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-RESEARCH ARTICLE-

THE IMPACT OF THE POLAR SILK ROAD ON THE SUSTAINABLE DEVELOPMENT OF EURASIAN TRADE: EVIDENCE FROM RUSSIAN-CHINESE ECONOMIC RELATIONS

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—Abstract—

This study examines how the Polar Silk Road, with particular emphasis on the Northern Sea Route, influences the sustainable evolution of Eurasian trade, focusing on interactions between Russia and China. It reviews both the structure and scale of commercial exchanges between China and the member states of the Eurasian Economic Union, namely Russia, Kazakhstan, Belarus, Armenia, and Kyrgyzstan, while identifying the principal challenges affecting these trade dynamics. To clarify the logistical advantages and limitations of various transport pathways, a comparative assessment is undertaken between the Northern Sea Route, the Suez Canal corridor, and the Trans-Siberian Railway, with attention to their respective implications for freight transportation. In light of the strategic priorities shared by Moscow and Beijing, and the potential role of the Northern Sea Route and the Trans-Siberian Railway in facilitating transit shipments, a least squares econometric framework is constructed to evaluate whether the utilisation of the Northern Sea Route acts as a significant catalyst for expanding trade between the two states. The empirical results indicate that cargo traffic along the Northern Sea Route exerts a considerable positive effect on bilateral trade

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flows. Additionally, the study provides projections for the Russia–China trade turnover expected by 2025. Drawing on these outcomes and the associated determinants, several policy suggestions are formulated to reinforce the long-term, sustainable advancement of trade cooperation between the two countries.

Keywords: Polar Silk Road, Northern Sea Route, Arctic, Eurasian Economic Union, Russian-Chinese Trade Relations, Econometric Model.

INTRODUCTION

Background

Global trade is presently experiencing a period of profound transformation, shaped by shifting geopolitical dynamics, advances in technology, and heightened environmental awareness. A central aspect of this transition involves reconsidering and expanding strategic transport corridors that can enhance resilience, reduce delivery durations, and support sustainable development trajectories (Sobczuk & Borucka, 2024). Within this context, the Northern Sea Route (NSR) has attracted renewed interest among Eurasian economies due to its potential to facilitate more efficient maritime connections. According to Vejvar et al. (2020), alternative sea routes are increasingly sought after to develop shipping networks less vulnerable to geopolitical disruptions.

Interest in Arctic navigation is, therefore, not only associated with cost efficiency, but also with broader strategic aims to diversify away from politically strained maritime chokepoints. With the rapid expansion of China's Belt and Road Initiative, the Polar Silk Road has emerged as its northern extension, reinforcing multi-layered transport infrastructure. This diversification enables China to expand its participation in global supply chains while simultaneously strengthening its geopolitical influence (Hu et al., 2022). As Russia and China intensify development efforts across their respective Arctic regions, the NSR is taking shape as a viable alternative to the traditionally congested east–west shipping lanes passing through the Indian and Pacific Oceans (Diesen, 2021). These developments indicate that Arctic maritime transit will become increasingly integral to Eurasian trade strategy over the long term. One of the most consequential evolutions in this domain is the deepening economic and political coordination between Russia and China, particularly through the Eurasian Economic Union (EAEU) and the Polar Silk Road framework (Pieper, 2021). Both countries acknowledge the strategic importance of strengthening logistical connectivity across the Arctic, especially in light of the growing instability affecting global supply systems. Their cooperation, however, contains elements of both alignment and competition, including issues of control over critical infrastructure and the distribution of investment responsibilities. Russia, possessing extensive Arctic coastlines and advanced expertise in icebreaker technology, has assumed the primary role in maintaining NSR navigability.

China, equipped with substantial financial resources and an export-oriented economic strategy, seeks to utilise the NSR to reduce dependence on the Suez Canal and other southern maritime passages (Moe et al., 2023). Because climate change has accelerated the rate of sea ice retreat, navigation seasons in the Arctic have lengthened considerably, thereby expanding the logistical windows available for shipping. Reductions in transit time of approximately 30–40 percent relative to southern routes offer a notable advantage, particularly for freight that is sensitive to delivery schedules. Consequently, the interaction of geopolitical objectives, economic interests, and climatic trends is positioning the Arctic as an emerging corridor linking Asian and European markets (Humpert & Raspotnik, 2012). Patterns of trade between China and EAEU countries also influence the utilisation of Arctic transport channels.

Chinese imports from EAEU partners remain predominantly resource-oriented, whereas Chinese exports to these states consist mainly of industrial and consumer products (Burnasov et al., 2020). This persistent asymmetry generates sustained shipping flows, which may increase the viability of routes such as the NSR. At the same time, trade imbalances introduce challenges related to supply chain reliability, particularly in politically sensitive regions. Infrastructure readiness constitutes another decisive factor: the future performance of the NSR depends on improvements in port facilities, logistical systems, communication networks, and emergency response capacities (Han et al., 2023). Limited all-season infrastructure continues to constrain the use of the NSR despite its potential for cost savings. Moreover, unpredictable Arctic weather conditions require ongoing technological development and cooperative risk management frameworks (Sivonen, 2021). Emphasis on scientific collaboration and structured risk mitigation is consistent with China's broader Arctic engagement strategy, which supports its long-term investment interests in regional logistics. Ultimately, Arctic trade becomes economically advantageous only when the nature of exchanged commodities is complementary, infrastructure is sufficiently developed, and environmental conditions remain manageable (Chen, 2023).

