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ORIGINAL ARTICLE OPEN ACCESS

Challenges for Energy Transition: Incorporating Maritime and Geopolitical Risks

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Received: 17 September 2024 | **Revised:** 2 March 2025 | **Accepted:** 8 May 2025

Funding: This work was supported in part by the Helmholtz Association under the program 'Energy System Design' and the project 'Helmholtz platform for the design of robust energy systems and raw material supply' (RESUR). Open Access is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) (491111487).

Keywords: geopolitical risks | maritime transport | multiregional input–output-analysis | value chains

ABSTRACT

Recent global events have underscored the significant impact on global value chains. Incidents such as the Suez Canal blockage, supply shortages caused by the COVID-19 pandemic and the Ukraine-Russia war have raised concerns about potential future risks and how to measure them. Risk assessments are crucial for stakeholders throughout the supply chain and play an essential role with regard to economic welfare and sustainability, including considerations for energy transition. To assess risks in global supply chains, it is important to map these chains and quantify the potential disruptions that could occur. Our research specifically examines the risks related to the trade of intermediates used in production, factoring in risks associated with maritime transport routes. Using the automotive sectors of Germany, Japan and the United States as examples, our analysis reveals that, in many risk categories, the US automotive sector faces lower risks compared to its counterparts. The findings emphasise that supply chains inherently involve risks, which must be considered and balanced against one another. Importantly, a higher share of imports does not necessarily lead to increased risks. Therefore, reducing import shares is not always a viable strategy for risk mitigation.

1 | Introduction

Traditionally, discussions about value chain risks primarily focused on fuel supply, especially oil and access to critical resources (Cunado et al. 2020; Klimek et al. 2015; Koch 2020). However, recent global disruptions have expanded this focus. Events such as the blockage of the Suez Canal (European Central Bank 2022; Lee and Wong 2021), supply shortages caused by the COVID-19 pandemic (Tan et al. 2022) and Russia's ongoing war of aggression against Ukraine (OECD 2022) have highlighted a broader range of risks (see, e.g., (Kancs 2024)). As a result, global value chain risks have gained greater attention in policy discussions. Assessing these risks is crucial not only for economic stakeholders across the supply chain but also for welfare and sustainability, particularly in the context of the energy transition (Ali et al. 2023; Comi et al. 2024; Koch 2020).

Supply chain risk can be defined as disruptions to the 'normal' supply chain and the potential losses that result from these interruptions (Ersahin et al. 2024). These interruptions can stem from both natural and human-made sources, either directly or indirectly. They may be triggered by extreme weather events, earthquakes, violent conflicts, restrictive trade policies or technological failures. Importantly, these disruptions can have overlapping impacts and similar transmission mechanisms. For example, any disruption might render a transportation route within global value chains unusable, necessitating rerouting, leading to delays and increased costs (Pratson 2023).[1]

Global value chains are typically described and analysed within the context of their role in global trade from a macroeconomic perspective (see, e.g., Cui et al. 2023; Inomata and Hanaka 2024). However, there is also a substantial body of literature focused on supply chain risk management and resilience from a business administration and management standpoint (Ivanov 2023; Shi et al. 2023). This research emphasises the actions of decision-makers within individual firms, aiming to enhance resilience and effectively respond to disruptions. Strategies may include rerouting shipments, leveraging inventories or sourcing from alternative suppliers (Hosseini et al. 2019), as well as nearshoring or reshoring production (Roscoe et al. 2022). While some risks are internal to individual organisations, others pertain to the broader supply chain and its external environment. Typical (academic) risk assessments have primarily focused on specific resources, such as rare metals (Klimek et al. 2015; Olivetti et al. 2017) and fossil fuels (Cunado et al. 2020; Graaf et al. 2020; Li et al. 2022), as well as particular types of risks, including those related to war (Cui et al. 2023; Wang et al. 2022) or climate change (EEA 2024). While these assessments are essential for understanding the impacts of specific events and resources, they often fall short of providing a broader perspective on the many facets of supply chain risks. This broader perspective should include risks associated with the countries involved in the transportation and production of resources, intermediates and final products.

Our objective is to offer a fresh perspective and address existing gaps within these fields. Unlike many other risk assessment studies, our research presents a comprehensive approach to evaluating the risks associated with importing intermediates essential for domestic production, as well as the risks related to exports. By integrating these two aspects, we aim to provide a more holistic understanding of supply chain vulnerabilities and their implications for businesses and policymakers. We place particular emphasis on assessing how maritime transport routes influence overall risk levels of supply chains.

When developing a methodology for assessing risks in global supply chains, two major conceptual challenges arise. First, it is crucial to map the relevant supply chains accurately. Second, it is necessary to identify and quantify the relevant risks to evaluate their significance within the supply chain. These challenges have predominantly been explored in the literature related to transportation and geopolitical risk.

Various methodological approaches have been employed to map transportation aspects within supply chains, generally concentrating on tracking the flow of goods along physical routes (Ford and Abdulla 2023; Zheng et al. 2024). Given that a substantial portion of international trade occurs via maritime routes, globally transported goods, along with ports and container throughput, have become key indicators for tracing these flows (Dui et al. 2021; World Economic Forum 2024). Research on disruptions in maritime transport often differentiates between nodes (i.e., ports) and links, which represent the connections between these ports (Calatayud et al. 2017; Drobetz et al. 2021; Notteboom et al. 2021). Disruptions can occur at both levels; however, they are more frequently analysed at the port level (Plakandaras et al. 2019). Critical points along transport routes, referred to as chokepoints, have been identified by several studies (Bailey and Wellesley 2017; Girardi et al. 2023; Pratson 2023). Studies like Inomata and Hanaka (2024) show that while trade volume has primarily been used to identify critical points, the frequency with which a certain point is traversed in a value chain has been somewhat overlooked. Volume alone may indicate general goods flow but fails to capture the impact of a disruption at a frequently passed point.

