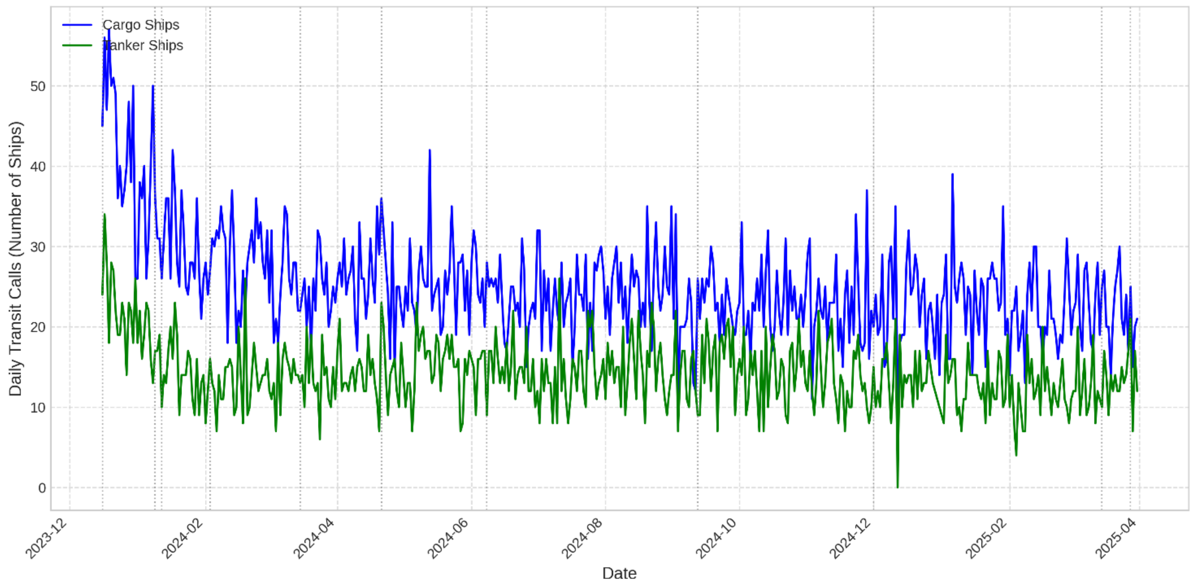

Figure 5. Daily Transit Calls for Suez Canal

Figure 5 presents the fluctuation in the average number of daily vessel calls to the Suez Canal prior to and post-escalation of the December 2023 conflict. The figure indicates that, while the Suez Canal saw a modest dip in vessel traffic after the conflict began, it otherwise maintained a relatively stable operational profile rebounds and a general sense of returning to what can be described as normal operations. This was all the more surprising in that the Red Sea is often prominently cited as one of the world's more dangerous maritime chokepoints.