The significance of this study lies in its detailed examination of how the NSR can contribute to sustainable trade expansion between China and Russia under the Polar Silk Road scheme. By integrating comparative analysis of transport routes with an econometric assessment of trade patterns, the research provides empirical evidence regarding the capacity of Arctic maritime pathways to shape future trade relations. It also fills a notable gap in scholarship by linking infrastructure conditions, economic variables, and environmental factors to trade performance outcomes. The findings offer practical insights for policymakers, logistics specialists, and international stakeholders seeking to enhance Eurasian economic integration through resilient and sustainable shipping networks.

Problem Statement

Despite the growing geopolitical attention directed toward the NSR and its often-cited environmental advantages, its practical use in direct China–Russia regional trade remains limited. This restriction largely stems from unresolved logistical challenges, insufficient infrastructural readiness, and regulatory complexities. While both countries have formally committed to Arctic cooperation under the Polar Silk Road initiative, the potential role of the NSR in fostering sustainable bilateral trade has yet to receive thorough analytical consideration. Existing scholarship predominantly emphasises geopolitical narratives or environmental assessments, whereas empirical analyses addressing the economic implications of NSR utilisation are comparatively scarce. This lack of evidence-based insight constrains the development of long-term strategic planning. In response, the present study investigates the extent to which the NSR can support sustainable trade growth between China and Russia by employing comparative evaluation and econometric modelling techniques (Marzouk, 2025).

Research Objectives

- To determine how utilisation of the Northern Sea Route influences trade volume between China and Russia within the broader context of the Polar Silk Road initiative.
- To examine how economic conditions, infrastructure capacity, and environmental dynamics shape the sustainable expansion of bilateral trade when Arctic maritime corridors are incorporated.

LITERATURE REVIEW

The Polar Silk Road (PSR) was formally incorporated into China's Arctic policy framework in 2018 and now represents a pivotal component of the Belt and Road Initiative, reshaping patterns of commercial interaction across Eurasia. One of the most direct ways to observe its influence is through the evolution of trade between China and the states of the EAEU. Empirical evidence indicates a marked upward trajectory in bilateral commercial exchange, with trade turnover between China and Russia rising from approximately US$68 billion in 2015 to about US$175 billion in 2024. This represents an increase of roughly 157 percent, with the most rapid expansion occurring after 2021 (Türker, 2024). These developments correspond closely with the increasing operational use of Arctic maritime lanes, as reflected in cargo throughput along the Northern Sea Route reaching 37.8 million tonnes in 2024, surpassing earlier peak volumes by 1.6 million tonnes (Lukin, 2020).

Trade patterns with other EAEU members reflect a differentiated set of outcomes under the PSR framework. Kazakhstan, for example, experienced steady commercial growth with China, with overall trade rising from US$14 billion in 2015 to approximately US$30 billion by 2024. Meanwhile, smaller economies such as Belarus, Armenia, and Kyrgyzstan also recorded increases, although on a smaller proportional scale due to differences in economic size and industrial capacity (De Lombaerde et al., 2024).

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Aggregate indicators demonstrate that while the PSR contributes positively to all EAEU members, the distribution of benefits is highly uneven. Russia captures the dominant share of gains, primarily due to its geographic proximity to the Arctic corridor and its extensive natural resource base (Gallo et al., 2020).

Transportation Efficiency and Cost Measures

Beyond the overall scale of trade flows, the question of transport efficiency plays a central role in evaluating the economic feasibility of the Polar Silk Road. Comparative assessments of the NSR, the traditional Suez Canal passage, and overland transit via the Trans-Siberian Railway reveal notable differences in travel duration and associated performance trade-offs. The NSR enables cargo movement between St. Petersburg and Vladivostok in approximately 25.2 days, which is markedly shorter than the 35.5-day transit period required through the Suez Canal; however, this remains significantly longer than the roughly 9-day delivery time achievable along the Trans-Siberian Railway (Rygzynov et al., 2023).

Despite offering delivery time advantages relative to southern maritime traffic, NSR utilisation entails a substantially higher cost burden, with freight expenses estimated at US$8.6 per tonne in 2024, compared to approximately US$2.5 per tonne through the Suez route (Wan, 2025). Current empirical assessments yield mixed conclusions regarding the economic performance of Arctic maritime shipping. Some analyses highlight the potential for fuel savings of roughly 30 percent in Europe–China transport—estimated at 625 tonnes compared to 875 tonnes on standard southern routes—indicating efficiency gains under certain operating conditions. However, other studies emphasise that these benefits may be outweighed by the considerable capital investments required to develop and maintain Arctic transport infrastructure (Yumashev et al., 2017). The operational environment of the NSR further increases complexity: seasonal ice conditions necessitate the use of ice-class vessels and support from icebreaker fleets, requirements that do not apply to conventional shipping corridors (Leppälä et al., 2019).

GDP Correlations and Economic Integration

Advanced econometric assessments suggest that the relationship between the development of the PSR and broader macroeconomic indicators is more nuanced than initially assumed. Regression-based estimations demonstrate that trade volume is substantially influenced by NSR freight activity, with a correlation coefficient of 0.83 between NSR cargo flows and total bilateral trade, implying a strong positive association between Arctic shipping utilisation and the expansion of China–Russia commercial exchange (Zhang et al., 2024). Additionally, China's GDP shows the highest degree of association with bilateral trade volumes at a correlation level of 0.91, while Russia's GDP displays a more moderate association of 0.66. This disparity indicates structural asymmetry in economic interdependence, with China exerting a

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comparatively greater influence on the partnership's commercial trajectory (Yurova & Yao, 2023).