Network theory has been applied to map and evaluate the interconnections formed between supply chain points due to maritime trade routes (Calatayud et al. 2017; Drobetz et al. 2021; Notteboom et al. 2021). Additionally, input–output (IO) tables and models serve as common tools for tracing the flow of goods across various production levels and regions or countries. They have also been utilised to assess risks in global maritime trade (Borin et al. 2021; Inomata and Hanaka 2024). Disruptions play a crucial role in global supply chains and maritime transport and their dynamics are examined more precisely in literature that focuses on geopolitical risks. This body of research frequently utilises geopolitical risk indices. A notable example is the Geopolitical Risk (GPR) Index developed by Caldara and Iacoviello (2022), which tracks geopolitical risk by monitoring coverage in major English-language news sources and considers factors such as social and political tensions, impacts of geopolitical risks (GPRs) on financial stress (NguyenHuu and Örsal 2024) as well as threats like war and terrorism. Although the GPR Index is comprehensive in its scope, it often overlooks other categories of risk in these analyses.[2]

Risk aspects have been addressed in various ways. However, there are notable gaps in the literature, specifically regarding two areas: (1) the combination of country-specific and transport-related risk assessments and (2) the evaluation of risks associated with the intermediates required to produce specific goods. Our study addresses this gap by developing a method to assess risks associated with the trade of intermediates that are crucial for production, as well as export-related risks. We place particular emphasis on analysing the impact of maritime transport routes and the risks linked to political instability in various countries. Our approach complements existing resource-focused studies by employing an extended multi-regional IO framework. By adapting this framework to include risk considerations—especially in relation to maritime transportation routes—we aim to enhance the analysis of supply risks associated with intermediate production.

To demonstrate the practical application of our approach, we empirically compare the risks faced by the automotive sectors in Germany, Japan and the United States. These countries were selected due to their substantial contributions to the automotive industry, which highlights the sector's significance in national economies (Yoshida and Sasaki 2024), its considerable impact on employment and its role in the ongoing energy transition (IEA 2023). Importantly, our approach accommodates various types of disruptions, whether they stem from natural disasters, political conflicts or crises such as disease outbreaks, by linking information on financial flows and transportation routes with relevant risk indicators. By doing so, we aim to address existing methodological gaps and offer a broader perspective on value chains and maritime transport within the context of diverse risks.

This paper is organised as follows: Section 2 presents our approach. Section 3 shows the results of employing our approach, particularly the risks related to the exports of final goods and the imports of intermediates needed for production. Conclusions are provided in Section 4.

2 | Method

We utilise a multi-regional IO (MRIO) model as the foundation for our analysis. These models are based on IO tables that detail the flows of commodities in financial terms, both within and between countries. In this study, we enhance the standard MRIO approach by integrating country-specific risk information, including institutional and socio-economic factors, as well as exposure to natural hazards. Furthermore, we incorporate data on the risks associated with maritime transportation routes. Figure 1 provides a schematic overview of our approach, while the following sections describe the methodology in detail. In the subsequent subsections, we outline the fundamental MRIO approach and our extensions concerning the assessment of risks directly associated with specific countries ('site-specific risks') and those related to maritime transport.

2.1 | Multiregional Input–Output Modell

2.1.1 | Basic MRIO Model

MRIO data not only provide insights into flows within a single region or country but also facilitate the analysis of interactions between the sectors of multiple countries or regions. As such, they can serve as a foundation for assessing transnational value chains (see, e.g., (Cabernard and Pfister 2021)). Basic IO models typically operate under the assumption that the share of a specific input factor remains constant, regardless of the production level of the sector utilising that factor. Additionally, IO models generally assume that the share of a specific input factor does not vary with the production level of the sector that employs it. These assumptions are often considered suitable for short-term analyses, such as the one conducted in this study (Miller and Blair 2009). Equation (1) represents the basic IO model:

$$X = (\boldsymbol{I} - \boldsymbol{A})^{-1}\, Y \qquad (1)$$

In this equation, vector X represents the production levels of different sectors, $\boldsymbol{A}$ denotes the matrix of fixed production coefficients, $\boldsymbol{I}$ is the identity matrix and vector Y represents the final demand vector (Miller and Blair 2009). This final demand vector reflects the aggregate demand from private households, government expenditures, investments and exports for specific commodities. This approach offers insights into both the direct and indirect demand for primary products, as well as the intermediates required to meet the specified final demand vector, Y.

Liang et al. (2016) noted that the Taylor expansion of the Leontief Inverse, $(\boldsymbol{I} - \boldsymbol{A})^{-1}$, can be used to describe production layers, as illustrated in Equation (2):

$$X = (I - A)^{-1} Y = IY + AY + A^2 Y + A^3 Y + \ \dots \qquad (2)$$

The term IY reflects the production of commodities required directly for the production of Y. Meanwhile, $\boldsymbol{A}Y$ represents the demand for intermediates necessary to produce Y. The additional terms on the right-hand side of Equation (2) describe both the direct and indirect requirements for producing these intermediates. This framework allows us to closely examine the effects on individual stages of value chains.

2.1.2 | Extending the MRIO

We extend the basic IO model by incorporating risk aspects into our analysis. Specifically, we account for risks that reflect the degree of instability in production within a particular country by including specific risk factors associated with the countries supplying the required inputs. In our study, we focus on the risks associated with value chains.

