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**THREE STUDIES ON SUSTAINABLE SHIPPING
MANAGEMENT: BALLAST WATER IMPACTS, MARKET
VOLATILITY, AND SEAFARERS' RIGHTS**

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Three Studies on Sustainable Shipping Management: Ballast Water
Impacts, Market Volatility, and Seafarers' Rights

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A thesis submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

August 2025

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Abstract

Sustainable shipping management is vital for achieving the United Nations' 2030 Agenda for Sustainable Development, addressing environmental (SDG 14), economic (SDG 8), and social (SDG 16) objectives. However, the evolving nature of international trade presents new challenges for maintaining the triple bottom line in the shipping industry. This thesis comprises three empirical studies that investigate the forecasting issues in ballast water, the causal inference issues in market volatility, and the policy evaluation issues in seafarers' rights.

Study 1 develops a generic approach to estimate ballast water discharge volumes and assess associated non-indigenous species invasion risks, employing the LASSO technique in machine learning and a three-stage biological risk spread probability model. Drawing on common port statistics and biogeographical and environmental parameters of ten Chinese ports, this study forecasts ballast water discharges from bulkers and tankers in China during 2017–2020 and the associated invasion risks in 2017. The study reveals that ports in the Yangtze River Delta and the Bohai Rim receive the most ballast water, tankers have greater discharge potential than bulkers at a per-unit cargo throughput capacity, and Chinese ports face a high probability of alien species introduction exceeding 0.9. This study provides a feasible decision-making tool to help developing countries without ballast water records, such as China, implement the Ballast Water Management Convention during its initial experience-building phase.

Study 2 disentangles the relationship between internal spillovers across shipping spot freight markets and external uncertainties. Utilising VAR-based methods, Diebold–Yilmaz spillover indices are constructed for container, dry bulk, dirty, and clean tanker spot markets from 2009 to 2023. The Granger causal and shock effects of Economic Policy Uncertainty (EPU) and Geopolitical Risk (GPR) on these indices are examined, with particular attention to the post-COVID-19 period. The study proves that the pandemic has altered the roles of net spillover transmitters and receivers within the four freight markets, while intensifying the causality and shock impacts of EPU and GPR on spillovers. Additionally, the study indicates that EPU and GPR affect spillovers through distinct mechanisms, with tanker markets acting as mediators that amplify uncertainty shocks. These findings provide policy implications for shipping stakeholders to mitigate uncertainty impacts.

Study 3 analyses the effectiveness of the Maritime Labour Convention (MLC) and its financial security amendments in protecting the rights of abandoned seafarers. Using abandonment reports from 2017 to 2023, the study constructs a new dataset and identifies crucial factors affecting repatriation and wage payment rights. With nested logit and fixed

effects models, these factors' effects on the choice probabilities and time efficiency of repatriation and payment are evaluated. The study reveals that Asian abandonment locations and mixed crew nationalities lower repatriation probability, while older ships decrease wage payment likelihood. Port State Control facilitates neither the likelihood nor the timeliness of repatriation. Flag of convenience States and Protection and Indemnity clubs indeed benefit the resolution process of abandonments, but it still takes more than half a year. The findings highlight the MLC's shortcomings and provide quantitative evidence to support improvements to its relevant provisions.

Keywords: sustainable shipping management; ballast water estimation; risk assessment of non-indigenous species; external uncertainty; volatility spillover; seafarer abandonment; repatriation rights; wage payment rights

Publications Arising from the Thesis

Publications of Journal Papers:

- [1] **Chen, D.**, Bai, X., Wang, Z., & Yang, D. (2023). A port statistics-based generic ballast water estimation and risk assessment approach and its application to Chinese ports. *Marine Pollution Bulletin*, 192, 115068. <https://doi.org/10.1016/j.marpolbul.2023.115068>
- [2] Wang, Z., Saebi, M., Grey, E. K., Corbett, J. J., **Chen, D.**, Yang, D., & Wan, Z. (2022). Ballast water-mediated species spread risk dynamics and policy implications to reduce the invasion risk to the Mediterranean Sea. *Marine Pollution Bulletin*, 174, 113285. <https://doi.org/10.1016/j.marpolbul.2021.113285>
- [3] **Chen, D.**, & Yang, D. (2025). Impact of external uncertainties on internal volatility spillovers among shipping freight markets. *Maritime Policy & Management*, 1–24. <https://doi.org/10.1080/03088839.2025.2511720>
- [4] **Chen, D.**, & Yang, D. (2024 submitted). Quantitative assessment of abandoned seafarers' repatriation and wage rights under the Maritime Labour Convention. *Marine Policy*. (Under review)

Conference Paper:

- [1] Yan, R., **Chen, D.**, Wang, T., Mo, H., Yang, D., & Wang, S. (2021). Vessel fuel consumption prediction considering shipping domain knowledge. *World Transport Convention, Xi'an, China*. (Presenter of excellent paper)

Working Paper:

- [1] **Chen, D.**, & Yang, D. Spatial spillover effect of port competitiveness on green operation: Evidence from Chinese coastal ports. (*Prepared, Data Analysis*)

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Chapter 1: Introduction

1.1 Research Background

1.1.1 Practical background

As the United Nations 2030 Agenda for Sustainable Development is now more than halfway through, major countries around the world are sprinting towards the overarching sustainable development goals (SDGs) that balance economic, social, and environmental aspects¹. Sustainable shipping management (SSM), as a pivotal industry representative in implementing the agenda, seeks to tackle the urgent challenges arising from the evolving maritime human activities, trade, and legal regulations (Chua et al., 2023; Zhou et al., 2023).

The concepts of SSM cover a broad range of topics (Wang et al., 2020). These topics are around the Triple Bottom Line (TBL) accounting framework that centres on the three pillars (3Ps): Planet (environmental dimension), Profit (economic dimension), and People (social dimension) (Elkington, 1997). Alongside the popular topics of green shipping and decarbonisation, the topics of ballast water management, freight market volatility management, and human rights at sea management are core parts of the SSM and embody the TBL performance in maritime-related SDGs. They correspond to SDG 14, SDG 8, and SDG 16, respectively². Because these three topics emerge in tandem with the shipping industry, participants in shipping have been dedicated to developing relevant policies for administration and oversight³. On the surface, the above topics appear to have been resolutely addressed. However, the ever-varying and tumultuous international circumstances in recent years have brought new challenges in ballast water, market volatility, and seafarers' rights (Thanopoulou and Strandenes, 2017; Olaniyi et al., 2024; Georgoulas et al., 2024; Blaskowsky, 2024). These challenges impede the shipping industry's progress towards sustainability.

The real-world problems of the 3Ps among the mentioned topics include:

¹ The detailed information about “Transforming our world: the 2030 Agenda for Sustainable Development” is retrieved from <https://sdgs.un.org/2030agenda> (last accessed in May 2025).

² SDG 14 is “Conserve and sustainably use the oceans, seas and marine resources for sustainable development”; SDG 8 is “Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all”; SDG 16 is “Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels”.

³ Generally accepted international rules, regulations, procedures, and practices about maritime laws can be found at: https://www.un.org/oceancapacity/sites/www.un.org.oceancapacity/files/tamara_2015-12-18_final.pdf

(a). The environmental problem of threats to the marine ecology and biodiversity.

Brogan (2023) reported the news that four vessels from the French shipping company CMA CGM illegally discharged untreated ballast water without biological sampling. They were penalised \$165,000 by the US Environmental Protection Agency (EPA) for causing biological pollution at the Port of Los Angeles and other US ports. It is worth noting that the EPA had previously penalised several ships for ballast water violations. Bartlett (2024) reported that 29% to 44% of ballast water treatment systems (BWTs) failed to effectively eliminate invasive species, leading to the release of large amounts of viable aquatic organisms. Some news reports show that the Arabian Gulf, Adriatic Sea, and Indian waters are threatened by the main culprit of ballast water for introducing non-native species, such as *Carcinus* and *Mytella strigata*, which have broken the local biodiversity (Bardsley, 2020; Dragović, 2022; Dass, 2025).

(b). The economic problem of disruptions to the cost efficiency and profit stability of the seaborne supply chain.

Shipping finance news columns show that the COVID-19 pandemic with the global lockdown policy has severely disrupted maritime supply chains and triggered inflation. In 2020, freight rates for a 40-foot container on the busiest routes from China to the US West Coast surged by 208% year-over-year, which usually drove an approximate 0.7% uptick in regional inflation (Leng, 2021; Carrière-Swallow et al., 2022). According to media reports about tensions in the Red Sea, Houthi attacks forced ships to reroute around the Cape of Good Hope, resulting in extended travel times by 10 to 14 days and driving up carbon dioxide emissions (Naidu et al., 2024). Shipping companies, for example Denmark's Maersk, also imposed a transit disruption surcharge and an emergency contingency surcharge for their operating routes to compensate for the loss of profit (Cooban, 2023).

(c). The social problem of damage to the seafaring profession and labour rights.

Social media posts indicate that, following the COVID-19 pandemic, the crew change crisis ultimately escalated into a surge in abandonment cases, and a few crews had to seize ships they worked on, starting a wave of seafarers being abandoned and exploited over the past five years (The Maritime Executive, 2023). Minchin (2024) and Wieffering (2025)'s reports show that the number of seafarer abandonment cases was 312 in 2024, double that in the previous year, which meant financially troubled shipping companies like Friends Shipping were leveraging this and harming the industry's reputation for profits. Nowadays, the rise in news of the dark fleet has contributed most to the second wave of seafarer abandonments and tarnished the industry's public image regarding labour rights (Raanan, 2024).

Sustainable shipping practices have evolved, continuously changed, and kept up with

different historical eras, with adverse implications being inevitable. The stakeholders, such as the port authority and vessel captains involved in ballast water, carriers and shippers involved in market volatility, shipowners and sailors involved in seafarers' rights, have to engage in a game of give-and-take to achieve a balance between benefits and expenditures, which is a dilemma in the SSM (Psaraftis, 2019; Tran et al., 2020).

Building on this context, the academic investigations should be further extended to some specific but pivotal TBL issues among ballast water management, freight market volatility management, and human rights at sea management. The meaningful insights on these issues will be fundamental to formulating responsible shipping strategies that effectively tackle the real-world challenges in the SSM (Xue and Lai, 2023).

1.1.2 Theoretical background

The core concern of sustainable shipping management is the rational allocation and efficient utilisation of resources. When confronting the real-world problems in ballast water, market volatility, and seafarers' rights, based on the Extended Resource-Based View, major international bodies—including the International Maritime Organization (IMO), the United Nations Conference on Trade and Development (UNCTAD), and the International Labour Organization (ILO)—have formulated many legal instruments of conventions or produced in-depth industry analysis reports. These documents include: (1) The International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWMC); (2) The Review of Maritime Transport (RMT); (3) The Maritime Labour Convention, 2006 (MLC). They reflect the ideology of different resource-related theories and strategies, which provide the thesis theoretical backbones.

The related studies applying resource-oriented theories to the conventions and major authoritative publications discussed above include:

(a). The Natural Resource-Based View (NRBV) and the Knowledge-Based View (KBV) studies in the BWMC.

The BWMC is a treaty proposed by the IMO to prevent the transregional spread of harmful invasive aquatic organisms and pathogens through the means of ballast water and sediments⁴.

⁴ The IMO Marine Environment Protection Committee established a Ballast Water Working Group in 1994 and this group began focusing on the development of an independent international convention—BWMC in 1999 to address the ecological threats posed by ballast water. The BWMC was adopted on 13 February 2004 and entered into force on 8 September 2017. Then, it immediately started a transition from the D-1 standard of exchanging ocean water to the D-2 standard of eradicating harmful organisms, leaving a long period for accumulating experience, which will continue until 8 September 2024.

It emphasises port authority supervision compliance and hence naturally covers the characteristics of NRBV and KBV. According to the NRBV and KBV theories (Hart, 1995; Grant, 1996), the pollution prevention of aquatic non-indigenous species (NIS) in ballast water, the stewardship of BWTS, and the common analysis of port ecological risk have been the important strategic capabilities for ports, and the corresponding explicit and tacit knowledge as a resource should be better integrated and transferred. These theories are particularly important during the experience-building phase of the BWMC, when the exchange standard D-1 is gradually replaced by the performance standard D-2. In line with the above theories, a lot of literature mainly focuses on the forecasting of ballast water discharge and the assessment of NIS risk. Some studies try to use the factors of the ship's size and the ship's loading and unloading process to estimate the ballast water discharge volumes (David et al., 2012; Holzer et al., 2017; Wang et al., 2021). Some other studies starkly consider different NIS risk spreading stages within the ballast water operations to create various risk probability assessment models for G7 guidelines of BWMC (DiBacco et al., 2012; Seebens et al., 2013; Saebi et al., 2020). However, these studies' approaches are only applicable to ports in developed countries capable of measuring ballast water discharge on an individual ship basis or possessing advanced and comprehensive ballast water data information records. They are not available for ports in developing countries without ballast water footprints or cargo handling logs of large numbers of arriving vessels to predict the discharge volumes and NIS risks. These gaps constrain the port's ability to conserve marine natural resources and apply the knowledge resources to manage ballast water.

(b). The Dynamic Capabilities View (DCV) and the Stakeholder-Based View (SBV) studies in the RMT.

The current RMTs published by the UNCTAD have placed particular emphasis on external uncertainty factors of the economy, geopolitics, climate and technology and their effects on shipping⁵. Following the RMT, the related Global Supply Chain Forum and Commonwealth Business Summit have discussed the changes in shipping subject to external uncertainties. This raises new requirements for the dynamic management capabilities of shipping players and the

⁵ UNCTAD has launched its flagship annual report, the Review of Maritime Transport, in 1968 to provide global policymakers, scholars, and industry professionals with reliable data and analysis on structural and cyclical developments in seaborne trade, ports, and shipping. From the 1980s to the 1990s, the RMT gradually broadened the initial basic statistics and trends to include the impacts of global industrial chain changes on the shipping landscape. Since the 2000s, more diverse topics have been added such as green transition, seaport investment, and digitalisation.

interest balance between different stakeholders. According to the DCV and SBV theories (Freeman, 1984; Teece et al., 1997), when facing an uncertain shipping environment, carriers and shippers should sense the possible menace, seize the principal contradiction, and transform the inventive business plan to sustain their competitive advantages. Meanwhile, maritime powers and international agencies should facilitate coordination among multiple stakeholders by promoting shared values and legitimacy, which enhances trust and policy alignment in long-term cooperation. These theories focus on the importance of collective resilience and adaptability of maritime transport amid market volatility. Based on the above theories, most existing studies mainly capture the interdependencies and spillover effects during periods of international instability, such as emerging market and oil supply crises, the US-China trade conflict and the early stages of the COVID-19 pandemic, between commodity, shipping, and freight derivatives markets (Kavussanos et al., 2014; Alexandridis et al., 2017; Li et al., 2018; Yang et al., 2022). Although part of the literature examines the multi-scale conditional and tail correlations between the shipping freight rates and the specific uncertainty indices like the economic policy uncertainty (Bai 2021; Khan et al., 2021), few studies pay attention to the role of uncertainty factors in the volatility spillovers within the shipping freight system. The linkages of uncertainty factors to the volatility interactions within freight markets remain unclear. These gaps constrain the shipping stakeholders from dynamically reconfiguring resources to maintain their benefits under global uncertainty.

(c). The Institution-Based View (IBV) and the Multi-Level Governance View (MLGV) studies in the MLC.

The MLC is an international agreement proposed by the ILO to enforce the rights of seafarers by setting minimum international standards for their working and living conditions⁶. The 2014 amendments to the MLC establish a mandatory financial security mechanism that is directly accessible to seafarers in cases of abandonment, death, or long-term disability. This signifies that the moral norms of decent work and fair competition are institutionalised as

⁶ The rapid development of the shipping industry in the early 20th century made the labour protection for seafarers become increasingly prominent. Since the 1920s, the ILO has established many international conventions related to the rights and interests of seafarers. Facing technological advances and structural changes in the industry, these existing fragmented standards had difficulty in meeting the modern shipping requirements. In 2001, the ILO, together with seafarers' unions, shipowners' organisations and governments, proposed the formulation of a comprehensive convention—MLC similar to a “Seafarers’ Bill of Rights”. The MLC was adopted in February 2006 and entered into force on 20 August 2013. The 2014 amendments mark a milestone in terms of financial security and enable the MLC to become the true “fourth pillar” of shipping legislation.

enforceable global standards, thereby creating a multi-level hybrid governance regime that incorporates feedback from diverse actors. According to the IBV and MLGV theories (Peng, 2002; Bache and Flinders, 2004), the MLC and its amendments give formal and informal “rules of the game” to shape institutional incentives for safeguarding seafarers’ rights, and encourage the sharing of responsibility and authority among international, national, and local levels. These theories collectively constitute the legal spirit of maritime human rights. Grounded in the above theories, previous studies have critically reviewed the strengths and weaknesses of the updated MLC context in protecting seafarers’ human rights, covering equal employment opportunities, safe and healthy labour conditions, and social welfare (Exarchopoulos et al., 2018; Mantoju, 2021; Chang and Khan, 2023). As abandonment events increased, several studies use normative and comparative analyses to examine seafarer abandonments and reveal ambiguities regarding the responsibilities of entities such as flag States, port States, and financial security providers (Cheng, 2020; Sampson, 2022; Gupta and Shanthakumar, 2023). Nevertheless, these studies are qualitative in nature, focusing on the legal theory and legislative framework of the MLC. They lack empirical evidence based on the jurimetrics to scrutinise the MLC’s shortcomings carefully. These gaps constrain the transnational labour governance capabilities of the MLC member states and relevant union organisations.

All the above studies remark on specific issues related to ballast water management, freight market volatility management, and human rights at sea management. Through the lens of extended resource theories, they uncover limitations in achieving the SSM when considering the legal instruments of the BWMC and MLC, as well as the industry report of the RMT. These limitations warrant further investigation.

1.2 Research Scheme and Boundary

Following the practical and theoretical backgrounds, this thesis constructs the research scheme in Figure 1-1. This scheme covers three studies with the order of “Study 1: Ballast water — Study 2: Market volatility — Study 3: Seafarers’ rights”. These studies are undertaken from the **perspectives of Planet, Profit, and People pillars** in the TBL and address **the research gaps in the BWMC, RMT, and MLC**, reflecting a broad view of resource theory, which brings new insights into understanding sustainable shipping and gives a different paradigm to support the 2030 Agenda for Sustainable Development.

In particular, the research boundaries of the above three studies are presented as follows. Study 1 highlights the development of a forecasting approach for the ship ballast water and biological invasion risk. Study 2 highlights the influence mechanisms of external uncertainties

on the internal information transmissions of major shipping spot freight markets. Study 3 highlights the quantification of important elements in the MLC and analyses their effects on abandoned seafarers' repatriation and wage rights.

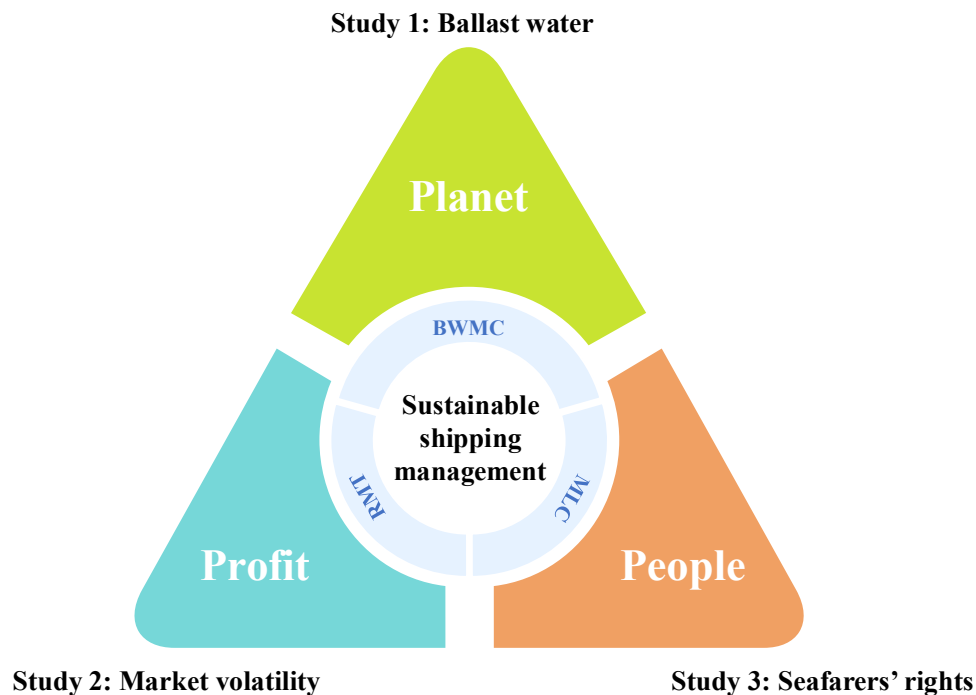


Figure 1-1 The research scheme of this thesis

Source: Author.

1.3 Research Questions and Objectives

In line with the scheme's research boundaries, this thesis endeavours to address the following three research questions for each study.

RQs of Study 1 (Environmental sustainability under the Planet pillar-ballast water):

What is the most effective way to create a simple and efficient tool for estimating ballast water discharge in developing countries without ballast water records? How can this estimation tool be combined with a risk assessment process for the NIS invasion to form a general approach applicable in different port contexts?

RQs of Study 2 (Economic sustainability under the Profit pillar-market volatility):

What is the evolutionary pattern of internal volatility spillovers among container, dry bulk, dirty, and clean tanker spot freight markets? How do external uncertainties, measured by the Economic Policy Uncertainty (EPU) and Geopolitical Risk (GPR) indices, impact these internal volatility spillovers?

RQs of Study 3 (Social sustainability under the People pillar-seafarers' rights):

Which critical factors linked to the MLC implementation need to be identified and explored when

compiling the seafarer abandonment dataset? How can the influence of these critical factors on the repatriation and wage payment of seafarers, as regulated by the MLC, be reliably evaluated?