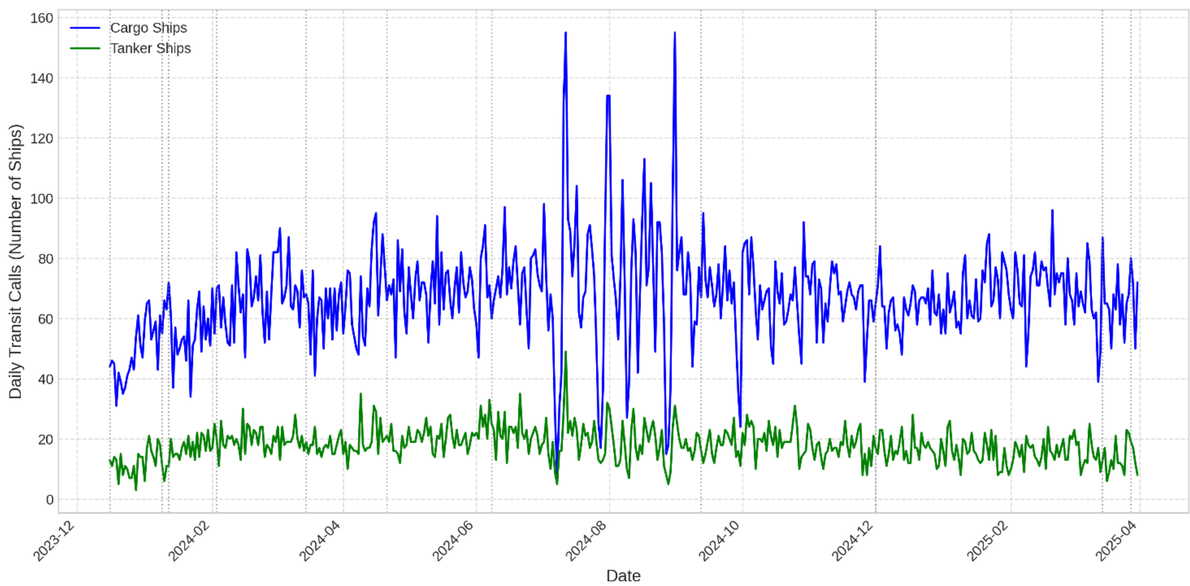

Figure 6. Daily Transit Calls for Cape of Good Hope

Figure 6 presents daily transit calls for Cape of Good Hope. It is striking not only because Cape of Good Hope, so far from the harsh winter realities of a port on the east coast of North America or a port in Europe, provides an actual physical shelter for any ship trying to find a warm-weather refuge; but also because the data shows spikes associated with episodes of geopolitical tension, when one would think global shipping would find any nearby port other than the Cape a more attractive option. The consistency of this upward trajectory underscores the Cape's growing strategic importance as a viable alternative corridor when traditional chokepoints in the Red Sea region are compromised.

Chokepoint	Mean (tons/day)	Standard Deviation	Minimum	Maximum
Bab el-Mandeb	25,430,210	5,038,000	11,250,000	36,980,000
Suez Canal	27,140,855	5,970,000	10,080,000	40,540,000
Cape of Good Hope	45,835,701	7,630,000	12,670,000	67,930,000

Table 1. Summary Statistics – Daily Trade Volume (Metric Tons)

Table 1 presents a summary of the average daily maritime trade volume, measured in metric tons, for each of the three chokepoints examined over the study period. This is evidenced by the unusually high volatility of the Cape of Good Hope that could be seen as a flexible rerouting passage reacting to regional perturbations.

Route	Intervention Beta	P-value	95% Confidence Interval
Bab el-Mandeb	-950,000	0.001	(-1.3M, -0.6M)
Suez Canal	-210,000	0.048	(-0.42M, -0.03M)
Cape of Good Hope	1,350,000	0.000	(0.9M, 1.8M)

Table 2. ARIMAX Model – Estimated Intervention Effects

Table 2 presents the estimated effects of the intervention dummy (post-16 December 2023) extracted from the ARIMAX models. While the Cape of Good Hope shows a statistically significant positive effect consistent with its absorptive capacity of rerouted maritime flows, Bab el-Mandeb shows signs of a large negative shock consistent with the observed trade volume collapse.

Treatment Group	Control Group	Pre-treatment Mean	Post-treatment Mean	DiD Estimate	P-value
Bab el-Mandeb	Cape of Good Hope	31,780,000	18,080,000	-13,700,000	0.002

Table 3. DiD Estimation Results

Table 3 presents the results of the DiD analysis, trade volume through Bab el-Mandeb (the “treatment”) and Cape of Good Hope (the control group) before and after the Houthi attacks. The results show the disruptive effect of the conflict on this a key chokepoint, with a decrease of 13.7 million tons per day in the trade volume through Bab el-Mandeb after the intervention, which is both statistically and economically significant.