2.1.2.1 | Extension I: Site-Specific Risks. In the first step, we collect information on site-specific risks of countries ($Risk^{country}$) that supply commodities needed directly and indirectly for the considered value chain. In the next step, the identified factors are assigned to the output values of the IO model as follows:

$$Risk^{country} = \sum\nolimits_{c=1}^{n} \sum\nolimits_{s=1}^{m} \left(r_c * x_{c,s}^{vc} \right) \qquad (3)$$

In this equation, vc represents the commodity value chain, c denotes the country index, n is the number of countries, s indicates the sector and m is the number of sectors. The variable r refers to the country specific risk factor, and $x_{c,s}^{vc}$ is the value of quantity of commodity s produced in country c being required for value chain vc. $x_{c,s}^{vc}$ *is* derived by rearranging the X vector,

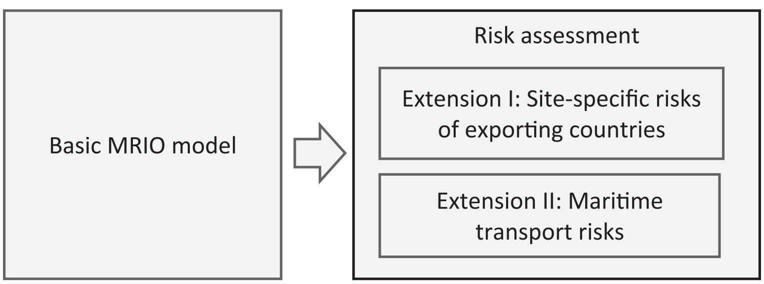

FIGURE 1 | Methodological approach.

where $x_{c,s}^{vc}$ correspond to x_i^{vc} with $i=(c\text{-}1)*m+s$. The quantity x_i^{vc} is calculated based on the given y_j^{vc}, where y_j^{vc} represents the element of the final demand vector that reflects the demand for the commodity whose value chain is under consideration. Implicitly, we assume that as the demand for production values increases within the value chain, the corresponding risk level will also rise.

2.1.2.2 | Extension II: Maritime Transport Risks. To incorporate transport route-related risks into our analysis, we closely examine shipping routes. Specifically, we consider the risks associated with maritime chokepoints, which are defined as 'geographic constraints shaping sea routes' (Weitz 2018). By utilising information on shipping routes between countries worldwide, along with data on the chokepoints that must be navigated along these routes, we develop a country-by-country route matrix. This matrix delineates the chokepoints that are typically traversed when transporting a commodity from one country to another.

Inomata and Hanaka (2024) emphasise that, in addition to trade volume, the frequency with which chokepoints are traversed (e.g., through the shipment of intermediates) significantly influences the risk associated with value chains. To assess the frequency of shipping routes and, consequently, the frequency of chokepoints crossed, we analyse commodity requirements at different production stages while explicitly considering the geographical interlinkages between sectors. To facilitate this analysis, we employ a final demand matrix $\hat{\boldsymbol{Y}}$ instead of the standard final demand vector Y. This new matrix includes individual final demand vectors for each country, whereas Y only provides aggregated demand, failing to account for the spatial origins of that demand.

The model is thereby calculated in several stages. These stages are indicated by superscript denoted *stage* and range from stage zero to stage 3. Each stage is specified in the following.

To account for regional interlinkages, $\hat{\boldsymbol{Y}}$ is implemented as squared matrix with the dimension $(n*m)\times(n*m)$. In the first step we specify matrix $\hat{\boldsymbol{Y}}$ by assuming $\hat{y}_{j,j}=y_j^{vc}$ for the initial demand and 0 otherwise. By multiplying matrix $\hat{\boldsymbol{Y}}$ and $\boldsymbol{A}$ we obtain the output matrix $\hat{\boldsymbol{X}}^{Stage_0}$. This matrix not only provides information on the intermediates required to meet the demand but also delineates the spatial origins of that demand.

In the subsequent step, we evaluate the requirements for producing the intermediates. To incorporate shipping routes into our analysis, we need to rearrange the elements of $\hat{\boldsymbol{X}}^{Stage_0}$ before we can utilise the results of the calculations for the next production level. The elements of $\hat{\boldsymbol{X}}^{Stage_0}$ are assigned to the new demand vector $\hat{Y}^{Stage_{+1}}$ by considering the regional dimensions of the corresponding elements in $\hat{\boldsymbol{X}}^{Stage_0}$. This ensures that the specific regional dependencies are accurately reflected in the assessment of intermediate production needs.

For example, if electronic equipment from Japan is identified in the initial stage as a relevant input for German vehicle production, we analyse the requirements for producing this electronic equipment at the second stage. This analysis involves assigning the calculated values from the previous stage as final demand, while considering that the required intermediates are destined for Germany. By doing so, we can assess the entire supply chain, ensuring that the dependencies and geographical relationships are accurately integrated into the subsequent production requirements.

For simplification, we aggregate all the demands for the specific commodities. Equation (4) reflects this data rearrangement and the assignment of the output from the previous stage as the demand for the next stage:

$$\hat{y}_{j,j}^{Stage_{+1}} = \sum\nolimits_{k-1}^{z} \hat{X}_{j,k}^{Stage_0} \tag{4}$$

Equation (5) illustrates the calculation of the production values for the next stage and Equation (6) the aggregation of flows from one country to another:

$$X^{Stage_{+1}} = A * \hat{Y}^{Stage_0} \tag{5}$$

$$X\_agg^{Stage_{+1}} = S * X^{Stage_{+1}} * S^T \tag{6}$$

where $X\_agg^{stage\ l}$: Matrix reflecting aggregated financial flows between countries.

S: Aggregation matrix of dimension $n\times(n*m)$.

S^T : Transposed aggregation matrix.

The calculations for stages 2 and 3 follow the calculation for stage 1.

Risks related to the demand for intermediates and associated with shipping routes ($Risk^{Maritime\_imp}$) are assessed by multiplying shipping route specific risk factors by frequencies of using the routes and adding up the resulting risks.

$$Risk^{Maritime\_imp} = \sum\nolimits_{c1}^{n} \sum\nolimits_{c2}^{n} riskroute_{c1,c2} * \left(x\_agg_{c1,c2}^{stage\ 0} + x\_agg_{c1,c2}^{stage\ 1} + \dots\right) \tag{7}$$

with $riskroute_{c1,c2}$: Risk of maritime transport between countries $c1$ and $c2.x\_agg_{c1,c2}^{stage\ 0}$: Element of matrix $X\_agg^{stage\ 0}$ reflecting financial flows between countries $c1$ and $c2$.