Based on the above research questions, the thesis aims to achieve the following research objectives. **First**, this thesis launches a suitable and feasible econometric framework to conduct rigorous interdisciplinary research integrating ecology, economics, and law. **Second**, this thesis conducts **forecasting**, **causal inference**, and **policy evaluation** related to the topics of ballast water, seaborne volatility, and human rights at sea, respectively. **Third**, this thesis provides decision-making support and policy recommendations for the SSM.

1.4 Research Framework and Technical Roadmap

In order to answer the aforementioned research questions and achieve the research objectives, the thesis conducts three empirical studies with the help of multiple data sources and multiple model-based methods. According to the guiding framework in Figure 1-2, the structural mind flows and each sub-study's analysis phases are elucidated.

To put it more expressly, Table 1-1 outlines the primary contents of technical roadmaps used in the above framework. From the empirical purpose perspective, Study 1 aims to estimate the ballast water volumes and forecast NIS risks in developing countries during the experience-building phase of the BWMC. Study 2 emphasises the causal inference between the uncertainty indices and shipping spot freight markets' volatility spillover indices. Study 3 sheds light on the policy evaluation of whether the MLC with its 2014 amendments effectively protects the repatriation and wage rights of abandoned seafarers.

From the perspective of research designs, Study 1 considers the general process of port ballast water operations and all associated common port statistics to formulate assumptions for the ballast water estimation model. Using the Least absolute shrinkage and selection operator (LASSO) regression model of machine learning, the coefficient biases are controlled to accurately estimate discharge volumes. Incorporating the estimated volumes as a key parameter into the NIS risk likelihood forecasting model with three successive stages, this study developed a new generic approach to manage ballast water and applied it to ten Chinese ports for illustration. Study 2 starts with the time-varying parameter vector autoregression (TVP-VAR) model to construct the Diebold-Yilmaz (DY) spillover connectedness indices of rates of shipping spot markets. After that, by linking the EPU and GPR to these spillover indices with the Granger causality in quantiles and the time-varying impulse responses, the impacts of external uncertainties on internal volatilities of the ocean transportation market network are

examined. Study 3 explicitly proposes hypotheses about choice probabilities and resolution times of repatriation and wage payment for abandoned seafarers. These hypotheses are evaluated with the MLC and financial security-related critical factors using the nested logit model and fixed effects model to find quantitative evidence.

Moreover, the robustness check is performed in different ways for every study. Some additional tests are also undertaken to validate the prediction performance, ensure the stationarity of the time series, and confirm the rationality of the nested structure, respectively.

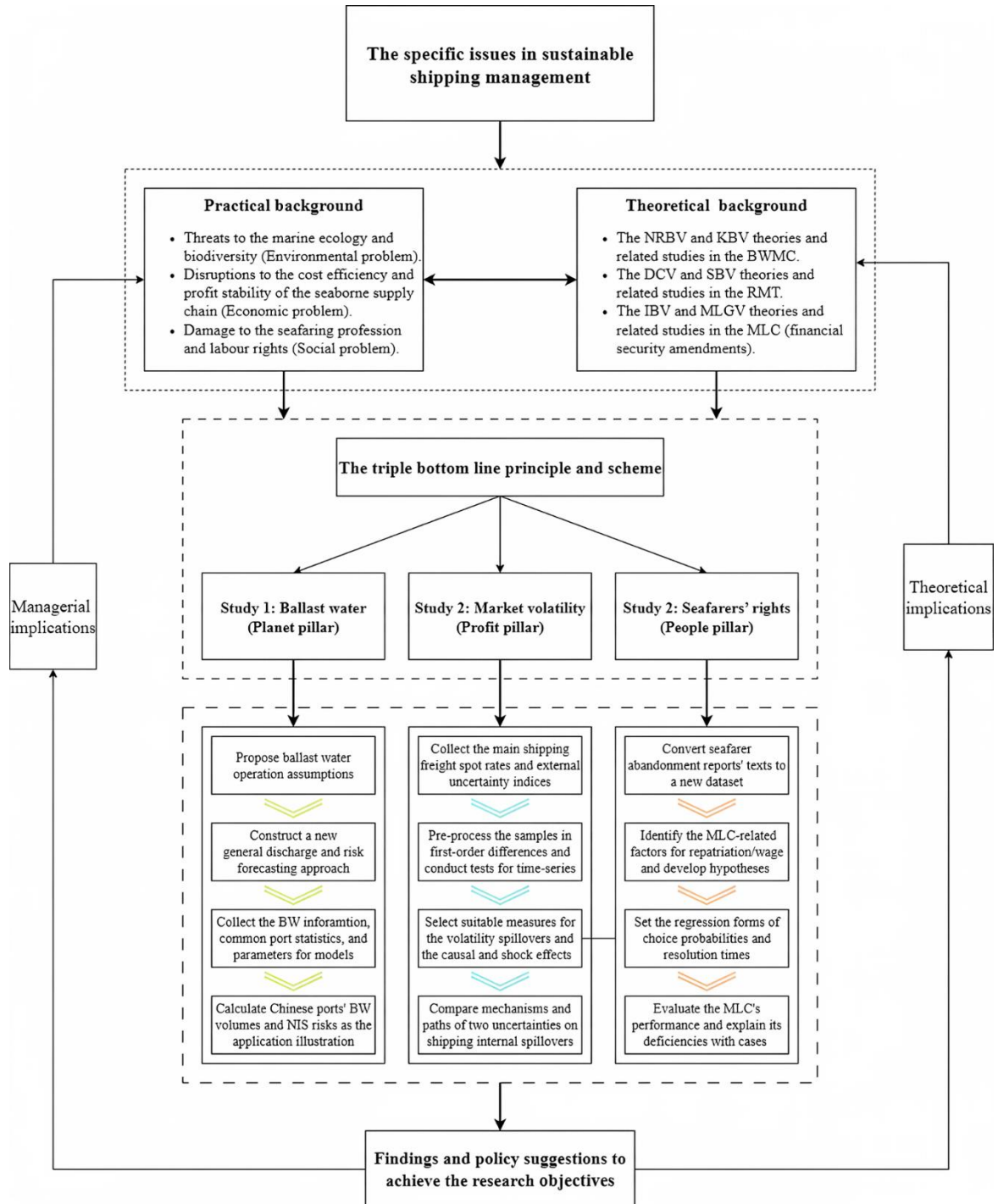


Figure 1-2 The guiding framework of this thesis

Table 1-1 A summary of the three studies' technical roadmaps in the thesis

	Study 1	Study 2	Study 3
Empirical purpose	Forecasting (to ten Chinese ports)	Causal inference	Policy evaluation
Data format	Panel data	Time-series	Text-based conversion (jurimetrics)
Dependent variable	Ballast water discharge volumes /Comprehensive NIS risk probability	Four major shipping spot markets' spillover indices	Choice probabilities and resolution times of repatriation and wage payment
Independent variable	Common port statistics /Three successive invasion probabilities (i.e., Being non- indigenous, Introduction, Establishment)	EPU and GPR indices	Critical MLC and financial security- related factors in seafarer abandonments
Sample source	National Ballast Information Clearinghouse; China shipping database; Automatic Identification System, etc.	Clarksons Shipping Intelligence Network; EPU and GPR official websites	ILO Seafarer Abandonment Database
Observation period	2010-2020	2009-2023	2017-2023
Assumption/Hypothesis	Yes	—	Yes
Research methods	LASSO regression in machine learning; Vector-based invasion likelihood model	TVP-VAR-DY; Granger causality in quantiles; Time-varying impulse responses	Nested Logit model; One-way fixed effects model
Robustness check	Alternative observational window, alternative methods	Parameters and forecast step adjustment	IIA assumption, modified variables, alternative methods
Additional test	Out-of-sample backtesting	Augmented Dickey- Fuller test and Ljung- Box test	Seemingly unrelated estimation test

1.5 Research Significance

Revisiting the sustainable shipping issues has created new opportunities to advance the modern development of maritime studies and enhance the industry perception of a series of

extended resource-based sub-theories. This thesis offers significant contributions in the following ways.

Extending the existing discourse on NRBV theory, Study 1 makes reasonable assumptions of the non-heterogeneity of global ports and the determining role of cargo statistics in ballast water (BW) discharge volumes. It allows the plentiful BW data from developed countries like the US to serve as a source and training material for developing countries with insufficient BW records. Study 1 also delivers fresh breakthroughs in the conceptual scopes of KBV theory, by creating a new generic framework through a simple and efficient combination of the above BW volume estimations and risk assessment procedures. Echoing the precautionary principles (Magaletti et al., 2018; Kraus, 2023), Study 1 predicts the BW volumes released into Chinese ports from 2017 to 2020 and assesses the associated NIS risks in 2017 to show the necessity of prudent management for irreversible damage prevention during the conversion process between the BWMC's D-1 and D-2 standards.

Broadening the potential application margins of the DCV theory, Study 2 validates the dynamic shifts among four shipping spot markets as net transmitters and net receivers of volatility spillovers and explains the distinct causalities between these markets' spillover effects with the uncertainty factors of EPU and GPR, which guides the shipping stakeholders' perceptions, shapes their attitudes and intentions, and inspires them to take the right actions. Study 2 also identifies tanker markets acting as mediators of amplifying uncertainty shocks and thus determining the maximum spillover thresholds of other seaborne sectors. It hints at the promising opportunity of real options to mitigate the external uncertainty risks on freight rates (Kou and Luo, 2018; Zhang and Yin, 2021). Furthermore, Study 2 enriches the literature on the SBV theory by focusing on market volatility under extreme conditions, especially during the COVID-19 pandemic.

Deepening the understanding of relevant contents in maritime human rights (Constantino, 2017; de Larrucea, 2022), Study 3 examines whether the MLC and its 2014 amendments' related responsible entities or elements effectively protect abandoned seafarers and the extent to which they foster the probability and time efficiency of repatriation and wage payment. The special factors of Port State Control (PSC), flag of convenience (FOC) State, and Protection and Indemnity (P&I) clubs are particularly focused on. Following the IBV theory usually appears in the international laws of the sea, the flaws and loopholes of the MLC's provisions to resolve the abandonments are identified and confirmed by factual and data-based evidence. Eventually, Study 3 puts forward reasonable and feasible suggestions to complete the MLC regulations. All these suggestions are based on real-world cases related to the above significant

shortcomings and hence extend the MLGV theory for the purpose of protecting seafarers' basic rights.

1.6 Structure of the Thesis

The thesis consists of six chapters, which are: Introduction, Literature Review, Study 1, Study 2, Study 3, and Conclusions. Each chapter's content is explained in the sections below.

Chapter 1 introduces the main storylines of the whole research on sustainable shipping management. The practical and theoretical backgrounds are primarily given to explain the scholarly motivation and present the dominant thematic scheme. Next, with the scheme's research boundaries, the research questions and objectives are proposed for three sub-studies, and the corresponding research framework and technical roadmap, as well as the research significance, are elaborated. Finally, the structure of the thesis is depicted.

Chapter 2 gives the literature review. First, the search strategies with keyword strings of three sub-studies are carefully designed to retrieve the literature from "Web of Science" and "Scopus" for a preliminary bibliometric analysis. Second, closely related studies to the following topic chapters are categorised and reviewed in detail to summarise the existing experiences and remaining gaps, respectively.

Chapter 3 is about the governance of ballast water. This chapter develops a port statistics-based generic ballast water estimation and risk assessment approach for developing countries without ballast water records and chooses China as an application instance. It introduces the research motivation and questions, elaborates the proposed generic approach with necessary assumptions, describes the data and parameters with a multicollinearity check, displays the fitting, forecasting, and assessment results, discusses the research implications and limitations, and concludes Study 1. By this chapter, the problems in the current development phase of the BWMC are addressed, and it enriches the BW supervision tool.

Chapter 4 is about the governance of market volatility. This chapter investigates the impact of external uncertainties on internal volatility spillovers among shipping spot freight markets. It presents the motivations and questions based on the real freight rate movements and commercial investment changes, explains data processing and variable settings, presents the methodology and empirical results, discusses the important findings, and makes policy suggestions in the conclusion of Study 2. By this chapter, the essential mechanism through which EPU and GPR affect the volatility of the shipping freight system can be further revealed, extending the understanding of related phenomena in the maritime economy.

Chapter 5 is about the governance of seafarers' rights. This chapter assesses abandoned

seafarers' repatriation and wage rights quantitatively under the Maritime Labour Convention. It voices the motivation and questions with a concern for the increasing abandonment events in recent years, elucidates the critical factors in the MLC and the justifications of hypotheses, elaborates the suitable methodology and the dataset compiled by abandonment reports, shows the evaluation results, discusses the hypothesis with examples, policy implications, as well as limitations for future research, and concludes Study 3. By this chapter, the MLC and its amendments' potential deficiencies are proven by statistical evidence through which the way forward for human rights at sea can be illuminated.

Chapter 6 presents the conclusions. The key findings are recapped and their implications are condensed for the whole thesis. Additionally, the possible avenues for future work are pointed out. Closing remarks of the thesis are provided at the end.

Chapter 2: Literature Review

2.1 Preliminary Bibliometric Analysis

Grounded in the aforementioned research questions and objectives of SSM in the triple bottom line and BWMC, RMT, and MLC scheme, this thesis commences with a bibliometric analysis (BA) for a systematic review (Donthu et al., 2021). BA is a semi-qualitative and semi-quantitative methodology to provide an in-depth grasp of current cutting-edge research and future research possibilities. This section consists of two parts: the study search and selection protocols and the visual information synthesis. The purposes of BA are:

- Reaching all the studies of thesis-related topics, including the ballast water topic, the market volatility topic, and the seafarers' rights topic.
- Achieving information on the scientometric mapping of both keyword development and thematic co-occurrence analysis.
- Providing comprehensive materials and domain-specific foundations for the subsequent narrative review of three studies.

2.1.1 Study search and selection protocols

The search and selection processes of papers are based on standard procedures. As shown in Figure 2-1, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram is employed with scientific and rigorous steps (Moher et al., 2009)⁷. Following the PRISMA, for the first step, the paper records are collected from “Web of Science” and “Scopus” search engines with refined search strings⁸. The search strings are designed to focus on the segmented areas of ballast water and biological invasion, volatility in shipping and external uncertainty, and rights of abandoned seafarers. As a supplement, some pre-research accumulated papers that are not found in both databases are added to the search records, and duplicate records are removed. Then, for the second step, the paper records are selected by their titles and abstracts and further filtered by the accessibility of keywords and contents. Lastly, the available papers are obtained. With the search period from 2010 to 2024 and the limitation of research or review articles, the PRISMA results of only English language publications are a

⁷ The guidelines and documents of PRISMA are available from <https://www.prisma-statement.org/> (last accessed in April 2025).

⁸ Web of Science is retrieved from www.webofscience.com and Scopus is retrieved from www.scopus.com (last accessed in April 2025). They are recognised as reliable sources of global academic knowledge.

total of 107 for the ballast water topic, 118 for the market volatility topic, and 36 (relatively scarce) for the seafarers’ rights topic (see detailed strings and selected records in Table A-1 of Appendix A).

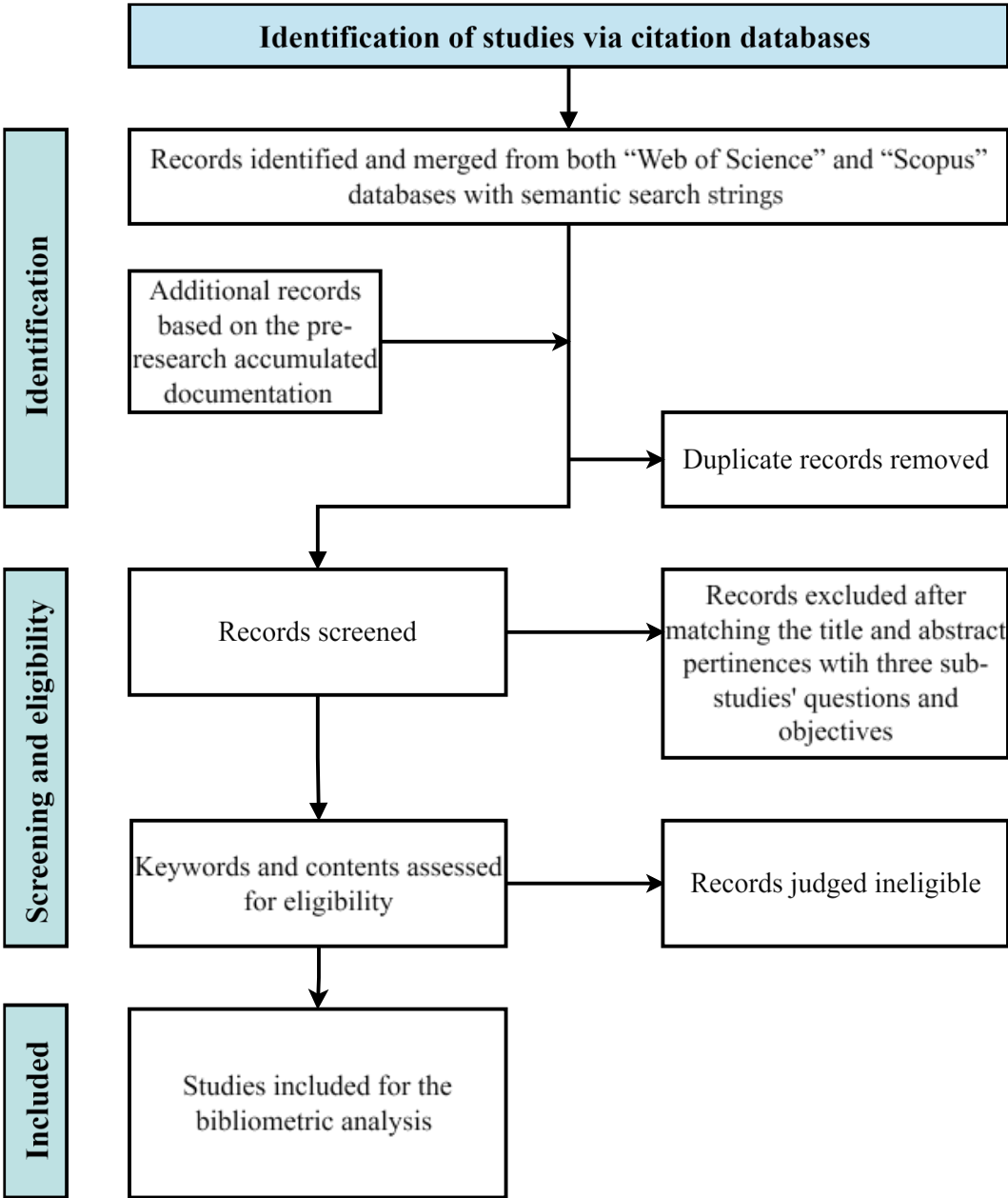


Figure 2-1 The PRISMA flow diagram for sustainable shipping management subfields
Source: Author.

Figure 2-2 indicates the yearly evolution of publication trends of thesis-related topics. During the past fifteen years (2010-2024), the distribution statuses for different topics have varied. The papers on the ballast water topic have been published extensively between 2013 and 2021, which is a status of generating groundbreaking new knowledge. After that, this topic falls within the status of knowledge aggregation and exchange. The published papers on the

topics of market volatility and seafarers’ rights have significantly proliferated since 2020, entering a rapid development status. This phenomenon shows that the close interplays between the COVID-19 pandemic and the two topics have promoted the attention and interest of researchers.

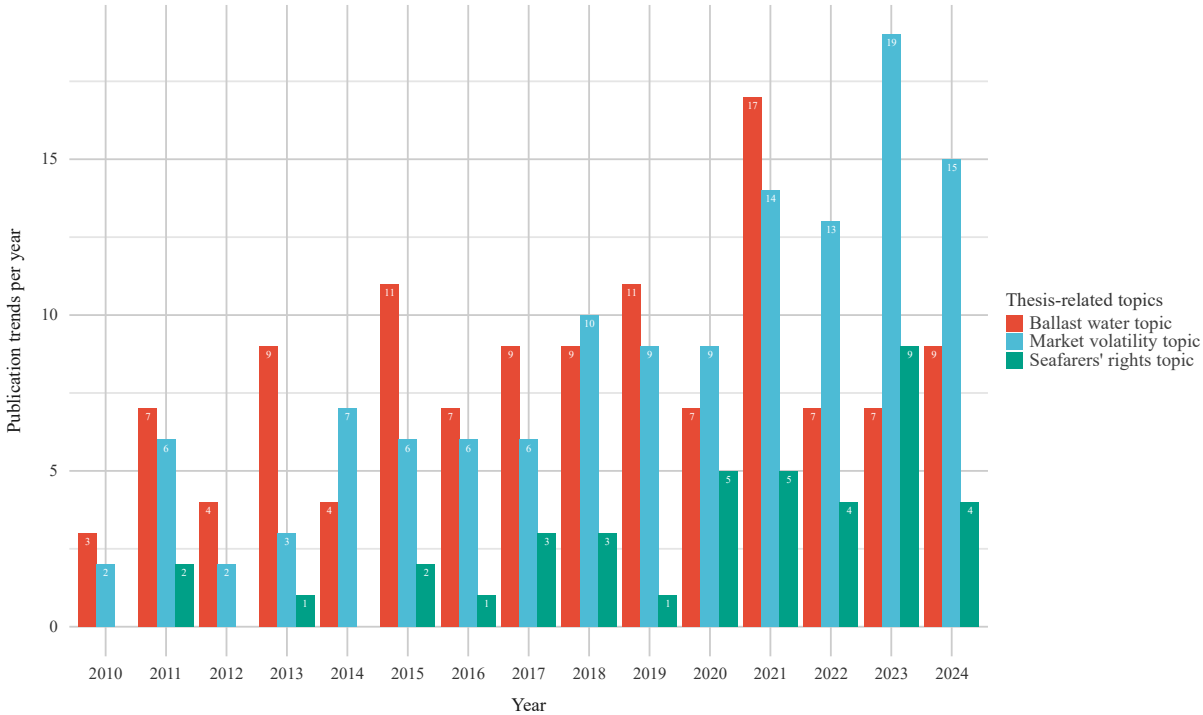


Figure 2-2 A timeline overview of the yearly retrieved publications for thesis-related topics

Table 2-1 lists the top 10 prolific journals of thesis-related topics. These journals account for at least 52% of the total publications, and their qualities are rated by the impact factor (IF)⁹. The selected papers’ academic performances and influences in the above journals are measured by the Hirsch index (H-index) (Hirsch, 2005)¹⁰. Among the three examined topics, the *Transportation Research Part E: Logistics and Transportation Review* (IF (J): 8.8 and H-index (TP): 10), *Marine Pollution Bulletin* (IF (J): 4.9 and H-index (TP): 14), *Maritime Economics & Logistics* (IF (J): 4.8 and H-index (TP): 8), *Marine Policy* (IF (J): 3.7 and H-index (TP): 5), and *Maritime Policy & Management* (IF (J): 3.6 and H-index (TP): 9) are the most impactful high quality journals. In addition, some journals are also significant references for scholars in the field. For example, the *ICES Journal of Marine Science* and *Ecological Applications* are for the ballast water topic, the *Energy* and *Ocean & Coastal Management* are

⁹ The impact factor of a journal reflects the yearly mean number of article citations published in the last two years.
¹⁰ The H-index is an author-level metric that measures both the productivity and citation impact of the publications.

for the market volatility topic, and the *WMU Journal of Maritime Affairs* and *Maritime Business Review* are for the seafarers' rights topic.