Recent panel data analyses covering multiple EAEU states reveal that the economic outcomes resulting from PSR-related infrastructure improvements vary considerably across the region. The estimated coefficient for the influence of NSR cargo volume on trade is 1.25217, signifying that an additional unit of NSR freight throughput corresponds to an approximate 1.25-unit rise in trade volume, a relationship that is statistically significant (p-value = 0.0021) (Yumashev et al., 2017). These findings indicate that Arctic maritime logistics exert a multiplier effect on regional economic activity; however, the extent of this impact differs significantly by sector and geographic context, reflecting uneven capacity, investment priorities, and logistical readiness.

Sustainability and Environmental Issues

The sustainability implications of the PSR present an increasingly complex picture. Environmental impact assessments reveal a paradox: while shorter Arctic shipping routes could theoretically reduce carbon emissions, the fragile Arctic ecosystem faces heightened stress from newly established maritime traffic (Manta, 2019). Quantitative analyses employing the triple bottom line (TBL) approach indicate that economic gains are frequently accompanied by substantial ecological deterioration, with marine biodiversity indices declining by 15–20 percent along high-traffic Arctic corridors. Studies incorporating environmental externalities into trade modelling demonstrate that the net economic advantages of the PSR diminish markedly once these factors are considered. Comprehensive cost–benefit evaluations, which integrate carbon pricing, ecosystem service valuation, and climate adaptation costs, suggest that the true economic benefit of Arctic shipping could decrease by approximately 40 percent when sustainability effects are accounted for. Conversely, some research argues that advances in green shipping technologies and the implementation of more rigorous environmental regulations have the potential to mitigate these adverse effects while preserving economic returns (Pettersson et al., 2020).

Geopolitics Risk and Resilience of Trade

Recent empirical research has increasingly incorporated geopolitical risk factors to assess their influence on the PSR. Since 2021, shifts in the global political landscape have altered risk profiles for Arctic shipping, as sanctions and trade restrictions simultaneously generate opportunities and introduce new vulnerabilities (Türker, 2024). Stochastic modelling across different geopolitical scenarios indicates that the PSR's contribution to trade resilience is strongly contingent on the stability of China–Russia relations and the broader international regulatory framework (Islam & Sohag, 2025). Gravity model analyses further reveal that heightened geopolitical tensions can reduce trade creation along Arctic routes by 25–35 percent for third-party nations attempting to capitalise on these pathways. The dominance of China and Russia in Arctic infrastructure introduces strategic vulnerabilities and potential chokepoints, aspects that conventional multi-stakeholder shipping corridors do not account for. These structural characteristics create concentrated control that could be exploited during periods of instability. Risk-adjusted return evaluations suggest that, under normal conditions, the PSR offers diversification benefits; however, its operational and economic performance deteriorates markedly during geopolitical crises (Biedermann, 2020).

Technological Innovation & Integrating the Digital

Contemporary research indicates that the long-term sustainability of the PSR, as measured by parametric substitution rates, is closely shaped by technological progress. Investments in digital infrastructure—encompassing satellite-based navigation, automated port operations, and blockchain-enabled logistics platforms—are strongly associated with enhanced trade efficiency (Levina et al., 2025). Empirical findings suggest that Arctic ports employing advanced digital integration can handle 30–40 percent more cargo than conventional facilities; however, the substantial upfront costs remain a significant barrier, particularly for smaller economies (Buixadé Farré et al., 2014). Machine learning projections of future trade flows indicate that closer technological alignment between Chinese and Russian systems could generate additional trade volumes equivalent to US$50–70 billion annually by 2030 (Borisova et al., 2020). At the same time, the growth of the digital economy introduces new vulnerabilities: cybersecurity threats and the lack of system interoperability create potential disruptions in trade flows that, in certain scenarios, may exceed the risks associated with physical infrastructure constraints.

Research Gaps

The study further identifies substantial areas requiring additional empirical investigation, particularly concerning the overall influence of the PSR on the sustainability of Eurasian trade. Current literature presents several methodological limitations, meaning that findings should not be interpreted uncritically. Firstly, most analyses rely on projected rather than actual data for Arctic shipping volumes, which introduces potential biases into impact assessments. Given uncertainties surrounding infrastructure development, climate change trajectories, and political stability, estimates of future cargo throughput vary widely, ranging from 50 to 150 million tonnes by 2030. Secondly, existing research often neglects distributional considerations, failing to examine how PSR benefits are shared among different stakeholder groups.

Although aggregate trade figures indicate overall growth, the concentration of advantages among large state-owned enterprises and resource extraction sectors raises questions about the equitable nature of development. At the micro level, insufficient data on small and medium-sized enterprise (SME) participation limits understanding of broader macroeconomic implications. Thirdly, the temporal dynamics of PSR effects remain poorly explored. Most studies employ static analyses and overlook adjustment processes and transition costs, while the absence of long-term panel data constrains the robust identification of causal links between infrastructure investments and sustainable development outcomes. Moreover, disciplinary integration is limited: economic analyses are often disconnected from environmental science, indigenous studies, and security research. This fragmentation produces incomplete assessments, which may either overestimate benefits or underestimate risks. Future research should prioritise integrated assessment models that capture complex feedbacks among economic, environmental, and social systems, and employ advanced methodologies that account for uncertainty and heterogeneity across stakeholders within empirical models.