The export-related risks of country *c1* are calculated accordingly by:

$$Risk^{Maritime\_ex} = \sum\nolimits_{c2=1}^{n} riskroute_{c1,c2} * \text{ex}\_agg_{c1,c2}^{vc} \tag{8}$$

where $\text{ex}\_agg_{c1,c2}^{VC}$: Financial flows related to final product of value chain vc being produced in country $c1$ and exported directly to country $c2$.

2.2 | Model Specification and Data Used

2.2.1 | MRIO Data

We make use of the OECD (2024) multiregional IO table for 2018, published in 2021, which includes data from 67 countries and regions across 45 sectors.[3] While our primary focus is on the motor vehicle sector in these countries, we also consider other countries and sectors to ensure a comprehensive analysis. We use this selected sector and the chosen countries as illustrative examples for our analysis, while also accounting for the multi-regional context that encompasses all other regions and sectors contained within the IO table.[4]

2.2.2 | Risk Related to Specific Countries

For the general risk assessment, we utilise country-specific risk factors from INFORM published for the year 2025 (Marin-Ferrer et al. 2017). INFORM is a collaborative initiative involving the Inter-Agency Standing Committee Reference Group on Risk, Early Warning and Preparedness, as well as the European Commission. The risk assessment conducted by INFORM (2025) is based on 76 indicators, which include exposure to natural disasters such as earthquakes, floods and droughts, as well as socio-economic vulnerabilities determined by factors such as inequalities and poverty, the presence of vulnerable groups, risks at the institutional level and infrastructure-related risks. In this system, a score of 1 indicates the best value (lowest risk) and a score of 10 indicates the worst (highest risk). Since the INFORM data are available for 191 countries, while the MRIO table from the OECD includes only 67 regions/countries, we adjust the INFORM data to align with the country classifications used by the OECD. This adjustment entails aggregating countries that are not individually listed into a category labelled 'rest of world'. This approach allows us to maintain consistency and relevance in our analysis while ensuring that we capture risks across all countries represented in the MRIO framework.

2.2.3 | Transport Routes

Using information on default shipping routes published by SEARATES (2024), we identify the shipping routes between the countries included in the MRIO database. In the next step, we focus on the so-called chokepoints that must be navigated along these shipping routes, as they represent critical points of vulnerability in maritime logistics. A list of maritime chokepoints, along with their associated risks, is presented in Figure 2. For the risk assessment related to these chokepoints, we utilise data from Girardi et al. (2023) and Bailey and Wellesley (2017). The information on shipping routes, combined with data on chokepoints, is organised into a country-by-country matrix. This matrix illustrates the specific chokepoints that are typically traversed when transporting a commodity from one country to another.

In the next step, we convert the risk information provided in Figure 2 into numerical values by coding low risk as 1, moderate risk as 2 and high risk as 3. Using this coding system, we calculate an average risk factor for each chokepoint, assuming that no single risk category significantly dominates the others. Subsequently, we link this risk information to the shipping routes, specifying the set of chokepoints associated with each route between the countries represented in the MRIO model. As a result, we create a country-by-country matrix, termed *Riskroute*, where each cell $riskroute_{c1,c2}$ contains the calculated risk factors associated with the shipping routes between country $c1$ and country $c2$.

3 | Results

We present our key results in the following subsections. We begin with the calculated risks associated with the export of the final product from the 'Motor Vehicles' sector. Following that, we present the results of the site-specific risk assessment and our analyses of the risks related to the maritime transport of intermediates.

3.1 | Export-Related Risk

According to OECD data from 2018, Germany's exports in the motor vehicle sector amounted to approximately $250.4 billion, making up about 16% of the country's total exports. In comparison, Japan's motor vehicle exports totalled around $156.8 billion, while the United States led with approximately $521.6 billion in exports for the same sector. As Germany, Japan and the United States supply motor vehicle commodities to various countries, the associated risk profiles for these exports differ significantly based on their destination countries. Figure 3 illustrates the distribution of motor vehicle exports alongside shipping

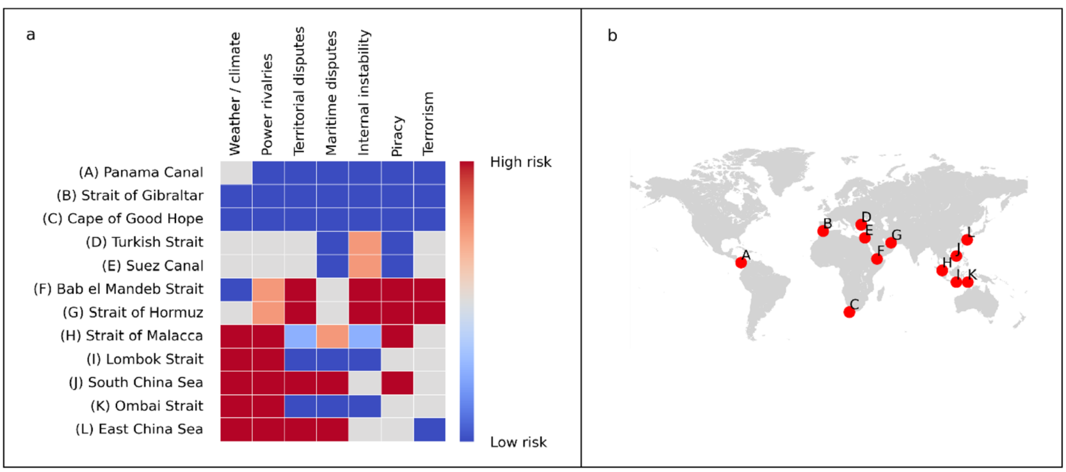

FIGURE 2 | Shipping routes and their risks. Author compilation based on data from Girardi et al. (2023), Bailey and Wellesley (2017) and Kpler (2024). [Colour figure can be viewed at wileyonlinelibrary.com]