Table 2-1 Top 10 journal sources contributing to thesis-related topics

Ballast water topic							
Journal name	IF (J)	Count (TP)	H-index (TP)	Journal name	IF (J)	Count (TP)	H-index (TP)
<i>Marine Pollution Bulletin</i>	4.9	22	14	<i>Frontiers in Marine Science</i>	3	3	2
<i>Ecological Applications</i>	4.3	3	3	<i>PLOS ONE</i>	2.6	5	5
<i>Diversity and Distributions</i>	4.2	3	3	<i>Biological Invasions</i>	2.6	5	2
<i>Marine Policy</i>	3.7	5	5	<i>Hydrobiologia</i>	2.5	3	3
<i>ICES Journal of Marine Science</i>	3.4	4	4	<i>Management of Biological Invasions</i>	1.2	5	3
Market volatility topic							
Journal name	IF (J)	Count (TP)	H-index (TP)	Journal name	IF (J)	Count (TP)	H-index (TP)
<i>Energy Economics</i>	14.2	3	3	<i>Maritime Economics & Logistics</i>	4.8	11	8
<i>Energy</i>	9.4	5	5	<i>Asian Journal of Shipping and Logistics</i>	3.7	4	3
<i>Transportation Research Part E: Logistics and Transportation Review</i>	8.8	12	10	<i>Maritime Policy & Management</i>	3.6	13	9
<i>Ocean & Coastal Management</i>	5.4	4	4	<i>Applied Economics</i>	2.1	4	3
<i>Transport Policy</i>	5.3	3	3	<i>International Journal of Shipping and Transport Logistics</i>	1.2	3	3
Seafarers' rights							
Journal name	IF (J)	Count (TP)	H-index (TP)	Journal name	IF (J)	Count (TP)	H-index (TP)
<i>Ocean & Coastal Management</i>	5.4	1	1	<i>WMU Journal of Maritime Affairs</i>	2.4	3	3

<i>Research in Transportation Business and Management</i>	4.4	1	1	<i>Maritime Business Review</i>	2.4	2	2
<i>Marine Policy</i>	3.7	6	5	<i>Economic and Labour Relations Review</i>	1.3	1	1
<i>Health Economics Review</i>	3.3	1	1	<i>International Maritime Health</i>	1	9	7
<i>European Journal of International Relations</i>	2.9	1	1	<i>Transactions on Maritime Science</i>	0.7	3	1

Note: IF (J) indicates the impact factor of a specific journal. Count (TP) and H-index (TP) indicate the number of papers related to three topics and these papers' scholarly impact, respectively.

2.1.2 Visual information synthesis

To conduct quick scientometric visualisation graphs of selected papers, this thesis uses the “Bibliometrix” software package for bibliometric analysis (Aria and Cuccurullo, 2017). The keyword progression relationships and the theme evolution are developed for Topic 1 – ballast water, Topic 2 – market volatility, and Topic 3 – seafarers' rights, respectively.

Keyword progression relationships. Figure 2-3 reflects the keyword information of Topic 1 as an illustration. For Topic 1, the high-frequency keywords are centred on two research areas of the ballast water releases by ship traffic and the invasion risk assessment of alien species. The former contains the location keywords like “United States”, “Port”, “Mediterranean Sea”, and “Baltic Sea”, while the latter contains the environment and biology keywords like “Propagule pressure”, “Salinity”, “Spread”, “Climate-change”, “biodiversity”, “Zooplankton”, “Organism”, and “Phytoplankton”. More than half of the authors within the areas come from the USA, Canada, and Germany, whose studies cover multiple keyword scopes.

Similarly, as Figure A-1 and Figure A-2 show in Appendix A, for Topic 2, the popular keywords can be divided into different groups. The supply-chain variables group contains keywords like “Four shipping markets”, “Crude oil price”, “Commodity-fuel prices”, “Stock”, and “Interest rates”. The modelling group contains keywords like “Freight rate”, “Returns”, “Baltic dry index”, “Time-series model”, “Unit-root”, and “GARCH”. The market fluctuation group contains keywords like “Volatility”, “Spillover”, “Cointegration”, and “Dependency”. The uncertainty influence group contains keywords like “Demand”, “Covid-19”, “Geopolitical risk”, “Investor sentiment”, and “Economic policy uncertainty”. Chinese and Greek authors contribute the most publications, while the United Kingdom authors are also prominent. For

Topic 3, the primary keywords are about the human rights of the maritime labour convention in abandonment events. The relevant keywords are “Seafarers”, “Repatriation”, “Occupational health”, “Medicine”, “Wages”, and “Piracy”. The top 3 author countries are France, Denmark, and the United Kingdom. Additionally, the Filipino authors are dedicated to the research area of medical repatriation and crew change during COVID-19, and the Indian authors are committed to the research area of financial security and repatriation in cases of abandonment.

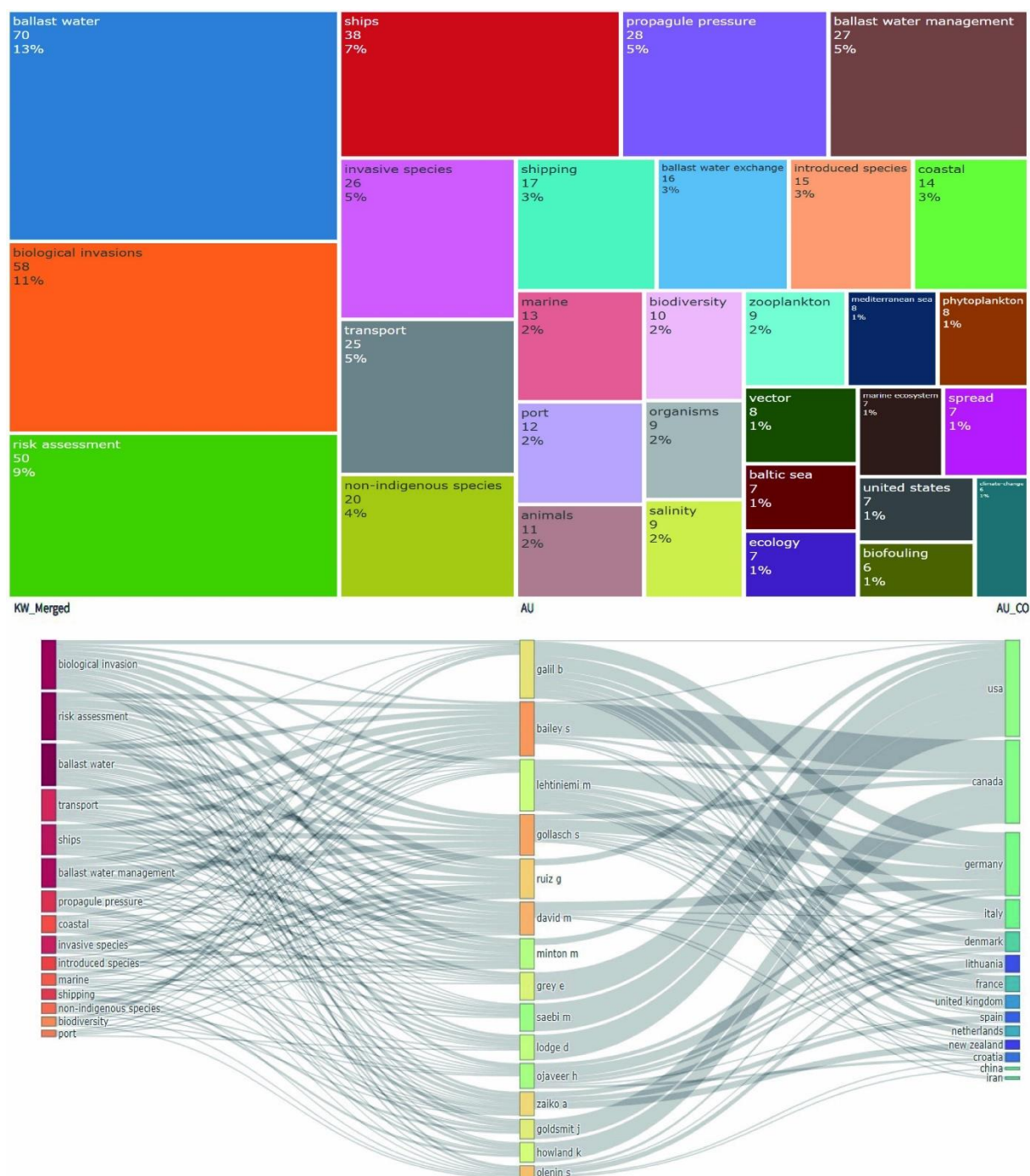


Figure 2-3 An illustration of Topic 1 with the keywords tree and the Sankey diagram of authors, countries, and keywords

Note: KW_Merged=All keywords extracted from full texts, AU=Authors, and AU_CO=Authors' countries.

Theme evolution. As illustrated in Figure 2-4, the thematic analysis of Topic 1 is displayed. For Topic 1, investigating the usage history of ballast tanks to reflect their operation footprints and thus precisely calculating the discharge amount of ballast water becomes an important motor theme, which can combine with the emerging themes about the survey of the most dangerous and resistant non-native species in ballast water and their life cycles change with various voyage durations. On this basis, the niche themes about the agent-based modelling of harmful organism introductions via ports receiving ballast water and the colonisation pressure analysis of invasive species can be further developed to improve the parallel management standards, like the exemption policy. Link strengths in the co-occurrence network between 'ballast water' and 'risk assessment' clusters are tight and indicate both should be treated as a whole research theme. Moreover, the two biochemistry clusters, involving the early detection of invasive species and the metabarcoding and high-throughput sequencing of DNA and RNA, are also valuable theme branches.

Correspondingly, referring to Figure A-3 and Figure A-4 in Appendix A, for Topic 2, the volatility of freight rates and other shipping markets during the COVID-19 pandemic forms the present basic themes. It is moving toward a motor theme about the spillover and connectedness among seaborne markets and their related upstream and downstream markets, finance markets, etc. With this backdrop, the interactions between the dry bulk and liquid bulk shipping and the EPU and GPR make a promising future niche theme, which can be measured by the advanced methods, for instance, variance decompositions. Among the thematic co-occurrence network, shipping spot freight markets are the core to drive links of different market clusters. In addition, the tanker sector, ship investment, and ship dismantling construct isolated clusters of meaningful themes for studying. For Topic 3, the protection of abandoned seafarers under the MLC, especially for repatriation rights, is the dominant basic theme. In light of this, future hotspots of niche themes centre on the roles of the MLC-related liable parties, such as port State and flag State, in the abandonment of seafarers and their associated social welfare and wage payments. Co-occurrence clusters of 'maritime labour convention' and 'seafarers' are the biggest themes, benefiting from each other. Seafarers need the MLC to be effective in solving their plights, while the MLC needs seafarers to recognise its significance in maintaining social order and justice.

Based on the above bibliometric analysis, the holistic picture of literature is clear. All of these keywords and themes provide the foundation for a narrative literature review.

Subsequently, the narrative reviews of three sub-studies will be performed.

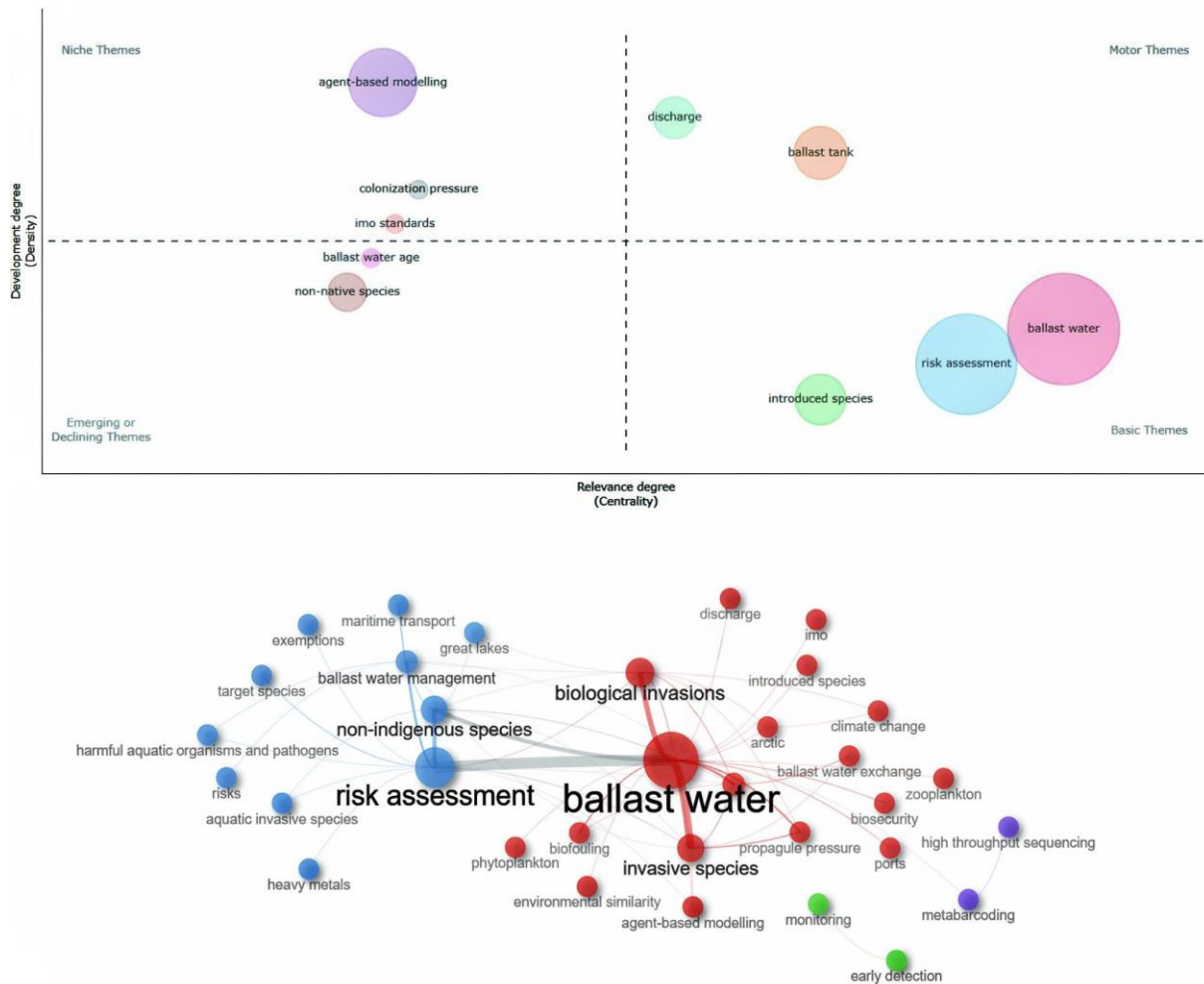


Figure 2-4 An illustration of Topic 1 with thematic nexuses and co-occurrence networks

Note: The thematic nexuses have four quadrants of niche, motor, emerging or disappearing, and basic themes. The thematic co-occurrence networks consist of theme word nodes (node size for frequency), links (link thickness for strengths), and clusters (colour for category).

2.2 Related Literature on Ballast Water and Biological Invasion

The research scope of ballast water and biological invasion encompasses multiple disciplines. This thesis provides an overview of the literature from three dimensions: ballast water discharge estimation, risk assessment of invasive species, and core regulations about ballast water and NIS. The detailed related studies on the development of the above dimensions in Table 2-2 are reviewed in the following text.

Table 2-2 Studies on the development of ballast water and biological invasion

Dimension	Approach and regulation development	Reference
Ballast water discharge estimation	Approach: DWT-based proportion — BWDA considering unloading/loading operations — Export commodity-based proportion — Machine learning using GT	(Enshaei and Mesbahi, 2011; David et al., 2012; Holzer et al., 2017; Wang et al., 2021; etc.)
Risk assessment of invasive species	Approach: Biogeographic connectivity risk (being non-indigenous) — NIS arrival risk (introduction) — Habitat reproduction risk (establishment)	(Zenetos et al., 2010; Wonham et al., 2013; Keller et al., 2011; Seebens et al., 2013; etc.)
Core regulations about ballast water and NIS	Regulation: (1) Ballast water (concentration-based discharge standard, BWMC exceptions and exemptions) (2) NIS (MSFD D2 criteria, EU-IAS Regulation, CBD)	(Albert et al., 2013; Outinen et al., 2021; Ojaveer et al., 2014; Tollington et al., 2017; Futhazar, 2021; etc.)

Source: Author.

2.2.1 Ballast water discharge estimation

The majority of studies regard the ballast water estimation as the cornerstone and prerequisite for the follow-up parts in their entire research. Scholars have proposed many variables and a series of approaches to estimate discharged ballast water volumes.

The most popular and widely used approach is the Deadweight Tonnage (DWT)-based model derived from the “Australian” model (ENRC, 1997). The GloBallast Partnerships Programme (2000-2017) recognises this approach and gives the ballast water (BW) capacities and associated ratios of DWT for different ship types, intended to help developing countries estimate and implement the BWMC (GloBallast, 2017). It lays a foundation for ballast water estimation. As an application of this method, Enshaei and Mesbahi (2011) develop the “BalEstiMate” algorithm to estimate the total ballast water operation volumes of 16 UK ports. They establish a primary correlation between freight amounts and ballast water volumes for both foreign and domestic shipping. Rata et al. (2018) give the generalised proportion of ballast water discharge to the DWT for every ship type in Black Sea ports, and thus calculate potential

discharge volumes in the port of Constanța for demand forecasting of land-based treatment devices.

With a further exploration of ballast water estimation approaches, enhanced models are developed. One part of the studies considers cargo loading/unloading conditions. The earliest representative model is the ballast water discharge assessment (BWDA) model introduced by David et al. (2012) as the decision support system tool for the BWMC. The BWDA model has two criteria for each ship: the first determines whether ballast water will be discharged, with unloading cargo indicating no BW release and loading cargo indicating release; if there are BW releases, the second calculates the discharge amount based on the quantity of loaded cargo and its relation to the ship's DWT. It is well validated by real ballast water discharge data for the Port of Koper, Slovenia. Maglić et al. (2015) employ the BWDA model to estimate the BW discharge volumes for barge-based treatment under worst realistic scenarios in the port of Rijeka to simulate the barge treatment service's cost-effectiveness and waiting time. Another part of the studies considers the substitute variable or correction coefficient of DWT. Based on the domain knowledge that exporting commodities is strongly positive to ballast water releases (a ship only discharging ballast water during the export activity), Holzer et al. (2017) and Verna et al. (2021) conduct the linear regression between the tonnages of export commodities such as LNG and the BW volumes and find a well-fitting relationship. Similarly, taking importing commodities with zero discharges, Seebens et al. (2013) propose a correction coefficient for non-zero release probability and add it, as well as the number of stopovers, into the double-logarithmic DWT-based model for BW volume estimation.

Moreover, with the development of machine learning techniques, Yoong and Enshaei (2016) use artificial neural networks with DWT, according to the ship type, as the indicator to estimate the BW discharges of 31 Australian ports for risk identification. Wang et al. (2021) propose a random forest model with the indicator of Gross Tonnage (GT) for ballast water estimation.

All these studies bring us insight into the array of approaches and variables that are related to ballast water discharge estimation. However, all these approaches only use a single variable, such as DWT, export activity, or cargo loading quantity. The associations of variables are not sufficiently explained and fully utilised. In addition, most approaches require the individual vessel information, which is hard to access for many ports. All these reasons limit ballast water estimation from being general and straightforward, especially at the port level.

2.2.2 Risk assessment of invasive species

The risk assessment of invasive species from ballast water is one of the popular research directions for the NIS management field. Due to the lack of a uniform criterion for risk assessment, existing approaches can be classified into three categories based on the IMO G7 guidelines (David et al., 2014; IMO, 2017a).

The first category adopts the biogeographic concept that the overlapping regions have a direct risk of sharing species. The connectivity of biogeographic regions is important to judge whether the introduced species through ship ballast water can be regarded as NIS in a new recipient port. A good example is that Zenetos et al. (2010) provide the updated marine species checklist among the four subregions of the Mediterranean Sea and validate the biotic homogenization of species spreading among neighbouring regions.