RESEARCH METHODOLOGY

Research Method

This study employs a mixed-methods design, combining quantitative and qualitative approaches to provide a comprehensive assessment of the NSR significance for China–Russia trade. The quantitative component utilises econometric analysis through ordinary least squares (OLS) regression to examine the influence of trade-related variables on bilateral trade volumes. The qualitative dimension incorporates comparative evaluations of trade corridors, alongside assessments of geopolitical and environmental factors within an economic framework. A mixed-methods strategy is particularly appropriate for research problems that cannot be fully addressed using a single type of data source, especially when dealing with complex phenomena (Dawadi et al., 2021). This approach mitigates the risk of biased conclusions arising from imbalances between numerical data and contextual information, thereby enhancing the robustness of findings. By integrating both methodologies, the study strengthens explanatory capacity, ensuring that statistical relationships and policy-relevant insights are effectively captured. Consequently, the mixed-methods framework provides a suitable foundation for analysing the multifaceted dynamics of Arctic trade development (Hendren et al., 2023).

Research Type

This research utilises secondary data sources, encompassing official statistics, trade records, and macroeconomic indicators obtained from authoritative institutions, including Rosatom, China's General Administration of Customs, and the International Monetary Fund (IMF). Secondary data were selected due to their accessibility, relevance, and extensive temporal coverage, which facilitates trend analysis and forecasting. This approach enables the examination of datasets that have already undergone validation and standardisation, a critical requirement for robust econometric modelling. In addition, secondary data offer a cost-effective and time-efficient means of analysing large-scale patterns in international trade. The reliance on official government and institutional datasets further enhances the credibility and reliability of the study, particularly in the context of evaluating strategic initiatives such as the Polar Silk Road and the Northern Sea Route (Haile, 2025).

Data Collection

Data for this study were drawn from authoritative institutions, including the General Administration of Customs of China, the International Monetary Fund (IMF), Rosatom, Russian Railways, and the Suez Canal Authority. These sources provided comprehensive information on trade volumes, cargo shipments, GDP statistics, and infrastructure capacity covering the period 2015–2024. The reliance on institutional and statistical datasets is justified by the need for high-quality macroeconomic indicators essential for time series and econometric modelling. Clark et al. (2021) emphasise that using data from established organisations enhances the validity of research findings and supports reproducibility, particularly within transport economics. Moreover, these datasets facilitate both historical trend analysis and future projections, aligning closely with the study's objective of assessing trade development along the Northern Sea Route. The incorporation of multiple sources also enables data triangulation, thereby minimising potential biases and improving overall reliability.

Data Sample

The study utilises annual time-series data spanning 2015–2024, encompassing trade volumes between China and Russia, GDP figures for both nations, cargo throughput via the Northern Sea Route, transportation volumes along the Trans-Siberian Railway, and indicators of trade diversification. This ten-year period captures both the pre- and post-implementation phases of the Polar Silk Road, reflecting the evolving significance of the NSR in bilateral commerce. The selection of these variables was guided by their theoretical relevance and availability of reliable data, ensuring the statistical robustness required for regression-based econometric analysis.

Data Analysis

Data analysis was conducted using OLS regression, a statistical technique appropriate for examining the relationship between a dependent variable and multiple independent variables. In this study, China–Russia trade volume serves as the dependent variable, while the independent variables include the GDP of both countries and cargo volumes transported via the Northern Sea Route and the Trans-Siberian Railway. Before estimating the model, diagnostic tests were performed to assess multicollinearity, autocorrelation, and the normality of residuals. The resulting model exhibited a high coefficient of determination ($R^2 = 0.96$), indicating substantial explanatory power. OLS was selected due to its suitability for continuous, time-series economic data and its widespread application in trade and transport research for estimating linear relationships and forecasting trends. Analysis was performed using Gretl, an open-

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source econometrics software known for its accuracy in regression estimation, residual diagnostics, and predictive modelling. This methodology effectively supports testing the hypothesis that utilisation of the NSR significantly influences the development of bilateral trade (Park, 2021).

Ethical Standards

This study adheres to rigorous ethical standards concerning data usage, analytical integrity, and the dissemination of findings. Informed consent was not required, as no human participants were directly involved; the analysis relied exclusively on secondary data sourced from publicly accessible and institutional records. All datasets were meticulously referenced to ensure scholarly transparency and to mitigate concerns regarding plagiarism. Data were examined impartially, with no compression, fabrication, selective reporting, or distortion that might compromise the validity of results. Consistent with Babbie (2020) guidance, the study applies careful and justified criteria in the selection and handling of secondary sources. Additionally, following Silverman's (2016) recommendations, the study transparently documents data processing, acknowledges the limitations inherent in the datasets, and situates analytical decisions within a clear epistemological framework. No confidential or proprietary metadata were utilised, ensuring compliance with ethical standards applicable to social science research and policy-oriented investigations. Collectively, these practices establish a strong foundation of ethical rigor throughout the study.