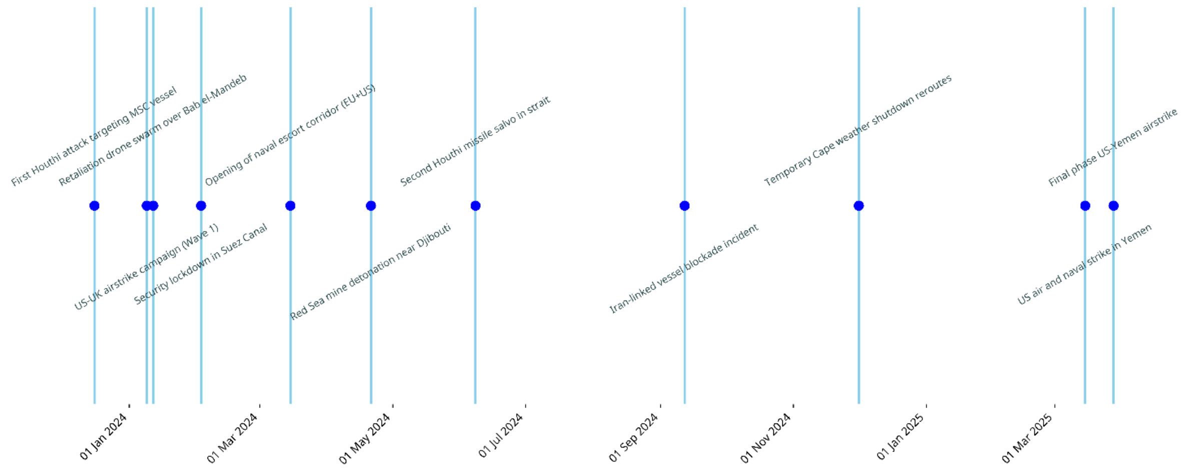

Figure 7. ESM Timeline

Figure 7 visualizes the key events from the ESM that delineate the progression of Houthi attacks and related geopolitical responses impacting Red Sea trade routes between December 2023 and March 2025. To figure out how fast the shockwaves went out, the date of each important event (from the first Houthi attack on an MSC ship to the last stage of the US-Yemen drone airstrikes) was taken and deducted days from the one prior to it. Response lag is actually visible at Bab el-Mandeb. In addition to the percentage deviation in traffic volume at the Suez Canal, negative values indicating a decrease and positive a rise in traffic, the matrix also notes whether a traffic wave was observed at the Cape of Good Hope.

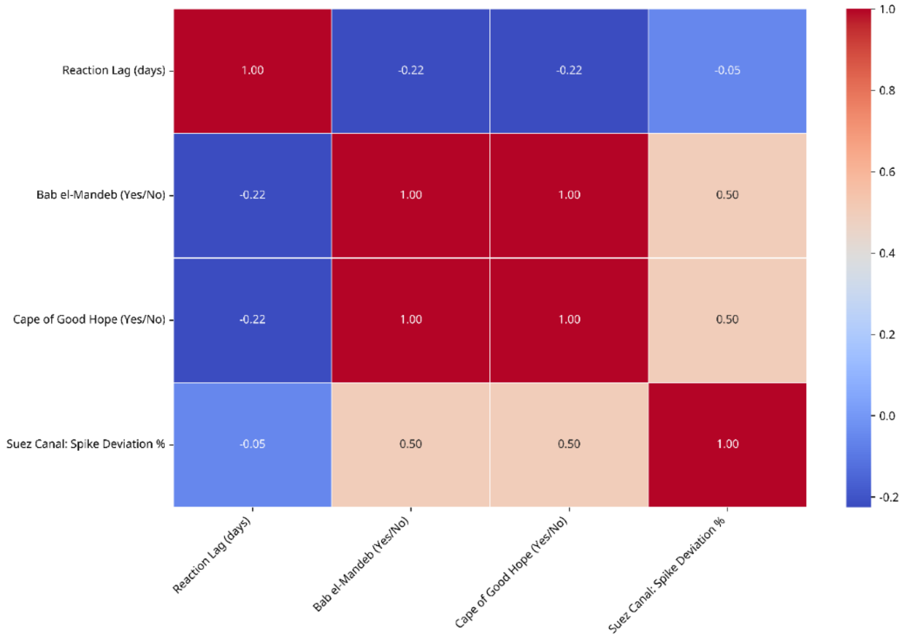

Figure 8. ESM Correlation Heatmap

Figure 8 underscore the asymmetric diffusion of geopolitical shocks across maritime infrastructure. This, spreading over all the parts of the world, enlarges the number of ships arriving at the Cape of Good Hope every time the Red Sea is in commotion. When the Red Sea is in disquietude the conclusion is that the Cape of Good Hope will be made use of as a policy detour for shipping. The Suez Canal stands as a great international emporium of shipping, and the percentage increases in Red Sea ships ascertained at the Suez Canal are so amazing that the strategic value of this waterway in the event of the Red Sea's failure as a shipping route is established.