The second category considers the historical sailing information and physiological tolerance of target harmful species to monitor these species within their life cycles as the basis of introduction risk. According to Gollasch et al. (2011), the duration of the voyage determines the transfer pressure of organisms inside the ballasts and implies the chances of surviving species before ship arrivals (mortality rate of organisms). DiBacco et al. (2012) and Casas-Monroy et al. (2015) construct the random distribution of the released number of NIS with a single de-ballasting process as a measure of arrival potential. Wonham et al. (2013) model the relationship between the propagule and colonisation pressures (number of introduced individuals and introduced species) and the population introduction probability. They extend the single-population introduction probability to the probability of repeated multiple species releases and discuss the possible application of this probability for the NIS caused by ballast water.

The third category mainly focuses on the environmental similarity by comparing the environmental conditions between the ballast water donor port and the recipient port. Salinity and temperature are two fundamental parameters to determine the risk probabilities of invasive aquatic organisms' establishment. Keller et al. (2011) identify the ports with high similarities of salinity and temperature to the Greater Great Lakes Ecosystem, and determine the possible source regions of established NIS by ship connections. Baek et al. (2011) conduct the viability experiments for phytoplankton in ballast water with various temperature and salinity conditions to explore the adaptive NIS establishment strategies.

Nevertheless, risk assessment methods of the above categories are not systematic. Consequently, a more comprehensive risk assessment model is developed by Seebens et al.

(2013). Their NIS spread probability model takes all three of the above categories into consideration and covers the successive spread stages of NIS, including the identification, introduction, and establishment stages. This kind of risk assessment approach is also widely adopted by researchers.

2.2.3 Core regulations about ballast water and NIS

Regulations and policies about ballast water and NIS are paid great attention to by researchers. Although these regulations vary across countries and regional organisations, some common grounds under the context of environmental protection bring us enlightenment.

For ballast water regulations, the core common grounds are the numeric concentration-based discharge limits and the exceptions and exemptions of BWMC. Albert et al. (2013) think the differences in global concentration-based ballast water regulations should be eradicated before thoroughly replacing the ballast water exchange standard. Their findings imply that the development of generally accepted risk tolerances and the refinement of risk assessment strategies are important to push the numeric concentration-based discharge limits forward. Olenin et al. (2016) and Outinen et al. (2021) emphasise that the BW exemption processes must be strictly reviewed by comparing the results of various risk assessments and consulting experts specialising in aquatic species invasions. Their findings indicate that exceptions and exemptions cannot be a common alternative and are only allowed in the smallest practicable areas without placing an unnecessary burden on the aquatic ecosystem.

For NIS regulations, the core common grounds are the European Union Marine Strategy Framework Directive (MSFD) as a pioneering legal framework. Ojaveer et al. (2014) give ten recommendations to improve the effectiveness of the integrated ecosystem-based approach and practice for MSFD D2 criteria. They highlight the aspects of NIS monitoring guidelines, standardisation of sampling, multi-vector management, choice of indicators, and involvement of stakeholders etc. Besides, the European Union Invasive Alien Species Regulation (EU-IAS Regulation) (Regulation (EU) 1143/2014) and the Convention on Biological Diversity (CBD) provide additional support to promote the implementation of MSFD D2 criteria against NIS. According to Tollington et al. (2017) and Futhazar (2021), the EU-IAS Regulation creates an inclusive and dynamic NIS list, while the CBD improves the European NIS laws by applying the norm diffusion theory.

2.3 Related Literature on Market Volatility and External Uncertainty

Volatility in the shipping market is a classical research topic and involves a lot of external

uncertainty factors. This thesis centres on the overview of both freight markets' internal volatilities and their relationships to external uncertainties of EPU and GPR. Table 2-3 presents some representative studies from the above perspectives. These studies and other related studies are reviewed in the follow-up sections for details.

Table 2-3 Representative studies on volatility in the shipping market and external uncertainty

Perspective	Focus of study	Technique	Period	Reference
Internal volatility connectedness of shipping freight markets	Interdependencies among dry bulk, tanker (dirty and clean), and container spot markets	GARCH-Copula and Granger causality	2002-2018	Li et al. (2018)
	Conditional correlation and covariance between the BDTI and BCTI indices.	DCC-GARCH	2016-2019	Ajith et al. (2023)
	Long-term cointegration and short-term causality relationships between container time-charter rates and second-hand prices as well as MA trading strategies.	VECM and Granger causality	1996-2021	Georgoudakis et al. (2023)
	Spillover effects and conditional correlation among tanker spot price and FFA prices.	BEKK-GARCH and DCC-GARCH	2006-2011	Li et al. (2014)
	Information transmissions among dry bulk freight futures, options, and time-charter rates	BEKK-VECM-GARCH and impulse response analysis	2008-2016	Alexandridis et al. (2017)
	Spillover effects across dry bulk and tanker spot sub-markets	DCC-GARCH and DY spillover indices	2006-2015	Tsouknidis (2016)
External uncertainty's influence on ocean transportation	Volatility spillovers across oil prices and tanker, dry bulk sub-markets	DY spillover indices	2006-2021	Riaz et al. (2023)
	Tail interdependences between EPU and tanker spot freight rates from a multi-scale view	Wavelet-based copula	2002-2019	Bai (2021)
	Mutually dependent relationships among the Chinese EPU and PMI, and dry bulk sub-markets.	VAR-LASSO and Granger causality	2012-2021	Gu and Liu (2022)
	Co-movements between GPR and dry bulk spot markets via the oil price intermediation	Wavelet analysis, ARFIMA, and FCVAR	2000–2020 & 1985–2021	Khan et al. (2021); Monge et al. (2023)
	GPR's impacts on the spot freight rates of LNG and LPG markets	VECM and impulse response analysis	2018-2021	Michail and Melas (2022)

GPR and EPU's relationships with the spot freight rates of Capesize and Panamax ships in dry bulk markets	Bayesian VAR and impulse response analysis	1991-2018	Drobetz et al. (2021)
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Source: Author.

2.3.1 Shipping freight market's volatility connectedness

As the principal component of the shipping industry, the freight market directly reflects the pricing and revenue of maritime transport services. Many scholars have made efforts in the volatility connectedness of the shipping freight market within related sub-markets and to other seaborne markets.

One part of the studies focuses on the co-movements, including the extreme tail interdependence, conditional correlation, and cointegration. For the tail interdependence measured by GARCH-Copula, Li et al. (2018) reveal that the tail dependences are higher between the dry bulker market and tanker markets than those associated with the container market. Bai and Lam (2021) suggest that the freight rates of clean product shipping in the same trade route or adjacent regions exhibit higher tail dependence and higher asymmetric risk spillovers captured by ΔCoVaR (delta conditional value-at-risk). For conditional correlation measured by DCC-GARCH, Ajith et al. (2023) and Chung and Weon (2013) discover that the significant conditional correlations are about 0.4~0.6 between the clean and dirty tanker freight rates, and about 0.317~0.326 between the Capesize and Panamax freight rates, respectively. For cointegration measured by VECM, Yin et al. (2016) identify the spot and forward freight agreement (FFA) prices of the dry bulk routes-BPI T/C and BCI C7 are long-term cointegrated and the BCI C7 prices have a faster mean reversion. Georgoudakis et al. (2023) reveal the cointegration relationship between the time-charter rates and second-hand prices of small containerships, and demonstrate that the sale trading rule is better than the buy-and-hold rule for larger 3,500 TEU containerships. Moreover, Michail and Melas (2022) find that the cointegration deviations led by COVID-19 are more negative for the clean tanker sub-sectors than the dirty tanker sub-sectors.

Another part of the studies focuses on the spillover effects. The spillover effects can usually be measured by VECM/VAR-BEKK-GARCH and Diebold-Yilmaz Connectedness Index models. For the former, Dai et al. (2015) and Alexandridis et al. (2017) investigate the information spillover mechanisms of dry bulk freight sub-markets, including Capesize, Panamax and Handysize ships. They find that the volatility spillover propagation orders are from freight markets through newbuilding markets to second-hand markets and from freight

futures through freight markets to freight options, which are affected by the asset attribute and liquidity. The trading strategies and portfolio weights vary among different vessel types. Li et al. (2014) confirm that bilateral spillovers exist among the tanker spot price of the TD3 route and its one-month and two-month FFA prices. For the latter, Tsouknidis (2016) examines the spillovers within and between dry bulk and tanker freight rates. The findings demonstrate that tanker markets as contributors have larger total spillovers than those of dry bulk markets as receivers, and smaller ships usually transmit volatility to larger ships in dry bulk sub-markets. Riaz et al. (2023) reveal that oil prices are always spillover transmitters for both dirty and clean tanker sectors, while the dry bulk sub-sectors of Supramax and Panamax ships become the transmitters for oil prices during stable periods. Moreover, Sun et al. (2019) and Li and Yip (2023) suggest that crude oil futures and Singapore bunker market spillovers lead to volatility in tanker markets.

The above studies provide evidence that different freight markets are not isolated and are also influenced by other markets. The supply-demand imbalances in one shipping sector rapidly propagate across others. The spillover effects in shipping freight markets should be given further exploration. Although tramp shipping is more volatile than liner shipping, the container market is still an important yet underexplored component of volatility transmissions. Additionally, some mentioned models have natural limitations. Specifically, the Copula-GARCH model is constrained by its performance depending on the types of Copula functions and by its ability to only capture the paired extreme risk of two specific markets. The BEKK-GARCH has the curse of dimensionality for parameters and the positive definiteness requirement for conditional covariances, while the DCC-GARCH model identifies interconnections between conditional variances with a fixed linear correlation coefficient. In comparison, the Diebold-Yilmaz model is much better and widely combined with other VAR-based approaches like the TVP-VAR.

2.3.2 Relationship between external uncertainty and the seaborne transportation market

Due to the growing tension in international trade, the external uncertainty factors of EPU and GPR are becoming increasingly important for seaborne transportation activities. Their relationship with the volatility in seaborne freight markets is being gradually researched.

Regarding the EPU, Bai (2021) uses the wavelet-based copula model to examine the dynamic relationship between EPU and tanker freight rates from multiple frequency domains. The findings show the EPU has stronger positive symmetric tail dependence and Granger causality with BDTI than with BCTI in the long term. Gu and Liu (2022) use the VAR-LASSO

model to explore the relationship between China's EPU, Chinese Purchasing Managers' Index (PMI) and freight rates of various dry bulk size types. They demonstrate that Chinese PMI only affects Panamax and Capesize rates, while China's EPU has no meaningful effect on global dry bulk freight rates due to a lack of shipping news characteristics when constructing Chinese EPU. Sun et al. (2024) employ multi-scale wavelet approaches to analyse the dependency between EPU, BPI and food prices, and suggest a significant increase in mutual wavelet coherences among them in the long run. Regarding the GPR, Michail and Melas (2022) and Y. Chen et al. (2024) use the VECM with impulse response analyses and TVP-VAR-DY (BK) to investigate the shock and spillover effects of GPR on the LNG and LPG freight rates, respectively. Their findings indicate that EPU shocks can significantly stimulate freight rates to more than 20% growth for LPG and LNG ships over around three months, and that LNG rates over multiple months will be the net volatility transmitter for regional GPRs. Khan et al. (2021) and Monge et al. (2023) employ the FCVAR model and wavelet coherency and phase difference techniques to clarify the relationships among GPR, BDI and crude oil prices. They unveil that GPR can produce persistent, prolonged impacts on BDI, with the oil price serving as the catalyst for expanding influence. Moreover, Drobetz et al. (2021) adopt the Bayesian VAR with Cholesky decomposition to explain the effects of EPU and GPR on dry bulk shipping. They reveal that global GPR and regional EPUs of the US, Brazil, and China can bring historical cumulative impacts on the spot and time charter rates of Capesize and Panamax ships.

Some researchers have studied the driving influences of external uncertainty on shipping and provided meaningful insights. However, the breadth and depth of research are insufficient. First, existing literature pays most attention to the direct linkages of EPU and GPR to freight rates. The potential linkages between the internal spillovers of different shipping freight markets and external uncertainties are less well-known. A more exhaustive investigation is necessary to comprehend the manner in which EPU and GPR influence systemic shipping volatility. Second, extant studies frequently encounter temporal limitations. EPU and GPR measurements mainly focus on early COVID-19 pandemic stages. The latter periods that cover the protracted health crisis and the Russia-Ukraine conflict are omitted. These omissions are particularly significant given that EPU and GPR indices have exhibited unprecedented fluctuations during the period from 2020 to 2023. It is critical to include samples from these periods to capture a comprehensive view of the landscape. Third, a harmonised methodological framework is rarely attempted to analyse the relationship between freight rate spillovers and EPU and GPR.

2.4 Related Literature on Rights of Abandoned Seafarers

Seafarer abandonment is an essential unit of maritime human rights law research and covers multiple fundamental labour protection rights. This thesis pays attention to the overview of the most important repatriation and financial security (wage) rights and their effectiveness evaluations. According to the critical factors determining the MLC's instruments (articles, regulations, and code) of repatriation and financial security in Table 2-4, detailed research is reviewed in the following passages.

Table 2-4 Research on the critical factors of repatriation and financial security in the MLC

Branch	Critical factor (importance level)	Research standpoint	Reference
Repatriation rights	Flag State (highest),	Doctrinal analysis, Process tracing, Case selection, Participant observation	(Gupta and Shanthakumar, 2022b; Ghaida and Ezra, 2022; Mantoju, 2021; Chen and Shan, 2017; Hebbar and Mukesh, 2020; Chang and Khan, 2023)
	P&I clubs (highest),		
	Port State-including both abandonment region and PSC (higher),		
	Labour-supply States-Crew nationality (higher),		
	ITF and ISF-coordinators (medium),		
	Medical assistance (lowest)		
Financial security for wage rights	Flag State (highest),	Conceptual analysis, Logical reasoning, Comparative research, Sociological qualitative investigation	(Gupta and Shanthakumar, 2023; Petrinović et al., 2017; Cheng, 2020; Sampson, 2022; López-Arranz et al., 2018; Bolton, 2024; Exarchopoulos et al., 2018; Khalili, 2022)
	P&I clubs (highest),		
	Ship's age-sales values (higher),		
	ITF and Mission to Seafarers-coordinators (medium)		

Source: Author.

2.4.1 The fundamental repatriation rights

When seafarers encounter the predicament of abandonment, their first reaction is to leave the isolated ships on the sea and return home. Unfortunately, the definition of abandonment inevitably leads to many real-life obstacles preventing them from fulfilling their fundamental repatriation rights. Scholars have made efforts to find what factors under the MLC play vital roles in the process of repatriation.

The MLC's contents and provisions give three primary responsible parties: the flag State, port State, and labour-supply State. For the flag State, McConnell (2011) and Gupta and Shanthakumar (2022b) point out that flag States have a clear obligation to communicate with shipowners and help seafarers repatriate in cases of abandonment. When shipowners fail, flag States should cover the repatriation costs. Flag States are also entitled to establish an efficient complaint mechanism to ensure the seafarers' repatriation rights. Besides, the Protection and Indemnity (P&I) clubs, in tandem with flag States, are the executors and participants in making detailed seafarer repatriation programmes, and P&I clubs have an equal priority position in terms of seafarer repatriation. For the port State, it involves the local laws in the region of abandonment and Port State Control (PSC). Ghaida and Ezra (2022) and Gupta and Shanthakumar (2022b) examine the laws of Egypt and India as port States to protect the seafarers' repatriation rights. Their findings show completely different outcomes and imply that the region where abandonment took place has an important function in repatriation decisions. Mantoju (2021) and Gupta (2023) indicate, to some extent, that PSCs replacing flag States are the actual enforcers of the MLC to handle abandoned cases on site and assist with repatriation activities. Notably, PSCs have great flexibility to determine the number of crew members repatriated when this is in conflict with other laws for safety reasons. For the labour-supply State, Chen and Shan (2017) and Carballo Piñeiro (2020) demonstrate, considering the absence of flag State and port State jurisdictions, seafarers' supply States or residence States are important entities to provide the minimum repatriation protection. Specifically, the Philippine Overseas Employment Administration has drawn up a series of norms for seafarer employment contracts and recruitment management, which include repatriation assistance.

In addition, some other factors also have an effect on the repatriation of abandoned seafarers. Hebbar and Mukesh (2020) and Abaya et al. (2023) suggest that the maritime health challenges have led to an increase in medical repatriation, especially during COVID-19, although the ratio of this medical repatriation is very small for abandonments. Saksela-Bergholm and Arasan (2020) and Chang and Khan (2023) think that the International

Transport Workers Federation (ITF) and International Shipping Federation (ISF) act as the abandonment reporters for the ILO and intermediaries for fostering the realisation of seafarers' rights to repatriation.

Previous studies underline the legal and conceptual significance of factors affecting repatriation rights. However, these studies do not have enough evidential data to support further discussion. The situations regarding the flag of convenience State and the multinational mixed labour supply are not analysed. The PSC's performance for repatriation facilitation is also not assessed properly. These problems limit the development and effectiveness of the MLC.

2.4.2 The financial security for wage rights

Due to most abandonments mainly caused by shipowners' financial woes, the wage claims are usually coupled with the repatriation requests from abandoned seafarers. The latest MLC amendment mandates shipowners to provide insurance or other financial security as the catch-all provision for crew's financial losses. This compulsory insurance is gradually gaining attention in the academic community.

The core parts of financial security under the MLC are usually P&I clubs taking charge of up to four months' outstanding wages and entitlements. Gupta and Shanthakumar (2023) use simple statistical analysis to examine the performance of implementing the financial security system (FSS) via P&I clubs and demonstrate that FSS has no effect in improving the resolution likelihood of abandonments involving wage issues. Their findings show two facts: one is that large numbers of ships cannot provide the financial security because the certifications have expired, P&I providers cannot be identified and may not even exist; another one is that the available financial security on board cannot cover the cumulative unpaid wages because most seafarers have been abandoned for more than four months. Petrinović et al. (2017) and Cheng (2020) review the roles of P&I clubs in the detailed provisions of the 2014 financial security amendment and the 2016 extension clauses. They address some legal drawbacks: P&I clubs face the vicious cycle of possible replacement seafarers and their wage claims, and P&I clubs are exposed to risks in recovering the reimbursement outside the scope of standard P&I cover. Notably, flag States and P&I clubs are complementary to each other for the protection of seafarers' wage rights. Gupta and Shanthakumar (2022b) and Sampson (2022) indicate that the flag States can urge P&I clubs to pay the owed salaries instantly and unconditionally, while the latter can inform the former to add the ships with certificate termination to the watch list in one month's advance. In certain situations, abandoned crew and flag States can transfer their maritime lien by subrogation, assignment or otherwise to P&I clubs for facilitating wage

remunerations (The Shipowners' Club, 2019). Sometimes, flag States and P&I clubs may share the cost of repatriation and wage arrears.

Ship's age is another part related to wage rights that is focused upon by both flag States and P&I clubs. López-Arranz et al. (2018) and Bolton (2024) suggest that the ship's age represents its remaining sale value for recovering the outstanding wages or the extra expenses for the stakeholders. Older ships, especially those in the extreme cases of long-term unresolved abandonment, typically signify that the flag States and P&I clubs may not get the costs back for assisting the abandoned seafarers with wage claims and reimbursement. To put it another way, the newer the ship, the greater the incentive there is for all parties to ensure the seafarers' wage rights (Exarchopoulos et al., 2018). Furthermore, Khalili (2022) thinks the third-party organisations, such as the ITF and the Mission to Seafarers, have some effects on the wage rights defence.

The above studies reveal the gaps in financial security for seafarer abandonments under the MLC. However, there is no evidence to quantify the roles of P&I clubs as well as the flag States and the ages of ships in abandonment cases. A further empirical policy evaluation by jurimetrics is needed to examine the legislative rigour and completeness of the MLC.

2.5 Summary

This chapter highlights the academic contexts and existing foundations for three sub-topics in this thesis: ballast water and risk assessment, ocean freight volatility and external uncertainty, seafarer abandonment and involved maritime human rights. In the first place, all studies related to the above topics are browsed through on “Web of Science” and “Scopus” citation databases, and a bibliometric analysis is conducted by the knowledge graph software package of “Bibliometrix” for a brief systematic review. In the second place, the highlighted authoritative and classic literature is thoroughly categorised and appraised to set the review scope. The narrative literature review clarifies the promising research directions and opportunities in every topic. It also brings inspiration for each sub-study, for example, obtaining the important predictor variables for ballast water volume estimations for Study 1, providing the time-series methods and techniques for Study 2, and defining the disputable and significant elements in the MLC for Study 3. Based on this literature review, the logic threads are built to match the aforementioned research scheme of the SSM.

Chapter 3: Study 1—Planet Pillar—Governance of Ballast Water: A Generic Discharge Estimation and Risk Assessment Approach and Its Application to Chinese Ports

3.1 Introduction

Vessel ballast water, as an important vector of harmful non-indigenous species (NIS), brings a significant risk to the marine environment and a great challenge to the maritime management (Carlton, 1985; Molnar et al., 2008). In total, an average of 2–3 billion metric tonnes of ballast water are shipped across the globe every year (Veldhuis et al., 2010). As shown in Figure 3-1, harmful aquatic organisms and pathogens are the main NIS in ballast water, such as phytoplankton (harmful algae) and pathogenic bacteria (Ruiz et al., 2000b). Recently, microplastics as a source of NIS have also been detected in ballast water (Naik et al., 2019). These harmful and invasive NIS have a significant negative impact on aquatic ecosystems and local economies around the world. More than 1,000 non-indigenous aquatic species have been transferred to coastal Europe and have caused significant harm, such as the anoxic water blooms in Bilbao Harbour (Gollasch, 2006; Butrón et al., 2011). The NIS invasion events in North America have increased exponentially and, in the US, cause annual economic losses of over \$100 billion (Ruiz et al., 2000a; Miller et al., 2007). New Zealand receives nearly 3 million tonnes of ballast water containing NIS from foreign ports, and Tasmania, Australia, spends a huge cost of about A\$23 million removing invasive marine pests like paralytic shellfish (Hewitt et al., 2005; Campbell et al., 2013). As a result, the hazards of ballast water have attracted increased attention from global academic institutions and international organisations.