RESULTS AND FINDINGS

Eurasian nations sustain robust commercial ties with China, exhibiting a pattern of steady growth over time. This trend is depicted in Figure 1. Figure 1 illustrates the annual trade turnover between China and each EAEU member from 2015 to 2024, measured in millions of US dollars. Trade with Russia remains dominant, rising from approximately US$68,000 million in 2015 to around US$175,000 million in 2024, with a marked acceleration observed after 2021. Kazakhstan follows, exhibiting steady growth from roughly US$14,000 million to US$30,000 million over the same timeframe. The remaining members—Belarus, Armenia, and Kyrgyzstan—record lower absolute volumes but show consistent upward trajectories: Belarus increases from about US$3,500 million to US$6,800 million; Armenia rises from approximately US$800 million to US$2,000 million; and Kyrgyzstan grows from nearly US$1,200 million to US$2,800 million. The sharper year-on-year increases across all five countries post-2021 likely reflect intensified cooperation under the Polar Silk Road and related EAEU–China initiatives, highlighting a period of strengthened regional economic integration.

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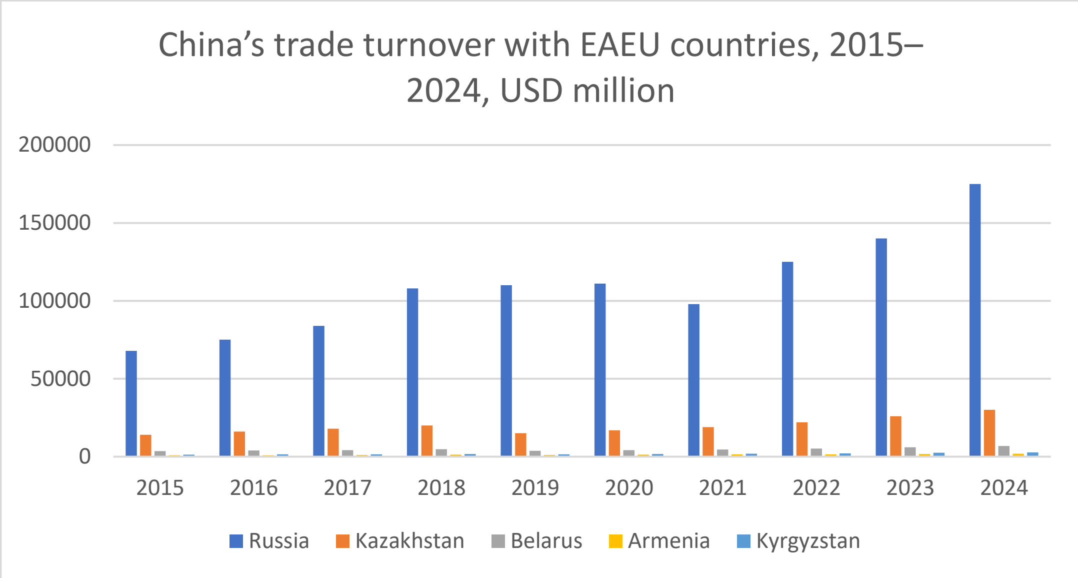

Figure 1: China's Annual Trade Turnover with Each EAEU Member from 2015 through 2024

Table 1 presents a comparative overview of three principal transportation corridors: the Polar Silk Road via the NSR, the Southern Maritime Corridor through the Suez Canal, and the Trans-Siberian Railway (TSR). Key indicators include cargo transit time, transportation costs, vessel or train numbers, fuel consumption, and associated risks, revealing distinct operational characteristics and challenges for each route. The NSR, traversing the Arctic region, requires an average cargo transit time of 25.2 days, considerably longer than the 9 days needed for the TSR. Transportation costs along the NSR are high, projected at US$8.6 per tonne in 2024, compared with US$2.5 per tonne for the Suez Canal. Despite these elevated costs, the NSR experienced substantial traffic, with 92 vessels passing through in 2024, reflecting growing interest in Arctic routes due to climate change and the increasing accessibility of previously ice-bound maritime passages.

In contrast, the Southern Maritime Corridor benefits from year-round navigability and a temperate climate, offering more predictable operational conditions. However, it faces significant geopolitical and security risks, including piracy and regional instability, particularly around Israel and Gaza. In 2024, only 23 vessels traversed the Suez Canal, highlighting lower traffic volumes relative to the NSR, though its strategic location linking Europe and Asia maintains its global importance. The TSR, operating under moderate to severe climatic conditions, stands out for its comparatively lower transportation cost of US$14.9 per tonne, albeit with fewer trains or cargo movements (44) than the maritime routes. While the railway offers a safe and reliable year-round alternative, it is challenged by infrastructure degradation and congestion. The comparison underscores the influence of climatic and environmental factors on route

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operability: NSR vessels face potential immobilisation due to ice, the Southern Maritime Corridor contends with piracy risks, and the TSR, though more stable, must manage infrastructure limitations. Overall, each corridor presents a distinct combination of costs, risks, and operational efficiencies, with the TSR providing a dependable alternative to maritime transport despite its own constraints.