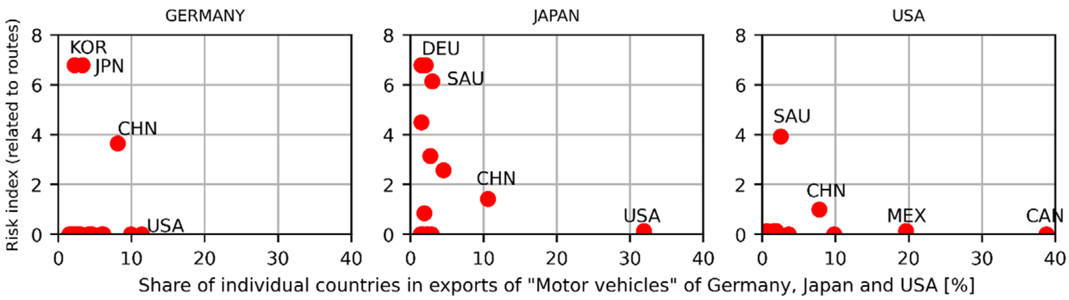

FIGURE 3 | Risk profiles for Motor vehicle exports (excluding risks associated with exporting countries). A risk index of 8 indicates that the export route involves traversing two high-risk chokepoints and one medium-risk chokepoint. In contrast, a risk index of 0 signifies that there are no risky chokepoints along the route. [Colour figure can be viewed at wileyonlinelibrary.com]

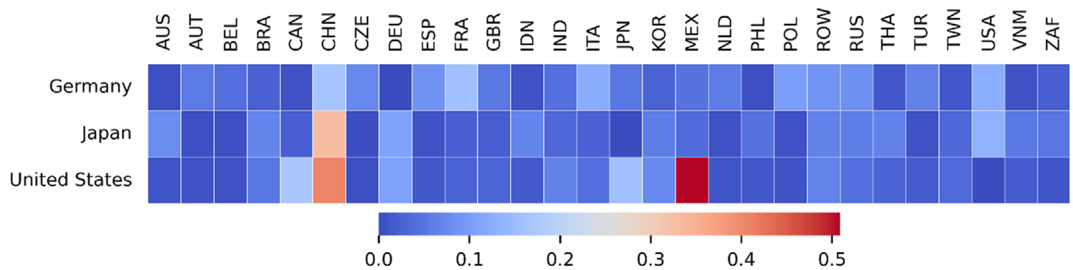

FIGURE 4 | Risks associated with imports needed for production of motor vehicles (normalised to a value of $1, excluding maritime transport risks). [Colour figure can be viewed at wileyonlinelibrary.com]

route-related risks, highlighting the variations in risk exposure linked to the export dynamics of these three nations.

According to the OECD database, over 11% of Germany's motor vehicle exports are directed to the United States, with an additional 10% shipped to Great Britain. The risk assessments for these shipping routes indicate negligible risks, yielding a risk index of 0. However, higher risks are associated with Germany's exports to China, Japan and South Korea. In contrast, Japan's export strategy is more concentrated. Approximately 32% of Japan's motor vehicle exports go to the United States, while another 10% are destined for China. These export routes are assessed to carry low risks. On the other hand, Japan faces higher risk values for its exports to Germany and the rest of Europe. For the United States, a significant portion of motor vehicle exports is directed to Canada (39%) and Mexico (20%), both of which present very low transportation risks. This distribution indicates that while Germany encounters notable risks in certain Asian markets, Japan enjoys a relatively low risk profile in its exports—especially to the United States—while the United States benefits from low-risk export routes to its neighbouring countries. Next, we consider the implications of import-related risks.

3.2 | Import-Related Risks

With up to 47% of the intermediates needed for motor vehicle production in the selected countries being imported—Germany at 47%, Japan at 28% and the United States at 37%—the sector faces not only export-related risks but also potential disruptions in the supply of these intermediates. Figure 4 illustrates the calculated risks for various countries that play a direct and indirect role in supplying the necessary intermediates for motor vehicle production. The risk values are derived by multiplying specific risk factors published by INFORM with the calculated direct and indirect demand for these commodities. This assessment highlights the vulnerability of the motor vehicle sector to supply chain disruptions and the importance of understanding both export and intermediary supply risks.

Our analysis indicates that Germany has a relatively low risk profile in international comparison regarding its motor vehicle sector. The highest risk factor is attributed to China, which significantly influences Germany's risk profile due to the high demand for goods originating from China that are indirectly necessary for production in the motor vehicle sector. In contrast, Japan places greater emphasis on commodities sourced from China compared to Germany. As a result, the overall risk index for Japan's motor vehicle sector is heavily shaped by the risk associated with China, leading to a notable concentration of risk in this area. For the United States, the sourcing of intermediates for the motor vehicle sector primarily comes from Mexico and China, followed by Japan and Canada. These countries play a crucial role in determining the overall risk profile for the United States. Given that these countries exhibit relatively high country-specific risks, our calculations indicate that the overall risk for the United States is greater than that of both Germany and Japan. This underscores the importance of addressing supply chain vulnerabilities, particularly for the United States, where reliance on high-risk sources could pose significant challenges to the stability and resilience of the motor vehicle sector.

Overall, our calculations indicate that Germany has a risk index of 2.5 per a demand for intermediates of $1. Japan also has a risk index of 2.5, while the United States exhibits a slightly higher risk index of 3.0. This finding highlights an interesting