The International Maritime Organisation (IMO) has acknowledged the significance of managing ballast water and controlling the risk of NIS spread in 1973 (IMCO, 1973) and enacted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWMC) in 2004 (IMO, 2004). The BWMC entered into force globally in 2017, covering 75.11% of world merchant shipping tonnage (Batista et al., 2017). Along with the BWMC coming into effect, the ballast water exchange standard D-1 is gradually being replaced by the ballast water performance standard D-2 through the installation of Ballast Water Treatment Systems (BWTS), which is being phased in over time for individual ships, up to 8 September 2024¹¹. During this transition process, the ballast water discharge volume at ports

¹¹ The implementation schedule for the transition from the D-1 standard (physically replace at least 95%

cannot be traced back satisfactorily. Therefore, to emphasise effective monitoring and enforcement of BWM, the IMO moves to the experience-building phase (EBP) and emphasises the evidence-based submission and analysis of ballast water data (IMO, 2017b; IMO, 2018)¹².

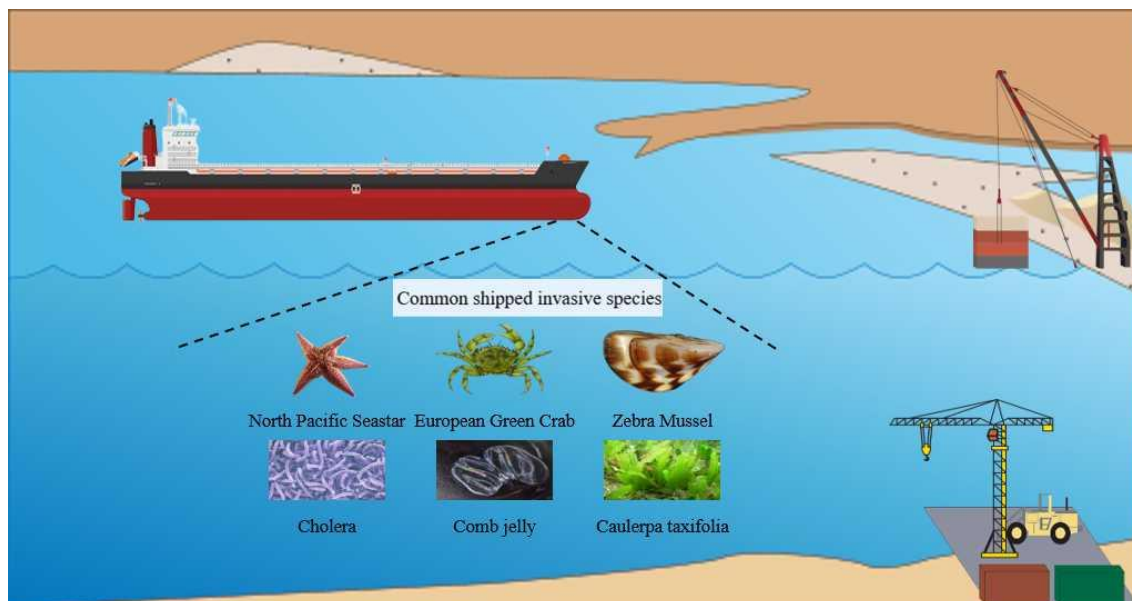


Figure 3-1 The NIS examples through the ballast water vector

Source: Author.

Unlike developed countries, such as the US, Canada, and Australia, which have specialised management authorities to gather and compile ballast water data for every port call (Chan et al., 2013; Cope et al., 2015), most developing countries have not established an official organisation responsible for collecting ballast water information from their ports. China is a quintessential

of ballast water by volume with open-sea water) to the D-2 standard (set a limit on the number of organisms and microbes in the treated ballast water) is divided into different time phases for new ships and existing ships. New ships built on or after 8 September 2017 must meet the D-2 standard. Existing ships must meet at least the D-1 standard. According to the International Oil Pollution Prevention Certificate (IOPPC) renewal survey, existing ships whose IOPPC renewal surveys will be after 8 September 2019, or whose previous renewal surveys were between 8 September 2014 and 8 September 2017 must comply with the D-2 standard by this renewal survey (first renewal survey). However, existing ships whose IOPPC renewal surveys were before 8 September 2014 can wait until the next renewal survey (second renewal survey).

¹² The EBP is structured as three stages: a data gathering stage, a data analysis stage, and a convention review stage. It was established in July 2017 to monitor the BWM's implementation and address challenges that may have arisen during its initial stages (approximately 5 years from the date of entry into force of the BWM). The Marine Environment Protection Committee has received the data analysis report of the EBP at its seventy-eighth session in June 2022. Now the EBP is at the convention review stage with amended, revised and/or developed provisions and will be approved and adopted in 2026.

example to reflect the ballast water management problems faced by developing countries. Although China has implemented the BWMC since 2019, vessel ballast water discharge and source records at Chinese ports are not yet systematically gathered and published in a unified platform. As a result, scholars can only estimate the volumes of ballast water released into the China Sea using the ballast tanks' overall capacity as a predictor, which is calculated by a ratio to ship size in deadweight tonnage (DWT) (Zhang et al., 2017; Wan et al., 2021). However, this discharge estimation approach depends on a single predictor with potential bias and is only updated until 2017 (Zhang et al., 2017). Given these gaps, this study focuses on the following questions:

RQ1: What is the best way to develop a simple and efficient ballast water discharge estimation tool for developing countries without ballast water records?

RQ2: How can this estimation tool be integrated with the risk assessment of NIS invasion as a generic approach for application?

To explore these questions, we propose a widely applicable and effective ballast water estimation model by the Least Absolute Shrinkage and Selection Operator (LASSO) regression. This model has the advantage of simplicity, only requiring common port statistics. Every port authority can adopt the model to estimate the ballast water volumes, regardless of whether the exchange standard D-1 or the treatment standard D-2 of the BWMC is implemented. Besides, building upon the work of Seebens et al. (2013), we also provide a modified risk assessment model. Combining both models as an innovative approach, we apply it to Chinese ports to study real-world cases. Various ballast water scenarios in China from 2017 to 2020 can be estimated, and the associated risks in 2017 are assessed. Thus, the port authority can obtain valuable discharge and risk information to develop management strategies, which are important for the initial implementation of the BWMC.

The contribution of our work is threefold. First, employing common port statistics of monthly total imports, exports, and DWTs ensures the data accessibility and generality for many underdeveloped countries. These statistics are rich but never well used for ballast water estimation and risk assessment at the port level. Second, we develop a generic approach for ballast water management with the above statistics. Third, we apply our model to major Chinese ports' ballast water estimations and related risk assessments within the period 2017-2020, which helps better implement the BWMC and submit evidence-based data for the EBP. Our findings are beneficial for port and government policymakers and provide suggestions for ballast water management.

3.2 Conceptual Assumptions and Theoretical Improvement

The ballast water volume estimation is an important foundation of NIS risk assessment. In order to measure the ballast water discharge (release) accurately, this study reviews the core concept of ballast water to develop a series of assumptions for creating a new theoretical model as follows.

Ballast is an essential part of the safety and stability of different types of ships (Elkady et al., 2014). Since the nineteenth century, solid ballast material has been substituted by water because it is more readily available and more efficient (Jing et al., 2012). Dry bulkers and oil tankers, these two types of ships, generate more than 76% of global ballast water (Endresen et al., 2004). According to the GEF-UNDP-IMO GloBallast Partnerships Programme (2007-2017), Table 3-1 shows the ballast water capacities and associated ratios of DWT of both ship types¹³. The distribution and number of their ballast tanks vary. Under the normal and heavy ballast conditions, the necessary ballast water volumes can vary from 10,000 to 113,000 tonnes for bulkers and from 12,000 to 45,000 tonnes for tankers, respectively. Similarly, the associated ratios of DWT are within the ranges of 30%~57% for bulkers and of 30%~45% for tankers. There is a remarkable difference in ballast water requirements (releases) between the two categories of tramp ships. Hence, we have the assumption:

Assumption 1: The measurement of ballast water discharge for bulkers and tankers should be grouped by ship type.

¹³ The original 'Global Ballast Water Management' programme and the GloBallast Partnerships Programme were undertaken by the IMO together with the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF). Both programmes were called GloBallast for short. They stretched over the period from 2000 to 2017 in two phases. In the first phase (the pilot phase 2000-2004), six developing countries (Brazil, China, India, Islamic Republic of Iran, South Africa and Ukraine) were assisted in developing effective measures to control invasive marine species in tackling the ballast water problem. In the second phase (the formal phase 2007-2017), 15 Lead Partnering Countries focused on developing global technology solutions and enhancing global knowledge management and information exchange, which became an outstanding example of fostering developing countries to reduce the transfer risk of harmful organisms and pathogens in ships' ballast water and implement the BWMC.

Table 3-1 Ballast water capacities by ship type and DWT size

Ship type	DWT size	Normal ballast		Heavy ballast	
		(tonnes and % of DWT)		(tonnes and % of DWT)	
Bulk	35000	10000	30%	17000	49%
	70000	25000	36%	40000	57%
	150000	45000	30%	67000	45%
	250000	75000	30%	113000	45%
Tanker	40000	12000	30%	15000	38%
	100000	40000	40%	45000	45%

Source: Adapted from the GloBallast Programme.

The typical ballast water ballasting and de-ballasting procedures are illustrated in Figure 3-2. At the source port, cargo is unloaded and the ship takes ballast water. During the voyage, it's in heavy ballast status¹⁴. At the destination port, it will load new cargo and discharge ballast water. The ballast tanks are empty with the light ballast status (sometimes in partial ballast status, as Figure B-1 shows in Appendix B) to the next destination port¹⁵. In other words, for any port, if a ship comes to load exported cargo, ballast water is released, and the released volumes are no more than the DWT. If this ship comes to discharge imported cargo, there is no ballast water release. The port's ballast water operations can be regarded as homogeneous in different countries, which implies that the geographic locations and service years of ports have no effect on the operations. Actually, the whole operational process is fully decided by common port statistics that reflect the export and import trade behaviour, including total export tonnages, total import tonnages, and total DWTs. Therefore, we make the assumption:

Assumption 2: The port's ballast water operations are homogeneous all over the world and can be depicted by common port statistics.

When common port statistics act as the estimation indicators for ballast water discharge volumes, total export tonnages represent the actual capacity of ballast tank discharging for vessels arriving at the port (sometimes not all ballast tanks), total import tonnages represent

¹⁴ Here, a heavy ballast status indicates that all ship ballast tanks are fully filled to their capacity.

¹⁵ The light ballast status indicates that all of the tanks are kept empty; a partial ballast status indicates that a small number of ballast tanks are not released for the port activity and subsequent sailing safety, especially when the cargo volume completely occupies the ship's cargo hold but the cargo tonnage is less than the DWT.

possible zero releases which usually mean no ballast water on board after importing cargo, and total DWTs represent the total capacity of all ballast tanks. Clearly, the three kinds of port statistics have a large probability of being highly correlated with each other because they are all constrained by the ship design displacement and produced following the same trade rules. So, we consider the assumption:

Assumption 3: The common port statistics for ballast water estimations have potential multicollinearity to be controlled.

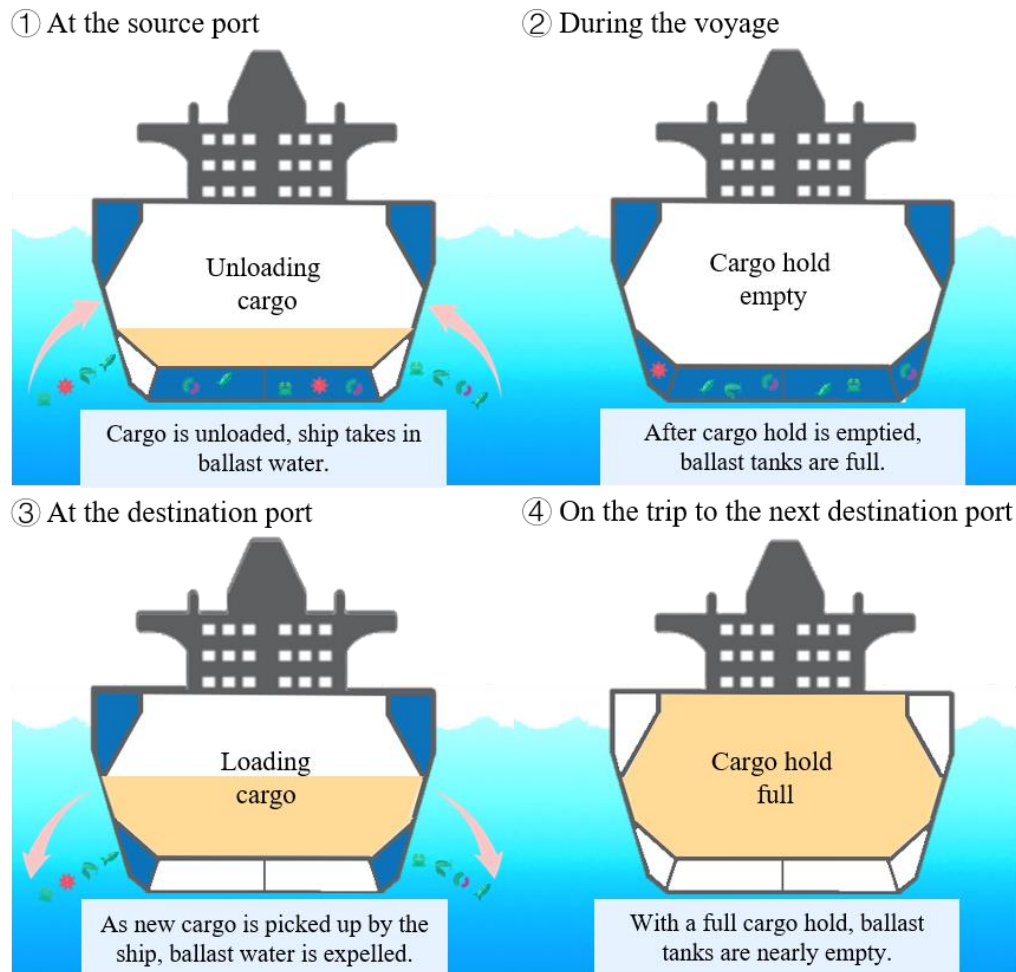


Figure 3-2 The principal procedures of ballast water operations

Source: Author.

With the above assumptions, the estimation of ballast water discharge can be reduced to a regression problem with restricted coefficients. The LASSO regression of machine learning techniques is a possible way to mitigate the negative impacts of multicollinearity within common port statistics. It helps find a trade-off between bias and variance to improve the fitting explainability and the forecasting accuracy for ballast water estimations. Based on the estimated ballast water volumes, we extend the risk assessment model of Seebens et al. (2013) from

individual vessels to individual ports to analyse the ballast water risks. It covers the successive NIS invasion stages that consider factors such as biogeographic overlapping, physiological tolerance, and environmental similarity.

3.3 Methodology

According to the research framework in Figure 3-3, this section introduces a two-step modelling of ballast water estimation and risk assessment models sequentially, which will be illustrated with an application in Section 3.5.

Step one is the ballast water estimation model. For two ship types as research objects, bulkers and tankers are considered separately for estimating monthly discharge (Assumption 1). For the discharge estimation, with the homogeneity of ports' ballast water operations, US ports' ballast water records provide rich discharge data as labels to train the LASSO regression model, and the trained model can be applied to Chinese ports (Assumption 2). For the potential multicollinearity, the LASSO regression model adopts cross-validation to optimise the fitting coefficients of common port statistics as features and hence minimise adverse outcomes of the multicollinearity (Assumption 3).

Step two is the risk assessment model. Compared with the existing models, the model developed by Seebens et al. (2013) is a better method. Before Seebens et al. (2013), risk assessment models primarily relied on either rough matching of port environmental parameters or detailed analysis of a small number of known high-risk introduction “target species” (Colnar and Landis, 2007; Keller et al., 2011). These models ignore the step of identifying whether a species brought by ballast water is alien. However, Seebens et al. (2013) model innovatively integrates global-scale shipping activities, port environmental conditions, and biogeographical information to construct a more dynamic and comprehensive risk assessment framework, which achieves stronger explanatory power and unprecedented extensibility. Its equation forms and parameters will be extended to be compatible with the ballast water estimation model.

Ballast water estimation

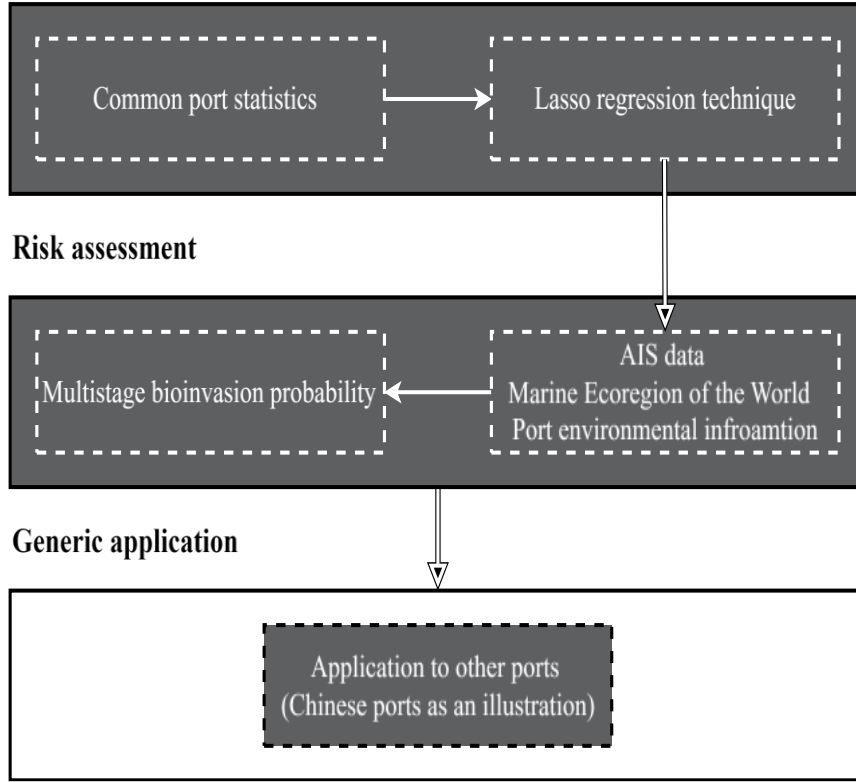


Figure 3-3 The research framework of Study 1

3.3.1 Ballast water estimation model

In this study, we select the Scikit-learn library of machine learning to develop our LASSO model with features of common port statistics that have not been well used in ballast water estimation before. The LASSO regression uses the L1 regularisation term in parameter estimation. It allows adjustment and restriction of the regression coefficients, which avoids the overfitting caused by multicollinearity and highlights the significant features. The detailed model equations are presented as follows.

Let y denote the monthly ballast water discharge at a port as the outcome variable, and x_1, x_2, x_3 denote monthly total exports, imports, and DWTs, respectively. $\beta_1, \beta_2, \beta_3$ are unknown coefficients of the above three predictor variables, and β_0 is the unknown intercept. The objective function to be minimised is shown in Eqs. (3-1) and (3-2):

$$\begin{aligned}
 & \text{Min}_{\beta} \left\{ \sum_{i=1}^N \left(y^{(i)} - \beta_0 - \sum_{j=1}^3 x_j^{(i)} \beta_j \right)^2 + \lambda \sum_{j=1}^3 |\beta_j| \right\} \\
 & = \left\{ \sum_{i=1}^N \left(y^{(i)} - \beta_0 - \beta_1 x_1^{(i)} - \beta_2 x_2^{(i)} - \beta_3 x_3^{(i)} \right)^2 + \lambda (|\beta_1| + |\beta_2| + |\beta_3|) \right\}
 \end{aligned} \tag{3-1}$$

$$\text{Subject to: } \sum_{j=1}^3 |\beta_j| \leq S. \quad (3-2)$$

Here, N represents the number of monthly ballast water discharges. $\lambda \sum_{j=1}^3 |\beta_j|$ represents the penalty term (L1 regularisation term). λ is a regularisation parameter that is determined by the minimised mean squared error. The sum of all coefficients is limited by $S=1$.

3.3.2 Risk assessment model

Based on the ballast water estimation model, we develop the port risk assessment of NIS model. We use the neighbouring marine ecoregions to identify whether a species is alien, use the Automatic Identification System (AIS) data to extract the ship movements and obtain the sailing time for the above-introduced species in ballast tanks, and use the port environment information, such as salinity and temperature, to measure the geographical similarity for potential invasive species. We consider three independent stages and their dynamic invasion risk probability, namely, the probability of NIS identification between the donor and recipient port waters, the probability of NIS introduction from the donor port water to the recipient port water, and the probability of NIS population establishment in the recipient port water (Seebens et al., 2013; Saebi et al., 2020)¹⁶.

Here, the monthly comprehensive NIS spread risk probability is first given with the above three probabilities:

$$P(\text{NIS spread})_m = P(\text{Non-indigenous})_m \times P(\text{Intro})_m \times P(\text{Estab})_m. \quad (3-3)$$

Then, the detailed risk assessment equations of different spread stages are written as:

i. The likelihood of being non-indigenous

$$P(\text{Non-indigenous})_m = \sum_i^N p_{ij}^{NI} / N_{port}. \quad (3-4)$$

We calculate the average probability that a species is non-native for the recipient port j . For a ship from the donor port i to the recipient port j , p_{ij}^{NI} is a binary variable: It equals 0 for native dispersal between the same or neighbouring ecoregions and 1 for NIS dispersal between the different ecoregions. N_{port} is the monthly frequency of port calls.