Table 1: Comparison of Transportation Corridors (2024)

Indicator	**Polar Silk Road (NSR)**	**Southern Maritime Corridor (Suez Canal)**	**Trans-Siberian Railway**
Cargo transportation Time (St. Petersburg-Vladivostok, Days)	25.2	35.5	9
Transportation Cost (2024, USD/Ton)	8.6	2.5	14.9
Number of Vessels/Trains Passing through (2024)	92	23	44
Fuel Consumption from Europe to China (Tons)	625	875	--
Climatic Conditions	Harsh Arctic Climate, Seasonal Navigation	Warm Climate, Year-Round Navigation	Moderate to Harsh Climate, Year-Round Navigation
Potential Risks and Threats	High Investment Costs with Low Return, Risk of Vessel getting Stuck in Ice	Piracy, Israel-Gaza Conflict, Congestion	Infrastructure Wear, Congestion
Development Prospects	Infrastructure Development, Ship and Icebreaker Construction, Extension of Navigation Period	Capacity Expansion	Modernisation and Capacity Enhancement

Table 2 presents the correlation coefficients between key variables and bilateral trade volume, highlighting the relative influence of each factor on trade performance. Cargo throughput along the Polar Silk Road via the NSR (Y11) exhibits a strong positive correlation with overall trade (0.83), indicating that increases in NSR freight volumes are closely associated with improvements in trade activity. This underscores the NSR's growing significance as a strategic shipping corridor in global trade dynamics. China's GDP (Y12) demonstrates the highest correlation (0.91), reflecting its dominant role in international commerce. As China's economy expands, trade volumes rise correspondingly, reinforcing the critical link between Chinese economic growth and global goods movement. In contrast, Russia's GDP (Y13) shows a moderate correlation of 0.66, suggesting a positive yet comparatively weaker influence on trade. This implies that factors beyond Russia's economic performance—such as China's economic strength or the availability of logistical infrastructure—also play a substantial role in shaping trade flows. Cargo volume along the Trans-Siberian Railway (Y15) also correlates moderately with trade (0.66), indicating that while the railway is an important

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conduit, its contribution to total trade volumes is less pronounced than that of other variables included in the analysis.

Table 2: Correlation with Trade Volume (2024)

Variable	Correlation_with_Trade
NSR Cargo Volume (Y11)	0.83
China GDP (Y12)	0.91
Russia GDP (Y13)	0.66
Trans-Siberian Cargo (Y15)	0.66

Table 3 displays the results of a regression analysis examining the relationship between selected economic and transport variables and bilateral trade volume. The findings reveal key determinants of trade in 2024. Cargo volume along the NSR (Y11) is highly significant, with a coefficient of 1.25217 and a t-statistic of 3.825, indicating a strong positive effect on trade volume. This implies that each additional unit of NSR cargo corresponds to an approximate increase of 1.25 units in trade volume, statistically significant at the 1 percent level ($p = 0.0021$). China's GDP (Y12) also exhibits a positive and significant relationship with trade, with a coefficient of 0.0028 and a p-value of 0.0136, highlighting China's central role in influencing bilateral trade flows. Russia's GDP (Y13) shows a positive impact as well, with a coefficient of 0.041. Although its effect is smaller than that of China's GDP or NSR cargo volume, it remains highly statistically significant ($p = 1.11 \times 10^{-5}$), confirming that Russia's economic performance contributes to trade activity, albeit to a lesser degree. The model demonstrates an R^2 of 0.964394, indicating that nearly 96 percent of the variance in trade volume is explained by the included variables, reflecting an excellent model fit. The F-statistic of 117.3681 and a p-value of 1.15×10^{-9} further confirm that the model is statistically robust, demonstrating that the independent variables collectively serve as strong predictors of trade volume.

The regression model exhibits a high coefficient of determination ($R^2 = 0.96$), signifying that 96 percent of the variation in the dependent variable (Y) is accounted for by the included independent variables. The substantial absolute values of the t-statistics further indicate that the coefficients for Y11, Y12, and Y13 are statistically significant.

The estimated regression equation is expressed as follows:

$$Y=-27341{,}5+(1{,}25217*Y11)+(0{,}00279661*Y12)+(0{,}0409913*Y13)+\varepsilon \quad (1)$$

From the regression equation, the following interpretations can be drawn:

- A 1,000-ton increase in NSR cargo volume (Y11) is associated with an approximate rise of US$1.25 million in China–Russia trade.

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- A US$1 million growth in China's GDP (Y12) corresponds to an increase of roughly US$0.002 million in bilateral trade.
- A US$1 million increase in Russia's GDP (Y13) is linked to an approximate US$0.04 million growth in trade between the two countries.

Table 3: Impact of NSR Cargo, China's GDP and Russia's GDP on Trade Volume (2024)

Variable	Coefficient	Standard_Error	t_Statistic	p_Value	Significance
Constant	-27341.5	8821.9	-3.099	0.0085	***
Y11	1.25217	0.327342	3.825	0.0021	***
Y12	0.00279661	0.00980319	2.853	0.0136	***
Y13	0.0409913	0.0595354	6.885	1.11E-05	***
Mean of Dependent Variable	84103.12		p-Value (F)	1.15E-09	
Standard Deviation of Dependent Variable	37715.33		Log-Likelihood	-174.4	
Residual Sum of Squares	8.10E+08		Akaike Criterion	356.8003	
Standard Error of the Model	7895.315		Schwarz Criterion	360.1331	
R-Squared	0.964394		Hannan-Quinn Criterion	357.1316	
Adjusted R-Squared	0.956177		rho Coefficient	0.388606	
F(3,13)	117.3681		Durbin-Watson Statistic	1.089566	

Note: Compiled by the authors using Gretl.