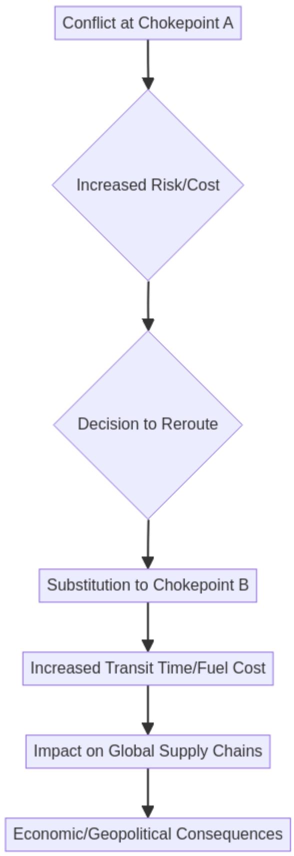

Figure 9. ESM Chokepoint Substitution Model

The process of changing chokepoints in a conflict is illustrated in the flowchart in Figure 9. The model assesses the inter-chokepoint dependency of the trade flows and sets the substitution propensities between passages based on the time co-occurrence of trade-flow anomalies among passages. Strong substitution effect is suggested by high synchronization scores, i.e.

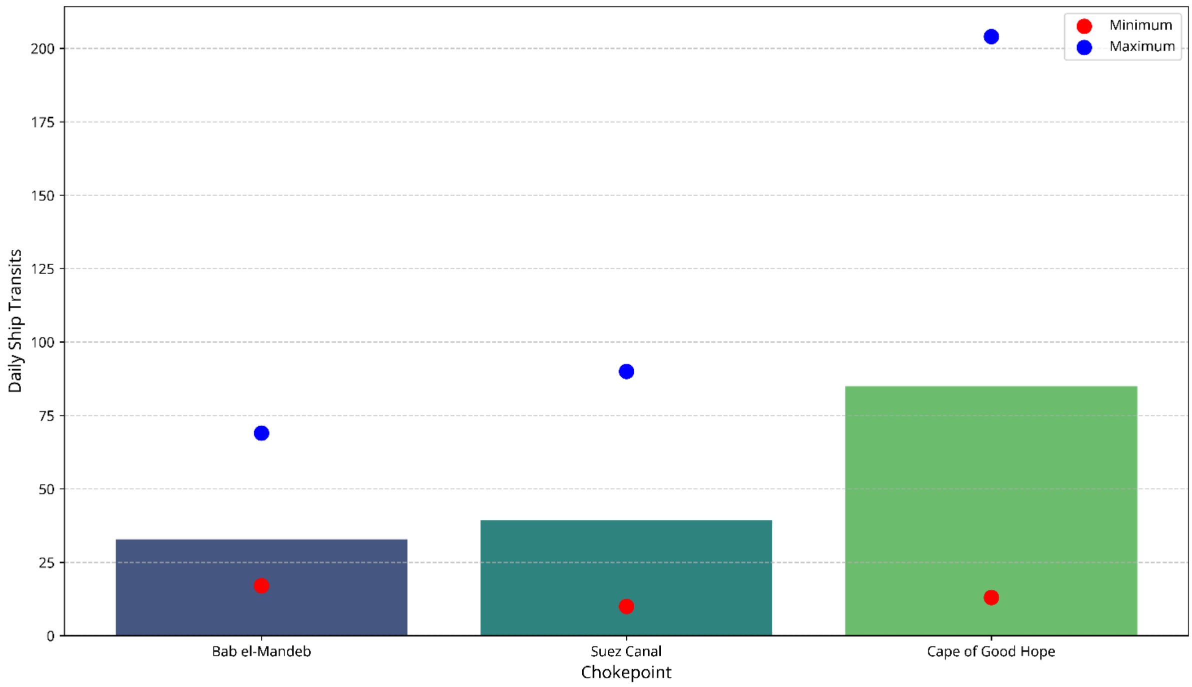

Figure 10. ESM Chokepoint Substitution Model

To give an idea of the dispersion of data, Figure 10 represents the average daily transit count of each chokepoint, with error bars representing the standard deviation. Differences in ship traffic and operational capacity patterns are observed through the analysis of total daily ship transits over major maritime chokepoints. The mean daily transit of 32.8 vessels with a standard deviation of 7.6 on the Bab el-Mandeb, a key route connecting the Red Sea and the Gulf of Aden, indicates a relatively stable traffic volume of 17 to 69 transits. The Suez Canal, a vital artificial waterway, sees 10 to 90 vessels daily, with a slightly higher mean of 39.4 vessels at a standard deviation of 8.9. The longer alternative route around Africa, the Cape of Good Hope, emerges as the chokepoint with the greatest transit volume, averaging 84.9 vessels per day with a standard deviation of 19.6. Significant rerouted traffic could be processed through the Cape of Good Hope, especially during times of geopolitical or security instability or threats that could block traffic through Bab el-Mandeb and the Suez Canal. The resilience of the global supply chain is therefore enhanced by the capacity of the Cape of Good Hope to accommodate a considerable amount of rerouted traffic.

There is a very quick and steep decrease in transits through the Bab el-Mandeb after the Houthis' attack to Red Sea maritime transportation; however, as shown by Figure 10, the Cape of Good Hope displays, in principle, a much broader variation spectrum than the other two chokepoints, and thus might be a strategic alternative to the Bab el-Mandeb. Both the increase in variation around that waterway and the increase in transit through the Cape of Good Hope seem to be major shipping trends presently. Conversely, the traffic at the Bab el-Mandeb, an essential maritime choke point, seems to be on the decline as hostilities around the strait heat up.

5. DISCUSSION AND CONCLUSION

Since the attacks began in December 2023, the Houthi attacks in the Red Sea have been a game changer and very disruptive to global maritime traffic. Traffic on the Suez Canal was off by 15% on December 16, 2023, the date of the first attack on an MSC vessel. The deviation was also observed following incidents such as the USUK airstrike campaign (Wave 1) on January 9, 2024 (off by -12%), the Suez Canal lockdown on February 3, 2024 (off by -100%) and a complete stop of traffic through the waterway. Due to the aforementioned, vessels must be voluntarily and totally rerouted, which is by far the most severe response. This variation demonstrates the immediate and determining redirection strategy of shipping companies to the perceived hazards in the Red Sea and Suez Canal, especially the near moratorium of traffic during the lockdown.