¹⁶ Tramp ships have no fixed routes and intermediate stopovers like container ships. Thus, their risk assessments do not involve the aggregated NIS invasion risks of the complex shipping network for a specific vessel. The model formulas have no multiplication sign, unlike the original model of Seebens et al. (2013).

ii. The likelihood of introduction

$$P(Intro)_m = \rho \left(1 - e^{-\lambda D_{port}} \right) e^{-\mu \Delta t_{avg}}. \quad (3-5)$$

We calculate the introduction risk with monthly ballast water estimation D_{port} . Factor ρ represents the ballast water treatment efficiency with the default value of 1. Δt_{avg} is the monthly average travelling time of all ships. Set $\mu=0.02$ as the mortality rate and $\lambda=3.22 \times 10^{-6}$ as the species introduction potential (Saebi et al., 2020).

iii. The likelihood of establishment (habit)

$$P(Estab)_m = \alpha_{init} e^{-\frac{1}{2} \left[\left(\frac{\Delta T_{avg}}{\delta T} \right)^2 + \left(\frac{\Delta S_{avg}}{\delta S} \right)^2 \right]}. \quad (3-6)$$

We considered the Gaussian distributions of temperature and salinity to evaluate environmental similarities. ΔT_{avg} and ΔS_{avg} are the average temperature and salinity differences between the donor port and the recipient port. α_{init} is the survival probability. Set $\delta T=2^\circ C$, $\delta S=10 ppt$ and $\alpha_{init}=1$ for maximum survival rate (Seebens et al., 2013).

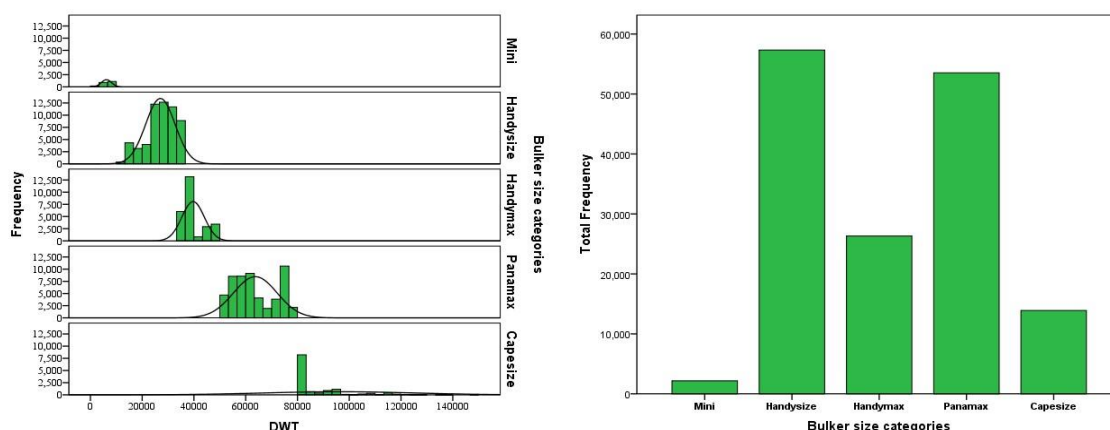
3.4 Data

3.4.1 Sample collection and parameter set

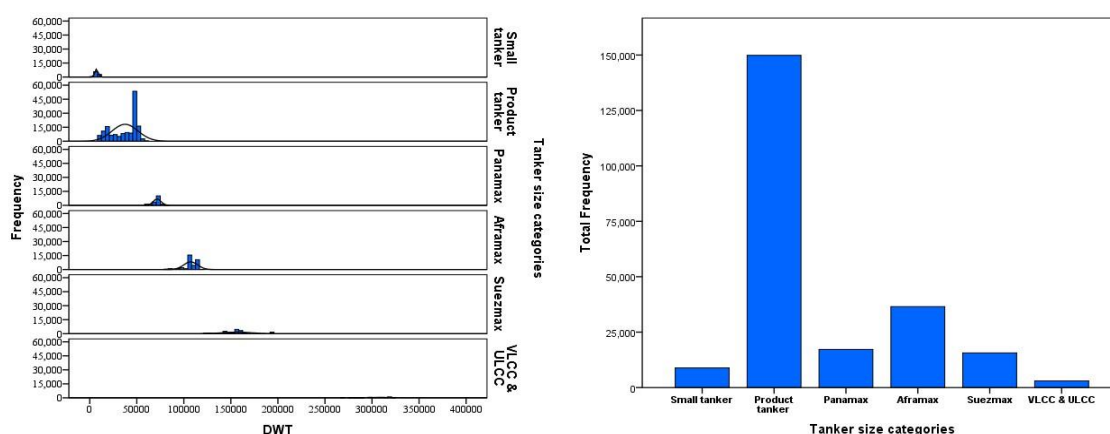
Firstly, considering the worldwide homogeneity of ballast water discharge behaviours, we construct the estimation model using the ballast water information platform of the National Ballast Information Clearinghouse (NBIC) (<https://invasions.si.edu/nbicdb?agree=true>) in the US, which has received ballast reports from all vessels arriving at ports in the United States since 2004 and provides rich ballast water release reports and samples. The ballast water release data from NBIC are collected for the period 2010-2020 to build our estimation model. In the meantime, to match the ballast water releases, the associated port statistics are derived from USA Trade Online (<https://usatrade.census.gov/>). Detailed information is described as follows.

Ballast water release data: NBIC can give access to ship operation data online for every port call, including IMO number, arrival date, discharge volume and gross tonnage, etc. We extract 159,216 releases for bulkers and 263,637 releases for tankers, which are from 68 major ports in the USA. As shown in Figure 3-4, these data cover most size categories of the two ship types. Bulkers in Handysize and Panamax sizes contribute more than 75% of releases. Tankers

in Product and Panamax sizes contribute more than 73% of releases. Notably, Product tankers account for about 57% of releases.



(a) Bulker size category distributions for ballast water discharges at US ports.



(b) Tanker size category distributions for ballast water discharges at US ports.

Figure 3-4 The ballast water discharge frequencies from 2010 to 2020 of different ship size categories at US ports

Port statistics data: For imports and exports statistics of the above 68 major ports, we obtain data from the USA Trade Online according to the Harmonised System (HS) codes of commodities. As shown in Table 3-2, the cargoes such as cereals, mineral products and corals are transported by bulkers, while the cargoes such as crude oil, petroleum products, mineral tars and bitumen are transported by tankers. For DWT statistics, the Lloyd's Maritime Intelligence database (<https://www.seasearcher.com/>) can provide the information for vessels in service. We match the DWT data with the ballast water releases, according to the ship names and their IMO numbers.

Table 3-2 Main categories of HS codes for both ship types

Ship type	Two- or four-digit HS code
Bulker	10,11,12,26, 47,2701,2702,2703,2704,7204, etc.
Tanker	2706,2707,2708,2709,2710,2712,2713,2714,2715, etc.

In order to ensure the data uniformity in the time dimension, we merge the daily ballast water releases data from different collection sources: coastwise, overseas and unknown. Then we sum the daily data to produce the monthly data for each ballast water recipient port. The frequency distribution of monthly ballast water data among different ports presents a normal distribution (see Table B-1 in Appendix B). Finally, we obtain the panel dataset of monthly discharge volumes and related statistics from 2010 to 2020 at US ports by combining three kinds of port statistics. Table 3-3 lists the descriptive statistics of the outcome and predictor variables of our dataset for US ports.

Table 3-3 Descriptive statistics of variables about US ports

Bulkers (unit: thousands of tons)						
Variable	Description	Obs	Mean	Std. Dev.	Min	Max
BWDs_b	Port monthly ballast water discharges by bulkers	4387	142.675	304.163	0	2686.224
Exports_b	Port monthly total exports by bulkers	4387	400.765	686.256	0.000407	5499.777
Imports_b	Port monthly total imports by bulkers	4387	56.325	85.16	0.000103	857.136
DWTs_b	Port monthly total DWTs by bulkers	4387	805.383	1378.95	2.926	12360.77
Tankers (unit: thousands of tons)						
Variable	Description	Obs	Mean	Std. Dev.	Min	Max
BWDs_t	Port monthly ballast water discharges by tankers	4401	199.026	457.293	0	4220.372
Exports_t	Port monthly total exports by tankers	4401	194.984	428.591	0.002501	3596.973
Imports_t	Port monthly total imports by tankers	4401	661.96	861.605	0.000159	6229.908
DWTs_t	Port monthly total DWTs by tankers	4401	1850.144	2503.859	5.887	18339.58

Using the panel dataset, we also confirm the reliability and generalizability of the model trained on US data and straightforwardly applied to Chinese ports. The F-test at a 95% confidence level is employed to diagnose the port-fixed effects. The *p-value* for bulkers is 0.089 and for tankers is 0.074, which means the ballast water behaviour can be assumed to be homogeneous for ports in different countries. Therefore, the pooled regression of the LASSO form is accurate enough and generic for ballast water estimation in China.

Notably, the US is currently not a party to the BWMC, and the United States Coast Guard has its own BW regulations, requiring most vessels entering US waters to install ballast water management systems (BWMSs) since 2014. However, these onboard BWMSs will not change the discharged volumes of ballast water. They are facilities for the treatment of viable organisms and bacteria in ballast water, not for releasing the ballast water. Therefore, implementation time points of such treatment policies in the two countries have no fixed-time effect, and thus the US research data for model setup will not have a significant impact on the follow-up risk assessment.

Secondly, for the risk assessment model, we assess the risks in 2017 of ten important Chinese coastal ports of Shanghai, Tianjin, Dalian, Qingdao, Yingkou, Rizhao, Ningbo-Zhoushan, Xiamen, Guangzhou, and Shenzhen. The imports and exports statistics of these ports are obtained from the China shipping database (http://www.shippingdata.cn/index_en.html) in terms of the above HS codes. The DWT statistics of these ports are also extracted from Lloyd's Maritime Intelligence database. In addition, the port environment and biogeographical information are obtained from Saebi et al. (2020), including the temperature and salinity data of 669 major ports of the world and the data of Marine Ecoregions of the World (<https://github.com/msaebi1993/Species-Flow-Networks/tree/master/data>). The corresponding ship movement data are extracted from the AIS, e.g., donor and recipient ports, sailing time of ships, etc.

3.4.2 Variance inflation factor bias check

Based on the above constructed dataset, we identify whether our ballast water estimation model is reasonable and feasible. Table 3-4 reports the results of the variance inflation factor (VIF) test for predictor variables. It shows multicollinearity mainly exists between the port statistics of *Exports* and DWTs. The multicollinearity is moderate for bulkers and minor for tankers. According to Belsley et al. (2005), when the VIF is below the allowed maximum of 10, the LASSO approach can eliminate the effects of multicollinearity without excluding any variable. Therefore, our estimation model is indeed workable.

Table 3-4 The results of multicollinearity diagnostics

Bulkers			Tankers		
Predictor variable	VIF	Tolerance	Predictor variable	VIF	Tolerance
Exports _b	5.6	0.178571	Exports _t	3.23	0.309292
Imports _b	1.11	0.902598	Imports _t	1.92	0.521385
DWTs _b	5.86	0.170648	DWTs _t	3.31	0.302058
Mean VIF	4.19		Mean VIF	2.82	

3.5 Results

3.5.1 Model building of LASSO regression

Our ballast water estimation model is established by the LASSO regression with the optimal regularisation parameter lambda (λ), which is searched for and determined by 10-fold cross-validation. We can describe the port monthly ballast water discharge of both ship types by (unit: thousands of tons):

$$\text{Bulkers: } BWDs_{_b} = 0.098Exports_{_b} - 0.056Imports_{_b} + 0.168DWTs_{_b} - 28.950, \quad (3-7)$$

$$\text{Tanker: } BWDs_{_t} = 0.736Exports_{_t} - 0.067Imports_{_t} + 0.071DWTs_{_t} - 30.826. \quad (3-8)$$

Robustness checks. To the best of our knowledge, extant studies have not conducted robustness checks when estimating the ballast water discharge volumes. In order to demonstrate the generality of LASSO regression results, we conduct robustness checks by varying the sample sizes and removing variables (Verbeek, 2018). The sample sizes are changed with different time windows. The year 2017 is when the BWMC formally came into force; therefore, it can be used to segment the different study periods. Specifically, Model 1 represents the full sample size from 2010 to 2019, the same as Eqs. (3-7) and (3-8). Model 2 represents the medium sample size from 2010 to 2016. Model 3 represents the small sample size from 2017 to 2019. Additionally, to compare with previous research, we set Model 4 with a single variable—*Exports* and Model 5 with a single variable—*DWTs*. We analyse both models by the OLS (ordinary least squares) regression.

Table 3-5 summarises the results of five models. In general, for fitting effects, the findings suggest that the mean absolute percentage error (MAPE) of LASSO models (Model 1~3) varies in the range of 8.47%~15.88% for bulkers and 8.05%~8.58% for tankers, while it varies in the

range of 15.21%~16.90% for bulkers and 10.89% ~20.96% for tankers in the single variable models (Model 4~5). The fitting results are acceptable within the tolerance range of 50% discrepancy (David et al., 2012). The adjusted R^2 of models including all variables of port statistics is more than 0.9 for bulkers and 0.85 for tankers. The significance level of port statistics as explanatory variables is at the 1% level. It implies that the port statistics contribute to an excellent estimation performance. For robustness effects, our models with multiple variables (Models 1~3) have smaller root mean squared errors (RMSEs) than those of Models 4 and 5 with a single variable. In addition, the robustness of LASSO regression is better guaranteed, approaching an unbiased estimation as the sample size increases.

In view of the model variables, the port statistics in LASSO regression (Models 1~3) show good interpretability for ballast water estimation. Specifically, the coefficients of *Exports* and *DWTs* indicate a positive relationship with estimated discharge volumes and are consistent with previous research. The effect of *DWTs* is larger than that of *Exports* for bulkers; the opposite result is true for tankers. One possible reason is that some tankers calling at port are used for the offshore storage of crude oil and refined oil (not fully loaded), in which *DWTs* makes no contribution to ballast water. Notably, as the sample size becomes sufficient, the coefficient sign of *Imports* becomes negative, especially in Model 1, where its value is -0.056 for bulkers and -0.067 for tankers. Although the negative coefficient induced by *Imports* is not of great numerical value, it demonstrates *Imports* should not be omitted and suggests a situation that some ships unload imported cargo at first, then they load exported cargo without any ballast water releases, which explains the negative effect of importing behaviour. These findings support that the common port statistics have favourable generality and feasibility when applied in the BW estimation model.

Table 3-5 The results of the robustness check

Variable	Bulkers				
	Model 1 (2010-2019)	Model 2 (2010-2016)	Model 3 (2017-2019)	Model 4 (2010-2019)	Model 5 (2010-2019)
Exports_b	0.099*** (0.002)	0.095*** (0.005)	0.086*** (0.004)	0.411*** (0.002)	
Imports_b	-0.056*** (0.014)	-0.054** (0.015)	0 (0.021)		
DWTs_b	0.168*** (0.001)	0.174*** (0.003)	0.147*** (0.002)		0.213*** (0.001)

Constant	-28.950*** (1.473)	-30.187*** (1.707)	-13.463*** (2.716)	-22.123*** (1.985)	-28.568*** (1.415)
Observations	4387	3038	1349	4387	4387
Lambda (Control shrinkage)	0.99	0.99	0.66	-	-
RMSE	80.79	92.41	85.46	113.48	89.93
MAPE	12.14%	15.88%	8.47%	16.90%	15.21%
Adjusted-R ²	0.936	0.942	0.918	0.861	0.861
F-Test	21468.5***	16457.4***	5034.6***	27109.9***	57542.4***

Tankers					
Variable	Model 1 (2010-2019)	Model 2 (2010-2016)	Model 3 (2017-2019)	Model 4 (2010-2019)	Model 5 (2010-2019)
Exports _t	0.736*** (0.003)	0.553*** (0.011)	0.83*** (0.009)	0.985*** (0.006)	
Imports _t	-0.067*** (0.003)	-0.023*** (0.004)	0 (0.004)		
DWTs _t	0.071*** (0.001)	0.069*** (0.002)	0.051*** (0.002)		0.158*** (0.001)
Constant	-30.826*** (2.951)	-36.356*** (3.231)	-29.557*** (4.594)	6.885** (2.904)	-93.909*** (4.273)
Observations	4401	3070	1331	4401	4401
Lambda (Control shrinkage)	0.01	0.9	0.93	-	-
RMSE	131.16	145.38	147.53	175.32	227.91
MAPE	8.12%	8.05%	8.58%	10.89%	20.96%
Adjusted-R ²	0.9	0.865	0.945	0.853	0.752
F-Test	13033.5***	6323.4***	7635.9***	25523.2***	13307.3***

Note: Standard errors are in parentheses. The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively. The unit of panel datasets is thousands of tons.

Out-of-sample backtesting. We also conduct an out-of-sample forecast test to validate the generalisation ability with 95% confidence intervals and prediction intervals. The testing dataset contains samples from 2020, and the training dataset contains samples of ten years 2010–2019. As Figure 3-5 shows, the estimations fall within the range of the prediction interval with an adjusted R² of 0.93 for bulkers. For tankers, when the monthly discharge volumes are larger than 3×10^3 thousands of tons, the model underestimates the ballast water discharge.

But we can accept the results with an adjusted R^2 of 0.90. Most estimations fall within the range of three standard deviations. Compared with the results of Verna et al. (2021), our model improves the R^2 by 7% for bulkers and by 3% for tankers.

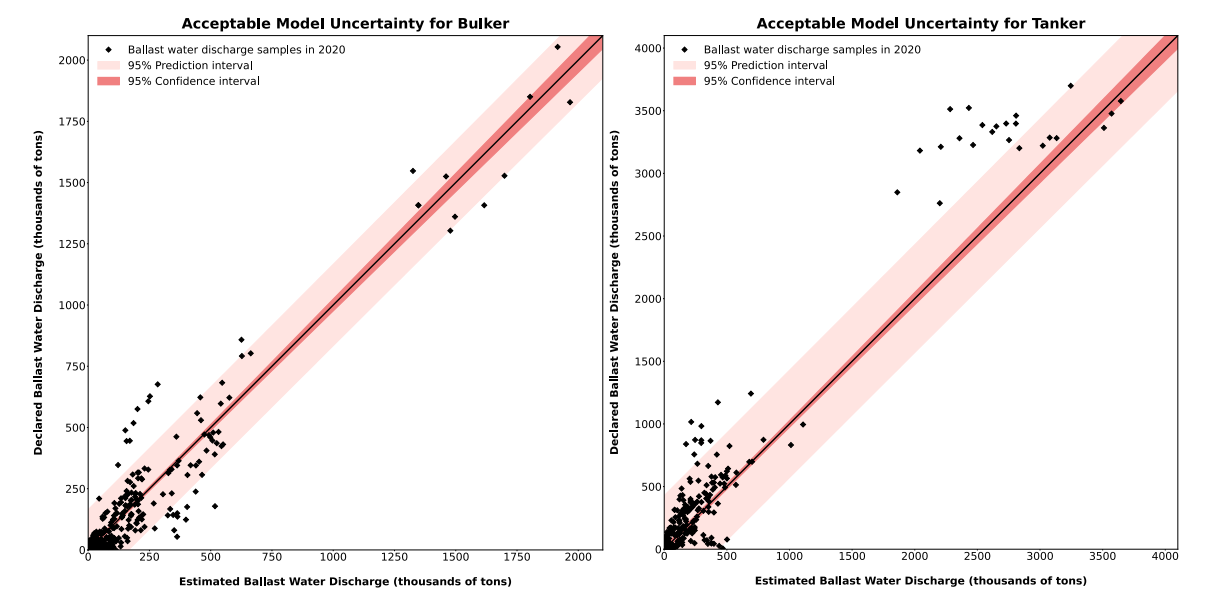


Figure 3-5 Declared ballast discharges versus estimated ballast discharges in 2020

Note: Each dot represents a monthly discharge into a single port, and a 1:1 regression line is plotted for reference in black.

3.5.2 Estimation for ballast water discharges into China

Based on the built LASSO regression model, we estimate the annual ballast water volume (sum of 12 months) released by bulkers and tankers to Chinese ports. The results in Table 3-6 show, during the years 2017–2020, the volumes contributed by bulkers show a slow decline from about 3.3 to 2.8 billion tons per year, while the volumes contributed by tankers have increased from 1.9 to 2.2 billion tons. The top 5 recipient ports are located at the Yangtze River Delta and Bohai Rim. They receive more than 80% of ballast water from both ship types. In contrast, the Guangzhou Port and Shenzhen Port, located at the Pearl River Delta, account for only 6%~8%. Notably, the Ningbo-Zhoushan Port has received the maximum amount of ballast water with an annual average of about 65 million tons from each of the ship types. These findings are in line with the attributes and functions of these ports.

Ballast water estimations for bulkers (unit: thousands of tons)					
Port	2017	2018	2019	2020	Total of years
Ningbo-Zhoushan	57929	59709	68105	68913	254654

Rizhao	54656	57269	45851	46048	203824
Tianjin	55744	51664	45184	47082	199674
Qingdao	49235	44804	34065	31281	159385
Shanghai	34559	33697	27117	21709	117082
Guangzhou	30696	26295	16210	16951	90151
Yingkou	21979	24349	22704	20395	89427
Dalian	12548	14143	13900	15364	55955
Xiamen	9853	9787	9104	9357	38101
Shenzhen	4939	3792	2068	2387	13186
Total of ports	332138	325507	284307	279487	

Ballast water estimations for tankers (unit: thousands of tons)

Port	2017	2018	2019	2020	Total of years
Ningbo-Zhoushan	56925	58392	65653	75803	256772
Dalian	30286	31006	37740	38045	137076
Qingdao	26134	29490	31334	31918	118875
Tianjin	22969	25837	26365	25747	100917
Rizhao	11993	14705	14615	17314	58627
Yingkou	16047	13045	12895	12667	54654
Shanghai	9519	8203	8832	8363	34916
Guangzhou	6633	6453	6338	6791	26215
Shenzhen	6020	6310	5410	5737	23478
Xiamen	659	848	2092	2095	5693
Total of ports	187184	194288	211274	224479	

We also define the concept of ballast water discharge potential, that is, the ratio of ballast water volumes to cargo throughputs (the sum of exports and imports for tramp ships). The value of discharge potential can be calculated as follows:

$$\text{Discharge potential (DP\%)} = \frac{\text{Ballast water discharge volumes}}{\text{Throughputs of dry (liquid) bulk cargo}} \times 100\% \quad (3-9)$$

Table 3-7 reports the ballast water discharge potentials of different ship types in Chinese ports. From 2017 to 2020, the average discharge potential of ten ports by bulkers exhibits an annual downward trend with a minimum of 17%, while by tankers it exhibits an annual growth trend with a maximum of 43%. It implies that China increases more dry bulk commodities

imports (leading to more zero discharges) and more petroleum products exports (leading to more ballast water discharges) every year. For the average discharge potential of an individual port in four years, the top 4 ports are Tianjin (*DP%*: 23%), Yingkou (*DP%*: 22%), Rizhao (*DP%*: 20%), and Qingdao (*DP%*: 20%) for bulkers, and Shenzhen (*DP%*: 43%), Yingkou (*DP%*: 42%), Dalian (*DP%*: 39%), and Tianjin (*DP%*: 38%) for tankers. It is consistent with the actual facts that the ports in Bohai Rim, as well as the Shenzhen Port, have the most export terminals of dry and liquid bulk. Notably, in China, tankers exhibit a greater discharge potential than bulk carriers. This is primarily because tankers engaged in exporting from Chinese ports are considerably larger than bulk carriers, which gives them a natural advantage in ballast tank capacity (Verling et al., 2005). Therefore, ballast water supervision at Chinese ports should be reinforced, particularly for tankers.