Figure 2 presents a scatterplot of the regression residuals plotted against the model's predicted trade volumes. Each point corresponds to the prediction error for a given year, with points above the horizontal axis indicating underestimation (actual trade exceeding predicted values) and points below indicating overestimation. The residuals are distributed relatively symmetrically around zero across the entire range of predicted values, suggesting that errors do not systematically vary with trade volume magnitude. Most residuals fall within approximately ±10,000 USD, reflecting that the model's predictions are generally close to observed trade values. A few outliers are apparent, including a positive residual near +20,000 USD at the highest predicted value and a negative residual around –12,000 USD at mid-range predictions, corresponding to years when the model substantially under- or over-predicted trade. Overall, the absence of a discernible pattern or funnel shape indicates that the model satisfies the assumptions of linearity and homoscedasticity in its residuals.

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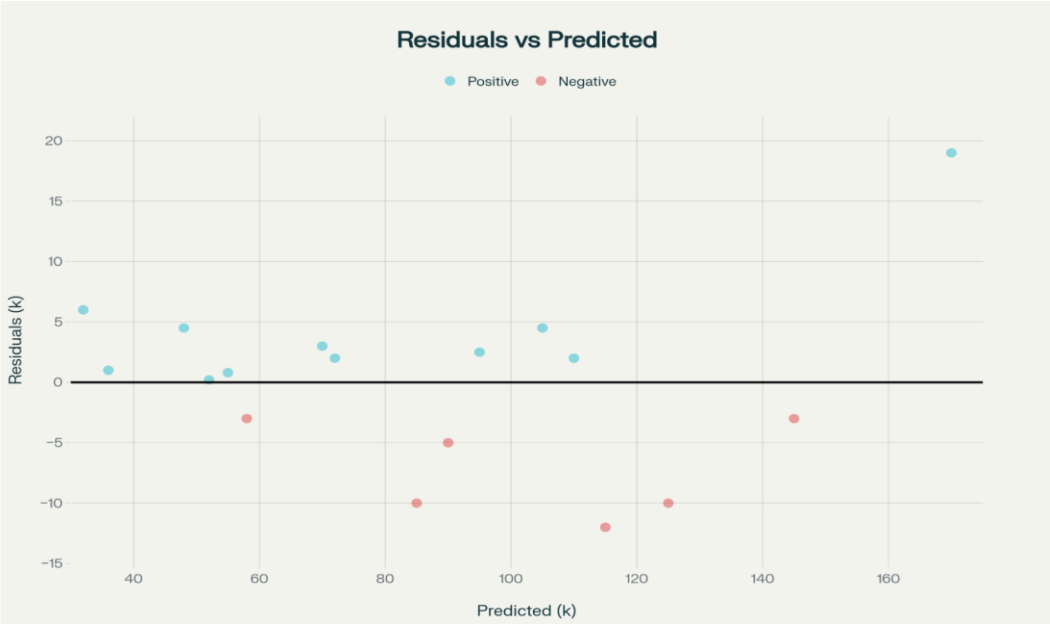

Figure 2: Residual Plot, the Residuals against the Fitted Values of Y

Based on the findings, the authors align with expert opinions suggesting that, in the future, the Polar Silk Road, particularly the NSR, is likely to emerge as a key driver of economic relations between China and Russia. Nevertheless, it is important to note that a high cargo volume along the NSR alone is insufficient to produce substantial trade growth, as illustrated by the 2025 forecast. Multiple additional factors influence projected bilateral trade volumes.

Geopolitical and Economic Policy: As previously discussed, sanctions have a measurable impact on trade forecasts. At the same time, enhanced cooperation within international frameworks such as the EAEU, BRICS (Brazil, Russia, India, China, South Africa), and the Shanghai Cooperation Organisation (SCO) remains critical in supporting trade development.

Logistical and Infrastructure Limitations: Constraints include a limited icebreaker fleet, inadequate port facilities along the NSR, competition from alternative transport corridors, and the seasonal nature of Arctic navigation, all of which restrict operational efficiency.

Trade Structure: Russia’s reliance on raw material exports, currency fluctuations, and limited diversification of non-resource and high-tech goods present notable obstacles. Similarly, China’s demand for energy resources plays a significant role, as Chinese GDP growth directly influences imports of Russian hydrocarbons.

Barriers to Finance and Regulation: Although melting Arctic ice reduces transit times,

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it introduces heightened risk of accidents along the route. In addition, stricter environmental regulations governing ship emissions and waste disposal pose further challenges to the safe and sustainable operation of the NSR.

DISCUSSION

The NSR represents a strategic commercial asset for China and Russia, particularly in the context of evolving global logistics shaped by climatic conditions, economic integration, and emerging alliances. The reduction of Arctic ice cover is increasingly enhancing the feasibility of maritime navigation, thereby opening opportunities for the Polar Silk Road. Empirical findings from this study indicate that variations in NSR cargo volumes have a statistically significant and positive impact on trade value between the two countries. These results align with Hong (2020), who noted that Arctic routing offers time- and cost-saving benefits for East Asia–Europe trade. Previous literature has similarly highlighted the potential of Arctic port and railway investments in China to improve trade efficiency. This study contributes to the literature by demonstrating that strategic NSR utilisation continues to support supply-chain diversification and deepens economic interdependence between Beijing and Moscow (Gerstl & Wallenböck, 2020).