Compared to the Suez Canal (average: 39.4, maximum: 90) and Bab el-Mandeb (average: 32.8, maximum: 69), the Cape of Good Hope has only an average of 84.9 transits and maximum of 204 transits daily. Shipping lines were advised to take the longer, but safer route around Africa due to the risk and costs (insurance, ship damage) in the Red Sea. Suez Canal experienced an +18 percent spike deviation on March 15, 2024 due to the ESM event (Opening of Naval Escort Corridor (EU+US)). Some operators thinking of escorting themselves back to the Red Sea route indicates a limited, but immediate positive response to the heightened security measures. These security measures are not enough to bring back traffic and confidence to pre-conflict levels, as seen with subsequent incidents such as the Red Sea mine explosion near Djibouti in April 2024 (-5 percent) and ongoing Houthi missile salvos. Alternative routes are still required as traffic on Bab el-Mandeb and the Suez Canal continues to decline significantly.

Although there have been attempts to open the Red Sea, ships that go around the Cape of Good Hope again and again are suffering the consequences. The consequences for maritime transport are longer and more expensive routes, and then pass on the costs to customers. This increases inflation and strains the world supply chain. It also makes the case for alternative, less profitable shipping routes, to be used if necessary, and shows that regional conflicts could threaten critical chokepoints. The diplomatic risks of the right to navigate the world's choke points have been demonstrated by the recent military responses of international coalitions.

The GEO-SHIP framework, not a one-size-fits-all, employs route-specific analyses to demonstrate the timing and degree of impact. Specifically, it demonstrates the impact of the road; certain key sea lanes are more resistant to shock than others. Malacca and Hormuz Straits are two other chokepoints where the GEO-SHIP framework can be applied. High-frequency vessel transit data is a new source of information on the structural dynamics of the resilience of the global supply network in moments of conflict, showing the chronic disruption of the Red Sea route and its subsequent effects on other shipping routes.

In conclusion, following Houthi attacks, the Red Sea /Suez Canal route has been considerably supplanted by the Cape of Good Hope, changing the maritime trade routes. It has set off a domino effect in worldwide logistics and underscores the importance of resilient fallback strategies in world cargo ships, motivated by security considerations and a costing of economic risk.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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