Table 3-7 The ballast water discharge potentials for both ship types

Discharge potential for bulker					
Port	2017	2018	2019	2020	Average of years
Tianjin	25%	24%	21%	23%	23%
Yingkou	20%	19%	27%	23%	22%
Rizhao	26%	21%	16%	16%	20%
Qingdao	26%	23%	17%	16%	20%
Shanghai	17%	20%	18%	19%	19%
Dalian	19%	19%	17%	17%	18%
Shenzhen	23%	20%	14%	13%	17%
Xiamen	13%	14%	16%	20%	16%
Guangzhou	20%	17%	8%	9%	13%
Ningbo-Zhoushan	11%	10%	12%	12%	11%
Average of ports	20%	19%	17%	17%	

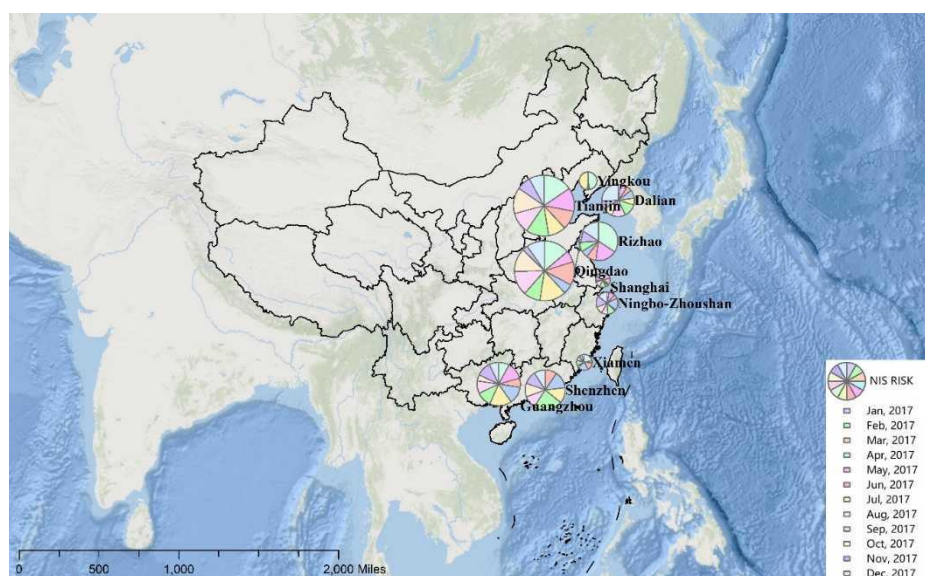
Discharge potential for tanker					
Port	2017	2018	2019	2020	Average of years
Shenzhen	45%	49%	40%	37%	43%
Yingkou	38%	41%	50%	42%	42%
Dalian	40%	40%	39%	36%	39%
Tianjin	40%	39%	37%	35%	38%
Ningbo-Zhoushan	35%	37%	37%	35%	36%
Shanghai	30%	30%	30%	30%	30%
Guangzhou	28%	28%	29%	28%	28%
Qingdao	25%	27%	26%	25%	26%
Rizhao	19%	21%	21%	22%	21%
Xiamen	16%	17%	31%	21%	21%
Average of ports	32%	33%	34%	31%	

3.5.3 Risk assessment for Chinese ports

We calculate the monthly comprehensive NIS spread risks for Chinese ports in 2017. The results in Figure 3-6 report that compared to the ports located at the Yangtze River Delta and Pearl River Delta, the ports in Bohai Rim, such as Tianjin, Qingdao, and Rizhao, have a higher probability of comprehensive NIS risk from ballast water. This implies the risk probabilities of these ports are proportional to their ballast water discharge potentials (ratios between the ballast water volume and cargo throughput in Section 3.5.2). Notably, the monthly comprehensive NIS risk probability is not significant for Chinese ports. The maximum risk magnitude is about 0.1, which has a limited impact on China's marine ecology. To provide further explanation, the average invasion likelihoods of three stages are investigated.



(a) Comprehensive NIS spread risks brought by bulkers.



(b) Comprehensive NIS spread risks brought by tankers.

Figure 3-6 The monthly comprehensive NIS spread risks for Chinese ports in 2017

Note: The sizes of the pie charts exhibit the rank according to the average NIS spread risk.

As shown in Table 3-8, for both ship types, the average likelihood of NIS introduction from donor to recipient port waters (*average introduction risk*) is high and exceeds 0.9, except for Shenzhen. It implies large amounts of marine species are introduced into the Chinese seas through the vector of vessel ballast water. For bulkers, the average likelihood of NIS identification between the donor and recipient port (*average non-indigenous species risk*) is larger than 0.4 in Xiamen Port and ports of the Pearl River Delta (Guangzhou Port and Shenzhen Port), which means these ports are more likely to find NIS from different marine ecoregions in the ballast water released by bulkers. However, regardless of whether for bulkers or tankers, the average likelihood of NIS population establishment in recipient port waters (*average establishment risk*) is quite low for all ports. This is because most NIS cannot tolerate a great difference in temperature and salinity among ports. As a result, the comprehensive NIS spread risk probability (*average NIS spread risk*) is not significant for Chinese ports. But the potential negative impact of introduced species cannot be excluded. It still threatens the biodiversity and hydrological condition of the recipient ecosystem, because secondary transfer of aquatic NIS along the coastline to the inland waterway usually occurs (Lavoie et al., 1999; Verna and Harris, 2016).

Table 3-8 The monthly average bio-invasion risks for Chinese ports in 2017

Port	Average comprehensive NIS spread risk probability		Risks of three distinct invasion stages					
			Average being non-indigenous species risk likelihood		Average introduction risk likelihood		Average establishment risk likelihood	
	Bulker	Tanker	Bulker	Tanker	Bulker	Tanker	Bulker	Tanker
Tianjin	0.036	0.024	0.164	0.115	0.993	0.990	0.232	0.255
Qingdao	0.019	0.023	0.089	0.141	0.992	0.993	0.217	0.187
Rizhao	0.020	0.010	0.126	0.072	0.988	0.951	0.208	0.203
Dalian	0.015	0.007	0.096	0.159	0.949	0.991	0.187	0.047
Guangzhou	0.001	0.012	0.592	0.138	0.993	0.824	0.003	0.121
Xiamen	0.011	0.002	0.417	0.224	0.918	0.917	0.038	0.053
Shenzhen	0.001	0.010	0.713	0.128	0.713	0.789	0.002	0.124
Shanghai	0.008	0.001	0.028	0.019	0.994	0.915	0.299	0.084
Ningbo-Zhoushan	0.002	0.003	0.036	0.032	0.991	0.993	0.052	0.098
Yingkou	0.001	0.002	0.105	0.133	0.990	0.978	0.011	0.035

3.6 Discussion

3.6.1 Methodological considerations

For the ballast water estimation model, for the first time, more available and public port management statistics are considered as predictors. It is particularly suitable for countries without ballast water records and information platforms. More importantly, classical models only depend on the correlation between DWT and ballast water on board, such as the Great Lakes model and the European model. Their estimated results are rough and show a large difference (David et al., 2012). Our estimation model can achieve a satisfactory accuracy by shrinking the variance of every variable with LASSO regression, which has great robustness and out-of-sample forecasting performance. As a ballast water decision tool, this new model is a good supplement to the BWDA model because: The BWDA model is based on the perspective of an individual vessel. It mainly considers the conditions of vessels that will discharge ballast water during the loading and unloading operations at every port of call, and then calculates the discharge volumes with various ratios of DWT. However, the data and information accessibility of an individual vessel and its associated loading and unloading operations limit the application of the BWDA model in different regions, especially in developing countries. In addition, our model shows that the variables—*DWTs* and *Exports* have different positive effects on discharge estimation for bulkers and tankers, while the variable—*Imports* presents a negative effect. For the risk assessment model, we extend the comprehensive probability of NIS spread model to the port level. It integrates the estimation model to act as a powerful management support framework.

3.6.2 Practical applications and policy suggestions

In practice, as the representative of developing countries, China is selected to forecast the ballast water volumes and assess the associated risk using the above proposed models. The findings reveal that: (1) For both ship types, bulker and tanker, Ningbo-Zhoushan Port receives the most, about 65 million tonnes of ballast water per year, and ports in the Yangtze River Delta and Bohai Rim are heavily affected; (2) Due to differences in vessel sizes for export activities, tankers have larger ballast water discharge potentials than bulkers in China and need more supervision, especially for Tianjin and Yingkou Ports; (3) Chinese ports are at a high risk (more than 0.9) of invasive species' introductions, although most NIS cannot establish their habitats. In fact, China, as the representative of developing countries, has no special legislation for ballast water regulation. BWM is included in many other pieces of legislation (e.g., the Chinese government formulated the Biosecurity Law and the Administrative Measures for Entry and

Exit Inspection and Quarantine on Ships of International Sails). However, our empirical results show these pieces of legislation are insufficient to address current ballast water challenges. In fact, in recent years, more than 660 NIS have been found in ballast water, and about 40 alien species of phytoplankton, 16 alien species of zooplankton, and 24 alien species of harmful microorganisms (Xu et al., 2012; Wu et al., 2017). Therefore, it is urgent to call for new ballast water legislation.

Based on our work, some policy suggestions are provided: (1) In the Yangtze River Delta and Bohai Rim, set up a regional pilot ballast water information online platform for experience accumulation; (2) Fill in the historical discharge data for main ports and assess the NIS risk of past years to carry out hierarchical remedial measures for the environment; (3) The allowable ballast water exemption rules should be reconsidered for stricter tiering by ship type, which is a supplementary provision for the current Regulation A-4 (Outinen et al., 2021); (4) Strengthen monitoring and detection of the density of aquatic species in high-risk ports. Furthermore, considering that the D-2 standard has become mandatory according to the BWMC, we also recommend that Chinese port authorities prepare onshore or barge-based ballast water treatment facilities. The biological and chemical sampling of treated ballast water should be conducted during Port State Control (PSC) inspections for further reduction of NIS risk.

3.6.3 Limitations and future directions

Although this study provides important insights for the implementation of BWMC in developing countries, it still has several limitations. First, the lack of real ballast water records in China makes the estimations difficult to calibrate, which is an unobservable error. Second, some other factors, like the barge-based ballast water reception and the port ballast water storage, are not involved in the models. Third, the port biological baseline surveys have not been conducted for Chinese ports to determine the presence and abundance of NIS. All these concerns will be the focus of future research.

3.7 Conclusion

The BWMC has moved into the experience-building phase immediately after its official entry into force in 2017 (IMO, 2018). The lack of historical ballast water discharge data records makes developing countries the main focus of this transition phase. Estimations of the released ballast water volumes and the relevant risk assessments in these countries' ports are important for the refinement of BWMC. However, difficulties in technology and capability have led to challenges for developing countries in accurately measuring the discharge volumes and

calculating the associated biological invasion risks. Accordingly, this study develops a new and generic ballast water discharge estimation and risk assessment approach, by integrating the common port statistics with LASSO regression and the theory of risk propagation probability. Under the context of BWMC's experience-building requirements, the first-ever approach considers the data richness and accessibility at the port level to manage ballast water. The performance and interpretability of this approach are well validated and analysed. Specifically, to illustrate the effectiveness of the approach, China, as one of the most important developing countries, is chosen for a case study. The unknown ballast water discharge volumes from 2017 to 2020 in ten main Chinese ports are estimated, and the different risk probabilities in 2017 are assessed. This paper is believed to contribute to previous literature both theoretically and practically.

On the theoretical side, the study utilises three common port statistics—DWTs, exports, and imports as the core predictor variables in the ballast water estimation model. These variables can cover the typical ballast water operation processes and are easily controlled by the L1 regularisation of the LASSO approach for their potential multicollinearity, which ensures a high prediction accuracy. This model has the following advantages: (1) For the port authorities, it is easier to estimate the past discharge volumes, especially when they face obstacles to reconcile ballast water record books from individual ships; (2) It facilitates the early implementation of BWMC regulations and data provision in developing countries; (3) It prepares the ground for a macro evaluation of the NIS risk. Based on the estimation model, the Seebens et al. (2013) model can be extended to the port level. The extended risk model avoids the consideration of complex risk propagations within intermediate stopovers, which is suitable for tramp ships. The target recipient port only needs to take into account the average lasting sailing time of each port call and the corresponding origin ports' information. All these settings simplify the computational cost of the risk model to improve serviceability.

On the practical side, the study demonstrates the application of the generic ballast water discharge estimation and risk assessment approach with a sample of Chinese ports. The forecast discharge volumes and NIS risk data provide relatively reliable evidence for the development of ballast water facilities and laws in China. They can act as baselines for Chinese ballast water information references during the conversion period from D-1 to D-2 standards, which help China to establish alternate discharge areas for challenging water quality, as well as physical containment and chemical treatment mechanisms for invasive species. Until all ships are equipped with BWTS, the expansion of the above approach in developing countries will be one of the most important means to boost the efficiency of BWMC and enhance the sustainability

of the health of the marine environment.

To wrap it all up, ballast water discharges and associated risks are issues that countries will be facing for a long time, and how to manage them correctly according to the BWMC still requires the joint efforts of many parties.

Chapter 4: Study 2—Profit Pillar—Governance of Market Volatility: The Role of External Uncertainties in Internal Volatility Spillovers Across Shipping Freight Markets

4.1 Introduction

Ocean freight services account for over 80% of international trade volumes and are inherently volatile due to fragmented business structures and sensitive transportation cycles (Alizadeh and Nomikos, 2011). Recent global crises, as shown in Figure 4-1, driven by external uncertainties, have profoundly impacted maritime logistics systems. During the COVID-19 pandemic, container spot freight rates soared to four times their pre-pandemic levels, with composite rates exceeding \$5,000 per TEU. Similarly, average spot freight rates in dry bulk and tanker markets saw significant increases in 2021 and 2020, respectively. Then, during the Russia-Ukraine war, freight rate volatilities across major shipping markets were further exacerbated due to rising grain and energy prices. The conflict increased dirty tanker market rates by 80% and clean tanker rates by 60%, while dry bulk rates rebounded and container rates slowed their decline between March and May 2022 (UNCTAD, 2022a; UNCTAD, 2022b). According to Baker et al. (2016) and Caldara and Iacoviello (2022), external uncertainties are typically represented by Economic Policy Uncertainty (EPU) and Geopolitical Risk (GPR) indices¹⁷. The growth of these external uncertainties, characterised by elevated levels of EPU and GPR, creates a volatile environment for shipping trade and spot markets.

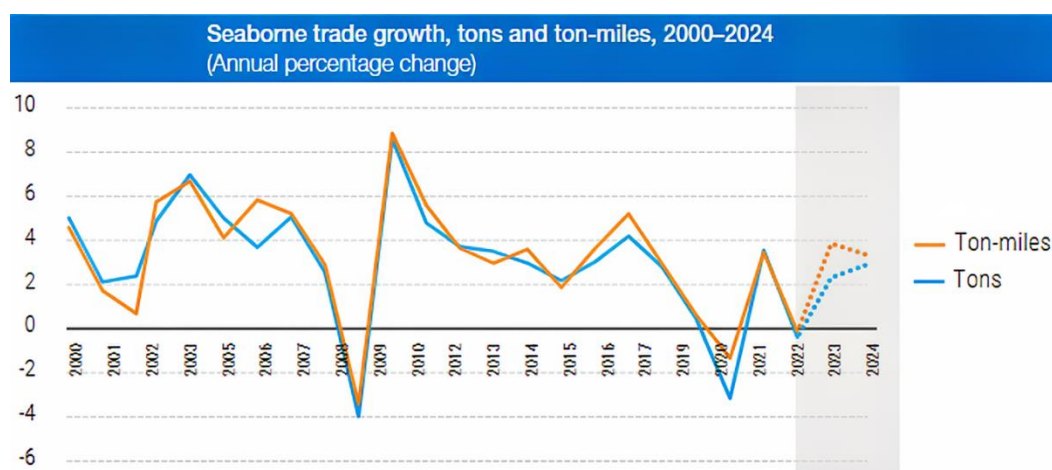


Figure 4-1 A chronology of maritime logistics services

Source: UNCTAD secretariat.

¹⁷ Both indices represent the flows of information and sentiment but with different emphases.

Four major shipping freight markets—containers, dry bulkers, dirty tankers, and clean tankers are capital-intensive sectors and usually characterised by natural interconnection and high volatility (Wiedmer et al., 2023). For instance, as claimed by news reports in 2021, Genco Shipping & Trading Company planned to transport container boxes via dry bulk carriers (Brady, 2021). In 2022, Lomar Shipping Company acquired the 166-year-old tanker company of Carl Büttner to expand its tanker fleet, while Celsius Shipping Company sold all dry bulk carriers to invest in tankers (Logan, 2021; Lomar Shipping Limited, 2022). Such behaviours by shipping companies, competing for similar goods with different ship types and shifting investments between freight markets, can propagate demand and supply imbalances across shipping sectors (Stopford, 2008; Sun et al., 2020; Tsouknidis, 2016). Consequently, freight rates across different markets exhibit co-movements and internal volatility spillovers.

Shipping players like the carriers and shippers always pursue profit maximisation in times of turmoil. Carriers care more about the arbitrage opportunities among different freight markets created by EPU and GPR, which may arise from route interruptions and port congestion (Drobetz et al., 2021; Theodossiou et al., 2020). They tend to update their short-term fleet diversity in second-hand ship markets while allocating long-term strategies in new-build ship markets to capitalise on excess returns resulting from spillovers. Conversely, shippers tend to estimate the extra risk costs induced by fluctuations in other freight markets, deciding whether to seek alternative transportation modes, such as railways, in the face of external uncertainties (Chang and Thai, 2017). Therefore, assessing the relationship between the EPU and GPR and the internal spillovers among shipping freight markets is vital.

To our knowledge, there is a paucity of studies investigating how shipping freight volatilities react to external uncertainties, despite the critical importance of understanding these linkages and their implications. This study aims to integrate internal spillovers across key shipping spot (freight) markets with EPU and GPR indices into a coherent framework. It clarifies the following research questions:

RQ1: What is the dynamic evolution of the internal volatility spillovers across container, dry bulk, dirty, and clean tanker spot freight markets?

RQ2: How do the external uncertainties proxied by EPU and GPR indices affect these internal volatility spillovers?

To tackle these questions, we develop a robust research framework based on vector autoregression (VAR) approaches. For the first question, we construct the Diebold-Yilmaz (DY) spillover indices through the time-varying parameter VAR (TVP-VAR), which allows us to quantify directional and nonlinear spillovers among these four shipping spot freight markets

(Diebold and Yilmaz, 2012)¹⁸. As demonstrated by Antonakakis et al. (2020), the accuracy of DY spillover indices is improved by the parameter adaptability and flexibility of TVP-VAR. For the second question, we investigate the Granger causality in quantiles and associated impulse responses between external uncertainties and spillover dynamics. The quantile VAR and the TVP-VAR with stochastic volatility are employed, respectively. All these approaches provide powerful tools to empirically assess how uncertainty factors impact the volatility in shipping from various dimensions.

The contributions of our study are threefold. First, we innovatively bridge the volatility spillovers across spot markets within both liner and tramp shipping and the external uncertainty factors. This research covers four crucial spot markets and two uncertainty factors of EPU and GPR. The outcomes reveal transmission paths across internal spillovers of these markets and detect the macro causality and shock impacts from external uncertainties on these dynamic spillovers. Second, unlike most existing studies, this research examines a longer period following the COVID-19 pandemic, including significant global events like the Russia–Ukraine conflict. This larger and updated sample range helps identify shifts in the roles of shipping spot markets between net spillover transmitters and receivers over different time horizons, and helps compare the mechanisms by which EPU and GPR Granger-cause volatility spillovers. Furthermore, the mediating and leverage functions of tanker markets are validated. Last but not least, this study offers actionable policy implications and strategic plans for stakeholders in the context of escalating economic and geopolitical risk trends.

4.2 Data Processing and Variable Settings

4.2.1 Data processing

Our dataset comprises four shipping freight rate indices and two uncertainty indices, covering samples from October 2009 to March 2023. To keep consistency in variable dimensions, we preprocess the spot freight rates as logarithmic returns and the uncertainty factors as percentage changes. The available highest frequency data are selected to better capture internal spillovers among shipping spot markets and their interactions with external uncertainties. Notably, freight rate returns are recorded on a weekly basis, whereas percentage changes in uncertainty factors are recorded monthly, resulting in mixed-frequency data.

¹⁸ The development introduction of DY spillovers can be found at <https://www.financialconnectedness.org> and <https://sites.google.com/view/davidgabauer/econometric-code> (last accessed in March 2025).