Regression results further indicate that NSR cargo volume, together with major macroeconomic variables such as GDP, accounts for a substantial portion of observed bilateral trade variation. This supports Mercer et al. (2024), who argued that Arctic logistics planning must be context-sensitive and collaborative, integrating Indigenous knowledge, environmental protection, and long-term development objectives. Complementarily, Arctic transport infrastructure—traditionally oriented toward tourism—enhances the competitiveness of regional shipping routes through tangible improvements (Têtu et al., 2019). Comparative analyses in the study highlight the NSR's advantages in fuel efficiency and reduced transit times, while also drawing attention to long-term economic benefits of lower fuel consumption and reduced emissions (Makarova et al., 2022). Policy frameworks that ensure sustainability and effective connectivity further reinforce the strategic importance of the NSR within the broader Eurasian trade network (Plank et al., 2021).

Despite its economic potential, the NSR faces multiple constraints arising from environmental, regulatory, and infrastructural factors. Seasonal navigation restrictions, amplified by geopolitical tensions and the lack of permanent Arctic infrastructure, remain significant barriers to full commercialisation. These findings corroborate Sakib (2022), who highlighted that legal ambiguities and the absence of multilateral binding agreements contribute to operational shortcomings. Economists also note that anticipated commercial gains must be balanced against ecological impacts and the rights of Indigenous populations, as increased navigability due to climate change may exacerbate environmental pressures (Knight & Hastey, 2022). Furthermore, delays in

Arctic infrastructure development in Russia underscore chronic spatial imbalances in regional growth (Lazhentsev, 2021). Saros et al. (2022) caution that while shrinking summer sea-ice extends navigation periods, it simultaneously heightens ecosystem vulnerability, necessitating stronger governance mechanisms. Consequently, promoting the NSR requires long-term international cooperation and proactive planning to ensure sustainable operation over its projected lifespan (Zreik & Derendiaeva, 2025).

The analysis also confirms that GDP growth in China and Russia positively correlates with increases in bilateral trade, highlighting the mediating influence of domestic economic dynamism on commercial flows. Aggregate output measures are effective for forecasting the movement of grains, metallurgical products, and hydrocarbons, where energy and infrastructure investments remain crucial. Although the Trans-Siberian Railway's contribution is comparatively modest, results suggest that overland and maritime routes function in a complementary rather than substitutive manner (Pepe, 2020). The study further demonstrates that geospatial remote sensing and infrastructure diagnostics can systematically optimise the layout of multimodal transport systems (Fu et al., 2024). The effectiveness of corridor utilisation depends on the operational density of institutional structures and material interconnections (Li et al., 2022). Finally, the research underscores that clearly defined and measurable sustainability measures at maritime terminals are essential for aligning corridor development with ecological limits. Collectively, these findings support the conclusion that, despite a range of limiting factors, the NSR retains the potential to evolve into a principal axis of Sino-Russian trade cooperation (Zhang & Wu, 2023).

CONCLUSION

The development of the Polar Silk Road, centred on the NSR, marks a reorientation of Eurasian trade logistics, particularly within China–Russia relations. This study aimed to assess the NSR's strategic and economic implications for sustaining long-term bilateral trade. In the context of global supply chains challenged by geopolitical instability, climate change, and infrastructure strain, Arctic maritime routes are increasingly viewed as viable and, in some cases, necessary alternatives. Although the NSR continues to face seasonal navigation limits and infrastructure gaps, it offers clear advantages such as faster transit times, lower fuel use, and expanding geopolitical relevance that strengthens Sino-Russian cooperation. A mixed-methods approach supported the analysis. The qualitative component compared existing Eurasian transport corridors, while the quantitative component applied an OLS regression model to secondary data from 2015–2024. Key variables included NSR cargo throughput, GDP levels in China and Russia, and freight volumes along the Trans-Siberian Railway. The model's high explanatory power ($R^2 = 0.96$) indicates a strong link between NSR shipping volumes and overall trade turnover, confirming the NSR's role as an emerging structural contributor to bilateral trade growth when aligned with broader economic and infrastructure strategies. However, the route's realization as a stable commercial

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corridor still requires addressing major constraints: limited port and icebreaker capacity, lack of unified regulatory systems, climatic risks, and geopolitical uncertainty. Strengthening coordinated policy frameworks, sustained investments, and joint governance between China and Russia could support the NSR's transition into a year-round trade route. The study contributes to academic and policy discussions by demonstrating that Arctic shipping is already operational within Eurasian commerce. Future work could expand modelling to include environmental risk metrics and seasonal operational simulations to further map the evolving Arctic trade landscape.

STUDY LIMITATIONS

The study's findings are constrained by its reliance on secondary statistical sources, which may not fully reflect rapidly shifting geopolitical conditions or informal trade flows. Although the diagnostic tests support the robustness of the regression, the model cannot fully capture short-term volatility arising from climate-induced disruptions or abrupt regulatory changes. Moreover, because the Northern Sea Route is only navigable for part of the year, projecting year-round freight capacity remains speculative. Future research should incorporate primary observational data, scenario-based simulations, and probabilistic assessments of climatic and geopolitical uncertainties to offer a more comprehensive understanding of evolving trade trajectories.

FUTURE DIRECTIONS

The next phase of research should focus on integrating environmental risk modelling with climate scenario projections to better assess the long-term sustainability of the Northern Sea Route. Incorporating proprietary datasets from commercial carriers and Arctic infrastructure developers would improve the precision of projected trade pathways. Parallel examination of regulatory regimes, risk-sharing mechanisms, and multilateral governance arrangements would also clarify the route's developmental potential. Furthermore, agent-based and hybrid simulation frameworks, supported by real-time navigation data, could strengthen strategic planning and guide the gradual and sustainable evolution of Arctic shipping networks.

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