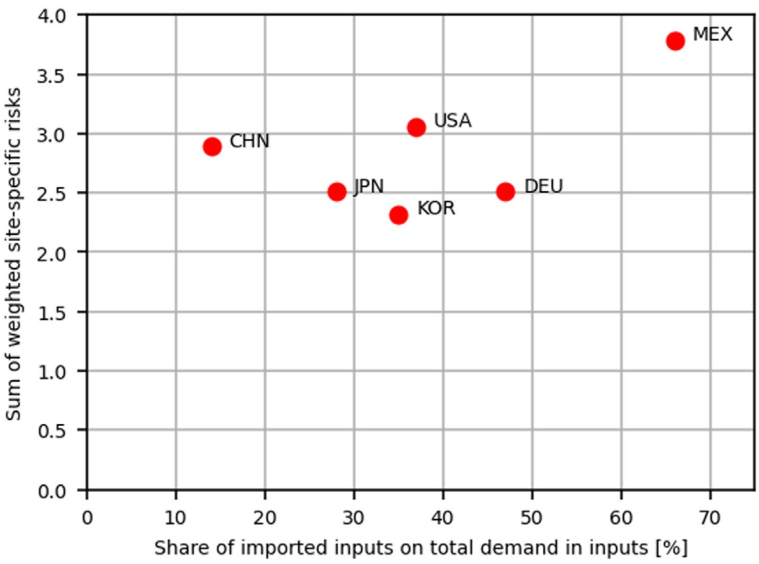

FIGURE 5 | Risks versus import share (Example: Motor vehicle sector). A weighted site-specific risk score of 10 indicates that all required intermediates are sourced from the countries with the highest risk levels. [Colour figure can be viewed at wileyonlinelibrary.com]

dynamic: despite the US having a lower import share compared to Germany, it presents a higher risk index. This leads us to conclude that a higher import share does not necessarily equate to increased risks. Therefore, the hypothesis that reducing import shares is always a desirable strategy for risk mitigation should be approached with caution. Several factors, including the specific sources of imports, the reliability of supply chains and the geopolitical context, can significantly influence the overall risk profile (Figure 5).

Regarding maritime transport risk (representing risk of choking points that have to be passed on a shipping route and the frequencies shipping routes are used) our calculation indicates the highest risk index for Germany whereby the choking point 'Bab el Mandeb Strait' contributes to 49% to Germany' risk (Table 1). For Japan's 'Motor vehicles' sector we calculated a lower index resulting from shorter distances for intermediates being directly and indirectly used for the production of the sector. Since imports of the United States are to a lesser extent transported on risky maritime transportation routes (incl. 'Bab el Mandeb Strait') we observe a relatively low risk for US's 'Motor vehicles' sector.

In terms of maritime transport risk—assessing the risk associated with chokepoints that shipping routes must navigate and the frequency with which these routes are used—our calculations show that Germany carries the highest risk index. Notably, the Bab el Mandeb Strait accounts for 49% of Germany's maritime transport risk (as shown in Table 1). For Japan's motor vehicle sector, we calculated a lower risk index, primarily due to the shorter distances for intermediates that are directly and indirectly utilised in production. In contrast, the US's motor vehicle sector experiences relatively low risk because a smaller proportion of its imports are transported through high-risk maritime routes, including the Bab el Mandeb Strait. This analysis highlights the varying levels of maritime transport risk faced by these countries, with Germany being the most vulnerable due to its reliance on specific chokepoints.[5]

TABLE 1 | Shipping route specific risks.

	DEU	JPN	The United States
Risk related to 'Bab el Mandeb Strait'	0.10	0.11	0.03
Risk related to other chokepoints	0.11	0.40	0.13
Total	0.21	0.51	0.16

Note: A risk index of 0.5 indicates that for every $1 of final demand, intermediates valued at $0.50 are being transported along low-risk maritime routes. A lower risk index indicates that a smaller value of intermediates is required on these low-risk routes.

3.3 | Overall Assessment

Table 2 provides a comparison of the three selected countries concerning various types of risks. To facilitate understanding, we normalised the specific risks by setting the highest risk value in each category to 100%, subsequently rescaling the values for each country's specific risk factors. According to our calculations, Germany's motor vehicle sector ranks second across all selected risk categories, largely due to its high direct and indirect demand for commodities. In contrast, the US's motor vehicle sector faces the lowest risks for both import and export shipping routes, as it utilises less risky transport routes for these commodities. Japan's motor vehicle sector relies on riskier transport routes for its commodity imports, resulting in a higher risk profile. Although Japan requires fewer intermediates from other countries, our analysis indicates that it occupies a riskier position compared to both the United States and Germany due to the longer and more hazardous transportation routes involved in its supply chain. The comparison across these three countries reveals that the US's motor vehicle sector is ranked as less exposed to risk compared to its counterparts, underscoring its advantages in risk management and supply chain strategy.

TABLE 2 | Risks comparison using normalised risks (highest risk set to 100%).

	Imports - Sum of weighted site—specific risks	Import—Maritime transport	Export—Maritime transport
DEU	88%	41%	58%
JPN	76%	100%	100%
United States	100%	31%	16%

3.4 | Risk Responses and Their Potential Impacts

The overall risks associated with on-site challenges in countries exporting intermediates essential for production can be effectively mitigated by shifting procurement to lower-risk countries. Likewise, transportation-related risks can be alleviated by opting for safer shipping routes. To evaluate potential responses to these risks, it is important to analyse the feasibility of modifying supply chains within each country, which would involve examining the supply curves for individual products. However, this type of analysis is inherently complex (Ersahin et al. 2024) and extends beyond the scope of this paper. Addressing these complexities would require a comprehensive approach that considers various economic, political and logistical factors influencing supply and risk management strategies.

Using the Suez Canal—Bab el Mandeb Strait route as a small example, we can illustrate the potential power and complexity of analysing supply chain dynamics. If a company has selected a supply country and transportation mode based on the criterion of lowest transportation costs, any modification to the supply chain, such as shifting to a lower-risk country or alternative transport routes, is likely to lead to increased expenses. For instance, Pratson (2023) estimates that selecting the Cape of Good Hope route instead of the Suez Canal—Bab el Mandeb Strait route could extend shipping duration by approximately 10 days. Given a charter rate ranging from $10,000 to $35,000 per day for a capsize vessel (UNCTAD 2022) with a capacity of 180,000 deadweight tons (DWT), the increase in transportation costs could range from about $0.60 to $1.90 per ton. Moreover, the environmental impact must also be considered. We can expect an increase of around 140 tons of CO_2 emissions per day, based on an assumed fuel consumption of 45 metric tons of fuel per day (Maritime Page 2023) and an average emission factor of 3.15 tons of CO_2 per ton of fuel (Marine Benchmark 2020). Taking into account the vessel's capacity and the extended shipping time, we calculate an additional emission increase of 0.01 tons of CO_2 per ton transported. Using Germany's motor vehicle sector and the decision to avoid the Suez Canal—Bab el Mandeb Strait route as an illustrative example, we conclude that while efforts to reduce transportation risk by 30% may enhance supply chain stability, they could also lead to a slight increase in both additional costs and carbon emissions.

The calculations of costs and emissions per day can also be applied to other scenarios involving changes in maritime transportation times. Because our calculations focus on the tons of goods transported by vessels, analysing the transport of necessary intermediates requires converting financial flow data into mass flows measured in tons. To achieve this conversion, we need more detailed information about the commodities being traded.

4 | Discussion and Conclusions

This paper contributes to the existing literature on global value chains, maritime transport and geopolitical risks by presenting a new methodological approach for risk assessment tailored to value chains. We analyse the Japanese, German and US motor vehicle industries to highlight both country-specific and transport-specific risks, quantifying these risks using an expanded Multi-Regional Input–Output (MRIO) approach.

A key advantage of our methodology is its ability to account for various types of risks, including political, social and natural disruptions, in addition to transport-related issues. This is a departure from previous studies that primarily concentrated on conflicts and political instability, often neglecting other potential sources of chokepoint disruptions. Our analysis demonstrates how threats to value chains can be incorporated into risk assessments, highlighting the crucial role of transportation routes and the diverse range of inputs required, both directly and indirectly.

Our analysis reveals that, in many risk categories assessed, the US motor vehicles industry experiences lower risks compared to its German and Japanese counterparts. This advantage stems not so much from a greater share of domestic production of necessary intermediates, but rather from the relatively low-risk maritime transportation routes it employs. However, a considerable portion of required inputs still comes from countries with higher associated risks, such as Mexico and China.

Furthermore, while our approach considers the frequency of encountering risky points along transportation routes—a factor increasingly recognised in recent studies—most prior research has largely focused on volume. Our model enhances the understanding of trade and transport dynamics by analysing how risk intensifies when a chokepoint is crossed multiple times. Importantly, our general method for assessing risks is not confined to the motor vehicles sector; it can be easily applied to other sectors and groups of sectors, including those dealing with commodities essential for complex technologies.

However, our database limits our analysis to the sector classifications defined by the OECD, which means we cannot model specific products, such as cars, in detail. While this paper presents a comprehensive model that addresses the complex risk factors impacting maritime transport and global trade, it mainly offers insights into effective risk management strategies and highlights areas for further research.

In connecting to the literature on value chain resilience, the model demonstrates how specific risks of disruptions on value chains can be addressed in practice. Incorporating factors related to the distribution of resources and economic power could further enrich the model, providing deeper insights into how decisions made by economic and political actors shape risk assessments for countries and industries. Finally, while we touch on sub-risk categories like the impact of climate change on maritime transportation routes, our analysis lacks a more thorough examination of risk avoidance strategies. This represents an important area for future research.

Disclosure

Declaration: During the preparation of this work, the authors employed OpenAI solely for language editing purposes. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Acknowledgements

Open Access funding enabled and organized by Projekt DEAL.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available provided by INFORM (https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk/Results-and-data/) and OECD (https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm). Additional data that support the findings of this study is listed in the manuscript.

Endnotes

[1] For a more thorough classification of different risks impacting value chains see, for example, Christopher and Peck (2004), Manuj and Mentzer (2008), or World Economic Forum (2024). These publications differentiate between various types of supply chain risks, such as supply, demand, operational and others. However, these distinctions are primarily focused on individual firms and do not directly apply to the context of this paper.

[2] Table A1 in the Appendix A offers an overview of select publications along with their thematic focus, showcasing the extent to which they address the various areas outlined above.

[3] These are the most robust and representative data available at the time of writing. Later data may be significantly distorted due to COVID-19 restrictions in place during that period. Therefore, we advise caution when interpreting our results, considering the base year of the data. However, we want to emphasise that the qualitative results presented in our study will remain largely unchanged, even if more up-to-date data were to be used.

[4] The degree of sector definition establishes the level of aggregation of the value chain under consideration. In this study, the value chain analysis is conducted for average products within the sectors of the OECD table rather than for individual commodities. Consequently, our analysis focuses on the average commodity produced by the "Motor vehicles" sector. This sector corresponds to the ISIC sector 29, which encompasses the "Manufacture of motor vehicles, trailers, and semi-trailers," and includes not only the production of motor vehicles for transporting passengers or freight but also the manufacturing of parts and accessories for motor vehicles. Therefore, the sector's scope extends beyond just passenger and commercial cars, and it does not pertain to any specific make or model of vehicle. Accordingly, our analysis differs from life cycle assessment (LCA) studies that are conducted for specific cars. While car-specific LCA analyses provide detailed insights into the environmental impacts of individual vehicles, our analysis focuses on international linkages and the risks associated with the need for intermediates within a broader context.

[5] The robustness of the results was analysed by conducting several sensitivity analyses (see Appendix B). In particular we modified risk assessments of chokepoint, risk categorization of selected countries and underlying economic structures. The sensitivity analyses carried out indicate a high degree of robustness of the results.

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Appendix: Literature Review A

TABLE A1 | Examples of studies on risks.

		Focus of research		Considered risks					
	Approach/method	Supply chains (without explicit consideration of maritime transport)	Transportation routes/maritime transport	Geo-political risk in general	Natural	Disease/pande-mic	Social/political	Econo-mic	Other/un-specified
Plakandaras et al. (2019)	Oil price data, GPR index, TVP-VAR forecasting	x (specific resource)		x			(x)		
Li et al. (2022)	GPR index, oil price (EIA), Chinese stock market data, nonlinear Granger causality, network model	x (specific resource)		x			(x)		
Pratson (2023)	GIS data of international shipping lanes, bilateral trade data		x	x					
Inomata and Hanaka (2024))	Input–output data (OECD, 2021), network theory (modelling of supply chain network concentration and centrality)	x		x					
Caldara and Iacoviello (2022)	News-based index			x			(x)		
Ross et al. (2025)	Dynamic nonequilibrium model based on MRIO data.	x		x			x	x	
Drobetz et al. (2021)	GPR index, U.S. Economic Policy Uncertainty Index (EPU), freight rates (net of operational and voyage costs, i.e., earnings), BVAR model (Bayesian)		x	x			(x)	x	
Cui et al. (2023)	UN Comtrade Database for energy import and export data, multi-sector general equilibrium model	x (energy- specific)					x		
Notteboom et al. (2021)	Container shipping, port data and operators' business data		x			x	x		
Borin et al. (2021)	Input–Output data, Trade in value-added (TiVA) model	x						x	
Hou et al. (2024)	GPR index, Trade cost data (World Bank), (panel) regression analysis	x		x			(x)		
Bailey and Wellesley (2017)	CH-MAT tool (combining trade, transport, logistics and energy supply risk data)	x (food-specific)	x	x	x		x	x	
Viljoen and Joubert (2016)	(complex) network model based on port and shipping data		x	x					

(Continues)

TABLE A1 | (Continued)

		Focus of research		Considered risks					
	Approach/method	Supply chains (without explicit consideration of maritime transport)	Transportation routes/maritime transport	Geo-political risk in general	Natural	Disease/pande-mic	Social/political	Econo-mic	Other/un-specified
Calatayud et al. (2017)	(complex) network model based on port and shipping data (for the Americas)		x					x	
Dui et al. (2021)	(complex) network model with selected ports and shipping data		x	x	Implicit	Implicit	Implicit		
Qin et al. (2023)	QQR regression; SOI (southern oscillation) and GPR index, GSCP index (AMEC, Federal Reserve Bank) for supply chain pressure	x			x	Implicit	x		
Our approach	MRIO	x	x	x[a]			x[a]		

[a]Aggregated, with possibility for disaggregation.

Appendix B

Sensitivity Analysis

To evaluate the robustness of our results, we conduct several sensitivity analyses. First, we perform calculations using the series of site-specific risk indices published by INFORM. Figure B1a illustrates that the impact of these site-specific risk indices on the import risks for the United States (USA), Japan (JPN) and Germany (DEU) remains stable across time, with only slight increases in Germany's import risk observed in the most recent periods. In a next step, we assess the robustness of risk factors against changes in economic structures, including shifts in value chains, by analysing input–output tables from different years. The resulting impacts on risks per $1 demand of intermediates are presented in Figure B1b.

Our findings indicate that the calculated specific import indices are less sensitive to variations in the underlying historical input–output table results than to the location-specific risk factors from other years.

Impacts resulting from changes in risk classification of selected countries are presented in Table B1. According to our calculations, increases in the risk performance of China impact Germany, Japan and the United States stronger than changes in the risk performance of the Russian Federation (Table B1).

Table B2 illustrates the effects of variations in the risk classification of maritime chokepoints. Specifically, we modified the risk factors for the chokepoints Panama Canal, Bab el Mandeb and Strait of Hormuz, and perform new calculations. For Germany, we observe only minor impacts. In contrast, Japan and the United States may experience more significant effects, with the most pronounced impacts identified for the United States due to the rising risk associated with the Panama Canal.

In summary, our sensitivity analyses underline the high degree of robustness of the results.

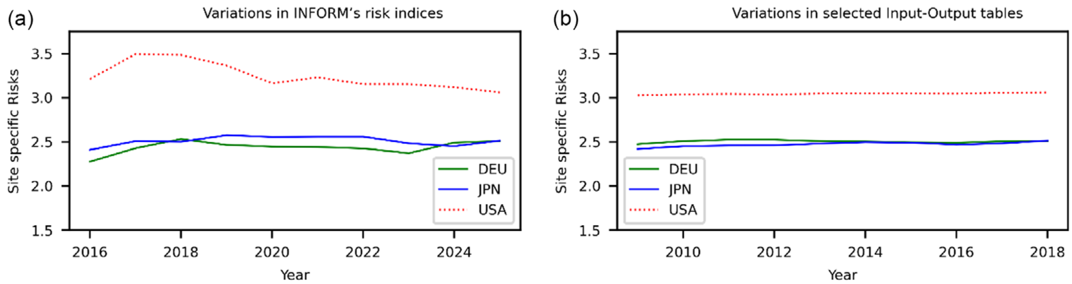

FIGURE B1 | (a, b) Sensitivity Analysis—Impacts of variations of INFORM's risk indices and underlying historical input–output tables. X-Axis shows years risk indices and input–output tables refer to. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE B1 | Import risks for selected countries (unweighted site-specific risks).

Modified site-specific risk index	Modification	DEU	JPN	USA
None		1.82	1.55	2.08
China	Low (2.9)* to medium (4.0)	1.89	1.69	2.25
Russian Federation	High (5.1)* to very high (6.7)	1.84	1.57	2.10

Note: Remarks: *INFORM (2025) values for 2025, for classification of low, medium, high and very high.

TABLE B2 | Sensitivity analysis—Impacts of variations in assumed risk factors for selected chokepoints.

Modified chokepoints	Modification	DEU	JPN	USA
None		0.20	0.46	0.12
Panama Canal	Low risk (1.1[a]) to moderate risk (2[a])	0.22	0.53	0.31
Bab el Mandeb	Moderate risk/high risk (2.5[a]) to high risk (3.0[a])	0.23	0.53	0.17
Strait of Hormuz	Moderate risk/high risk (2.6[a]) to high risk (3.0[a])	0.21	0.51	0.16

Note: Remarks: Risk factors represent average risks of chokepoints, compilation based on data from (Girardi et al. 2023), (Bailey and Wellesley 2017).
[a]Low risk is indicated by '1', high risk by '3'.