Therefore, when linking the returns' spillover indices to the percentage changes in uncertainties, we convert the former from a weekly format into a monthly format by computing monthly averages to ensure the same frequency. Here are the detailed data processing steps:

- **Step 1.** Collect weekly price indices for spot markets of container ships, dry bulk carriers, crude oil and product tankers, and monthly uncertainty indices for EPU and GPR.
- **Step 2.** Fill in missing holiday data using linear interpolation based on values before and after the missing points, particularly for freight rate indices.
- **Step 3.** Compute the logarithmic freight rate returns by $R_t = 100 * \ln(P_t/P_{t-1})$ and the percentage changes in uncertainty indices by $\Delta C_t = 100 * (I_t - I_{t-1})/I_{t-1}$ at a given time t , where P_t is a specific spot market's price index and I_t is a specific uncertainty index.
- **Step 4.** For freight rate return spillover indices produced by the DY spillover index model, calculate the mean value of weekly spillovers within the same month to get the monthly spillovers.

4.2.2 Variable settings

Table 4-1 provides details on the time series variables involved in data processing. Our time series dataset includes four freight rate return variables of $rBDI$, $rBDTI$, $rBCTI$, and $rSCFI$ with 701 observations, and two uncertainty factor percentage change variables of ΔEPU , ΔGPR with 162 observations.

Table 4-1 List of variables

Latent variable	Symbol	Description	Source
2009/10-2023/03 Weekly shipping freight rate returns (701 samples)			
Returns of Shanghai Containerized Freight Index	rSCFI	Shanghai Containerized Freight Index (SCFI) is published by the Shanghai Shipping Exchange. Its returns reflect the short-term movements of international container spot markets, which have a higher sensitivity than others.	SCFI, BDI, BDTI, and BCTI are available from Clarksons Shipping Intelligence Network: https://sin.clarksons.net/
Returns of Baltic Dry Index	rBDI	Baltic Dry Index (BDI), Baltic Dirty Tanker Index (BDTI), and Baltic Clean Tanker Index (BCTI) are published by the Baltic Exchange in London. They are famous shipping indices. Their returns represent the composite levels in global spot	
Returns of Baltic Dirty Tanker Index	rBDTI		
Returns of Baltic Clean Tanker Index	rBCTI		

markets of dry bulk, crude oil, and product oil shipments.

2009/10-2023/03 Monthly percentage changes of uncertainty indices (162 samples)		
Percentage changes in the Global Economic Policy Uncertainty Index	ΔEPU	The global EPU index is the weighted average of national EPU indices of 21 countries, counting the text frequencies about the economy (E), policy (P), and uncertainty (U) in the own-country newspapers. Changes in EPU show the rise and fall of the world economy. EPU data of the PPP-adjusted GDP version are available from the website of Baker et al. (2016): https://www.policyuncertainty.com/
Percentage changes in the Geopolitical Risk Index	ΔGPR	The GPR index is constructed by the electronic texts of geopolitical events from 10 famous newspapers. It considers eight threat categories, such as war and military. Changes in GPR show the average variation of security levels in global commercial transportation. GPR data are available from Matteo Iacoviello's website (Caldara and Iacoviello, 2022): https://www.matteoiacoviello.com/gpr.htm

Table 4-2 presents the descriptive statistics and correlation coefficients for freight rate returns. In part A, all return series exhibit nonzero skewness and their kurtosis values exceeding 1.5, highlighting their sharp-peaked and fat-tailed characteristics. The Augmented Dickey-Fuller (ADF) test illustrates that all return series are stationary for the construction of DY spillover indices by TVP-VAR, while the Ljung–Box test confirms the presence of autocorrelation. In part B, most correlation coefficients are statistically significant, indicating potential co-movements among these freight rate returns. While many correlation coefficients are positive, the coefficients between $rSCFI$ and $rBDI$, $rBDTI$ are negative.

Table 4-2 Descriptive statistics and Spearman correlations for freight rate returns

Variable	rBDI	rBDTI	rBCTI	rSCFI
Part A: Descriptive statistics				
Observations	701	701	701	701
Mean	-0.040	0.061	0.058	-0.005
Std.Dev.	4.058	2.928	3.267	2.535
Min	-12.875	-16.953	-18.03	-8.47
Max	20.784	23.614	28.666	23.368
Skewness	0.265	0.845	0.855	2.702
Kurtosis	1.476	10.175	13.893	17.499

Jarque-Bera	73.021***	3129.995***	5762.945***	9860.767***
ADF	-15.005***	-17.971***	-18.844***	-5.748***
Ljung-Box (20)	378.649***	142.714***	176.713***	240.291***
Part B: Spearman correlation coefficients				
rBDI	1			
rBDTI	0.082**	1		
rBCTI	0.101***	0.268***	1	
rSCFI	-0.058*	-0.061*	0.033	1

Note: The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 4-3 presents the descriptive statistics of percentage changes in uncertainty indices. The ΔEPU and ΔGPR are not normally distributed; instead, they exhibit skewness and excess kurtosis behaviour. The Jarque-Bera test confirms the non-normality. The ADF results demonstrate that the ΔEPU and ΔGPR satisfy the models' stationarity assumption of the quantile Granger causality test and impulse response analysis.

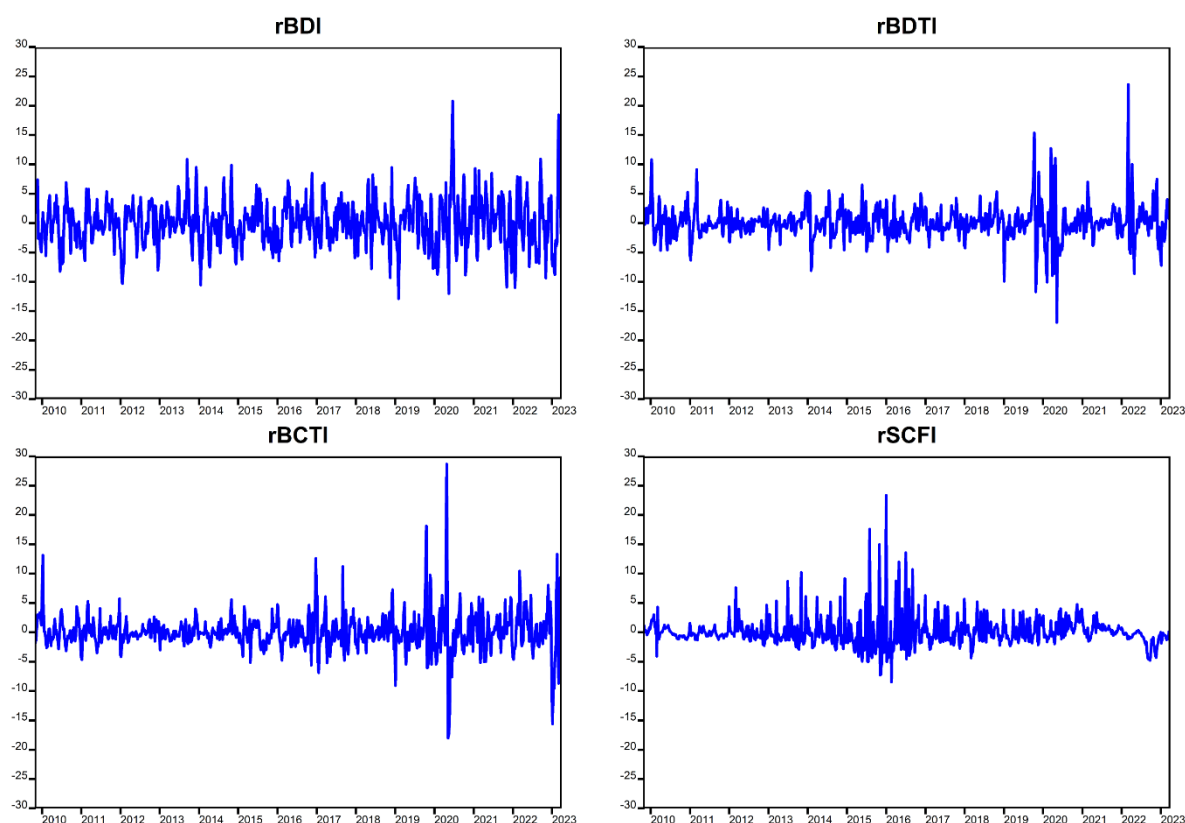
Table 4-3. Descriptive statistics of percentage changes in uncertainty indices

Variable	Observation	Mean	Std.Dev.	Min	Max	Skewness	Kurtosis	Jarque-Bera
ΔEPU	162	2.302	19.258	-36.567	84.106	1.190	2.924	99.598***
ΔGPR	162	2.112	21.319	-45.127	86.350	1.129	2.279	72.189***

Note: The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

A preliminary analysis of our variables is also provided. Figure 4-2 illustrates the trends and fluctuations of variables. In panel A, the trends of $rBDI$, $rBDTI$, and $rBCTI$ suggest that dry and liquid bulk spot freight markets exhibit significant volatility throughout the sample period, exceeding 20% after the COVID-19 pandemic. In contrast, the $rSCFI$ trend indicates the container spot freight market experiences lower volatility, with sharp fluctuations only occurring primarily during the period of 2015–2018. In panel B, the fluctuations of ΔEPU and ΔGPR are trend-synchronised with global events over the years. Notably, ΔEPU shows pronounced volatility during the emerging market crises of 2016 and 2017. ΔGPR reached its peak when the COVID-19 pandemic broke out, and has continued to grow for a long time since the Russia-Ukraine conflict in 2022.

Panel A: Freight rate returns of different shipping spot markets.



Panel B: Changes of uncertainty indices.

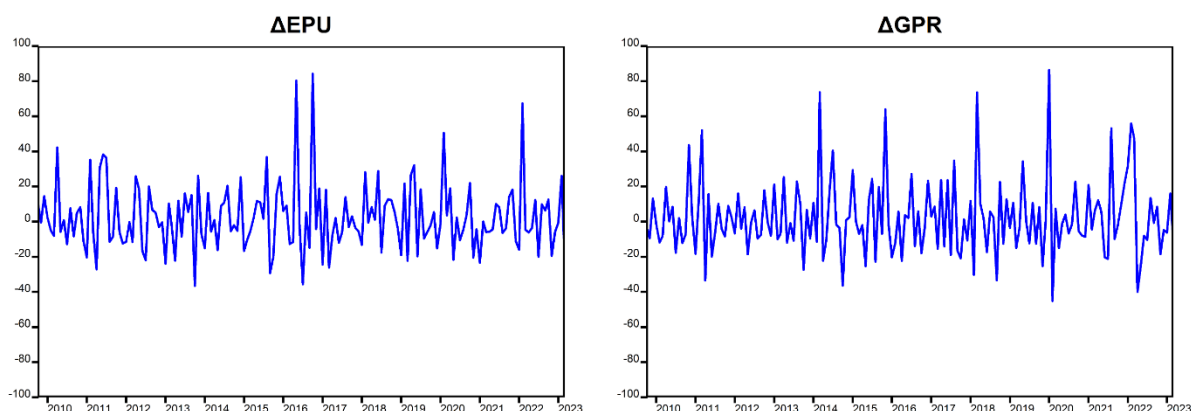


Figure 4-2 Returns of freight rates and changes of uncertainty indices

4.3 Methodology

According to the workflow in Figure 4-3, the internal volatility among shipping spot freight markets and the external uncertainties' effect are examined. All involved approaches are introduced as follows.

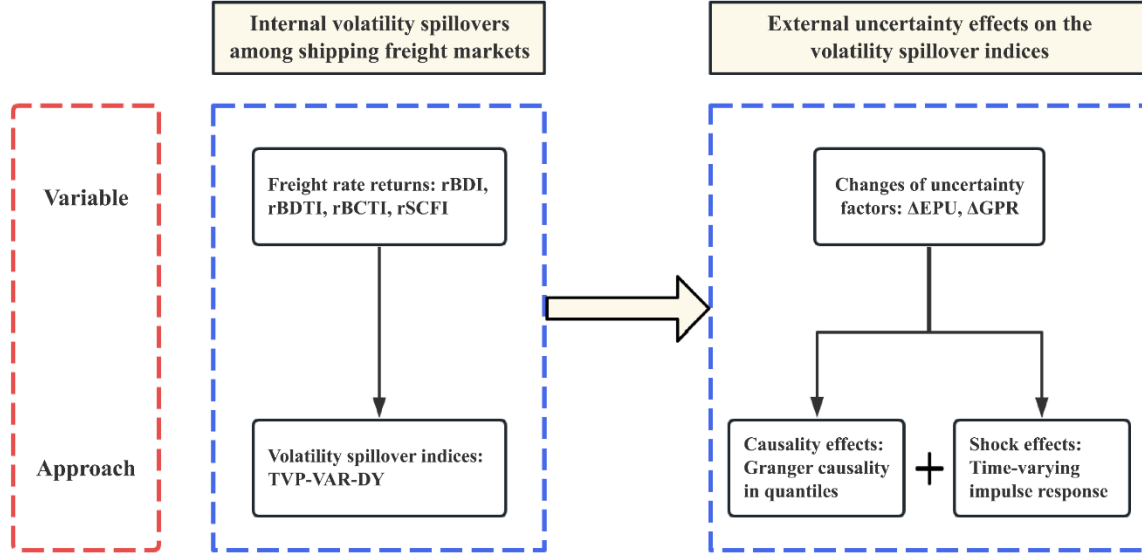


Figure 4-3 Research methodology workflow of Study 2

4.3.1 TVP-VAR-DY model

For internal spillovers within four shipping spot markets, the directional volatility connectedness is time-varying and sensitive to the sample window size (Diebold and Yilmaz, 2012). Hence, we use the TVP-VAR approach to overcome this shortcoming with robust self-adaptation. Directional spillover indices can be estimated via the generalised impulse response function (GIRF) and the generalised forecast error variance decomposition (GFEVD) (Koop et al., 1996; Pesaran and Shin, 1998). They do not require ordering variables before the Cholesky factorisation and imposing orthogonalized shocks, which ensures the fitting accuracy with the Kalman filter algorithm (Chan-Lau, 2017). Following the work of Antonakakis et al. (2020), given the vector form of $y_t = [rBDI_t, rBDTI_t, rBCTI_t, rSCFI_t]^T$, the TVP-VAR is:

$$y_t = A_t z_{t-1} + \varepsilon_t, \quad z_{t-1} = [y_{t-1}, \dots, y_{t-p}], \quad \varepsilon_t \sim N(0, S_t) \quad (4-1)$$

$$vec(A_t) = vec(A_{t-1}) + \zeta_t, \quad \zeta_t \sim N(0, R_t) \quad (4-2)$$

where A_t is the time-varying coefficient matrix and $vec(A_t)$ is the vectorisation of A_t , ε_t and ζ_t are error disturbance vectors with the corresponding time-varying variance-covariance matrices of S_t and R_t , respectively.

Then, the TVP-VAR can be redefined in vector moving average form by the Wold theorem: $z_t = \sum_{i=1}^p A_{i,t} z_{t-i} + \varepsilon_t = \sum_{j=0}^{\infty} B_{j,t} \varepsilon_{t-j}$, where $B_{j,t} = \sum_{l=1}^p A_{l,t} B_{j-l,t}$ is the response function and $B_{0,t}$ is a unit matrix. Based on this, the H-step-ahead forecast $GRIF(\varphi_{ij,t}(H))$ and the normalised $GFEVD(\tilde{\theta}_{ij,t}(H))$ (by the row sum to one) are calculated as:

$$\varphi_{ij,t}(H) = S_{ij,t}^{-\frac{1}{2}} B_{H,t} S_t e_j \quad (4-3)$$

$$\tilde{\theta}_{ij,t}(H) = \frac{\sum_{t=1}^{H-1} \varphi_{ij,t}^2}{\sum_{j=1}^n \sum_{t=1}^{H-1} \varphi_{ij,t}^2} \quad (4-4)$$

where GIRF denotes the response of all markets j to the volatility of freight rate return in market i , and e_j is a unit vector with the j th element being 1 and 0 otherwise. Normalised GFEVD denotes the influence of market j on market i , which is the forecast variance share. All markets together can explain 100% of forecast variances.

Finally, dynamic DY spillover indices are defined in Table 4-4. The *total spillover index* (TSI_t) denotes the average overall spillover effect of each market on other markets under volatility. For a specified market i , the *total directional spillover to others* ($DS_{TO,it}$) and the *total directional spillover from others* ($DS_{FROM,it}$) denote its aggregate spillovers through transmission and reception, respectively. The positive (negative) value of *net total directional spillover* (NS_{it}) represents that the market i is a net transmitter (net receiver) of spillovers. Similarly, the positive value of *net pairwise total directional spillover* ($NPS_{ij,t}$) indicates that market i is driving the net spillover between itself and market j , and vice versa.

Table 4-4 Denotations of dynamic DY volatility spillover indices

DY volatility spillover indices	Definition
$TSI_t(H) = \frac{\sum_{i,j=1, i \neq j}^n \tilde{\theta}_{ij,t}(H)}{n} * 100$	The sum of all non-diagonal elements (the spillover of the entire system for all involved markets) is divided by the number of markets to measure the average contribution of total spillovers.
$DS_{TO,it} = \left(\frac{\sum_{j=1, i \neq j}^n \tilde{\theta}_{ji,t}(H)}{\sum_{j=1}^n \tilde{\theta}_{ji,t}(H)} \right) * 100$	The aggregated spillover of a specified market i on all other markets.
$DS_{FROM,it}(H) = \left(\frac{\sum_{j=1, i \neq j}^n \tilde{\theta}_{ij,t}(H)}{\sum_{i=1}^n \tilde{\theta}_{ij,t}(H)} \right) * 100$	The aggregated spillover of all other markets on a specified market i .
$NS_{it}(H) = DS_{TO,it}(H) - DS_{FROM,it}(H)$	The aggregated net spillover of the market i on all markets.
$NPS_{ij,t}(H) = (\tilde{\theta}_{ji,t}(H) - \tilde{\theta}_{ij,t}(H)) * 100$	The difference between the net spillover from market i to market j and that from market j to market i .

4.3.2 Granger causality in quantiles

For measuring external uncertainties' impacts on internal spillovers among shipping spot markets, Granger causality is a popular tool. It is a kind of VAR model assuming all variables

are endogenous without adding control variables. The traditional Granger causality test can only confirm the average causal relationship between two time series, which ignores the heterogeneity of specific quantile locations. Therefore, we use the Granger causality in quantiles to accurately portray the predictive power of uncertainties for the spillover indices at each quantile interval. Assuming that the conditional distribution can be completely determined by the quantile VAR model, the explanatory variables of uncertainties as $U_t \in \{\Delta EPU_t, \Delta GPR_t\}$ and the response variables of spillovers as $V_t \in \{TSI_t, NS_{it}, NPS_{ij,t}\}$ are set. Following the approach of Chuang et al. (2009), the null hypothesis of quantile Granger non-causality is that $H0: U \overset{Q}{\Rightarrow} V$, i.e., to test whether the following equation holds:

$$Q_{V_t}(\tau | (V, U)_{t-1}) = Q_{V_t}(\tau | V_{t-1}), \quad \tau \in [a, b] \quad (4-5)$$

where $Q_{V_t}(\tau | (V, U)_{t-1})$ denotes the τ th quantile of the conditional distribution of V_t . Then, if the τ th quantile model is correctly expressed as:

$$Q_{V_t}(\tau | (V, U)_{t-1}) = \alpha(\tau) + V'_{t-1}\gamma(\tau) + U'_{t-1}\beta(\tau) \quad (4-6)$$

Here, testing Eq. (4-6) amounts to testing $H0: \beta(\tau) = 0, \tau \in [a, b]$ by the Wald test. The Wald test statistic is $W_T(\tau) = T\hat{\beta}_t(\tau)' \hat{\Omega}(\tau)^{-1} \hat{\beta}_t(\tau) / \tau(1 - \tau)$, where T is the number of observations, $\Omega(\tau)$ denotes the variance-covariance matrix of $\beta(\tau)$. The sup-Wald test statistic for the null hypothesis proposed by Chuang et al. (2009) is $\sup W_T = \sup_{\tau \in [a, b]} W_T(\tau)$. It can test the significance within a specified quantile interval. All critical values of the sup-Wald statistics are estimated by means of Monte Carlo simulations. The quantile τ is set within the range [0.1-0.9] by 5 intervals.

4.3.3 Time-varying impulse responses

To further capture potential dynamic linkages, this study examines the effects of uncertainty shocks on internal spillovers among shipping spot markets. We also adopt the TVP-VAR approach to estimate impulse responses at different lag intervals and at different time points, which can better identify dynamic structural shocks and breaks. Along the lines of Nakajima (2011), time-varying coefficients and stochastic volatility are introduced into the standard VAR model. Given the vectors for model specification, $Spillover\ indices_t \in \{TSI_t, NS_{it}, NPS_{ij,t}\}$ and $Y_t = [\Delta EPU_t, \Delta GPR_t, Spillover\ indices_t]^T$, the type of TVP-VAR is written as:

$$Y_t = X_t\beta_t + A_t^{*-1}\Sigma_t\eta_t, \quad \eta_t \sim N(0, I_k) \quad (4-7)$$

where Y_t is the vector of variables, β_t is the vector of stacking time-varying coefficients, and

$X_t = I_k \otimes (Y'_{t-1}, \dots, Y'_{t-s})$ is defined by Kronecker product notation- $\otimes$. Assuming A_t^* is a time-varying lower triangular matrix and Σ_t is a time-varying diagonal matrix of the structural shock with standard deviation σ , these matrices can be expressed as:

$$A_t^* = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \alpha_{21,t} & 1 & & \vdots \\ \vdots & & \ddots & 0 \\ \alpha_{k1,t} & \cdots & \alpha_{k,k-1,t} & 1 \end{bmatrix}, \Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{k,t} \end{bmatrix} \quad (4-8)$$

Then, set $\alpha_t = (\alpha_{21}, \alpha_{31}, \alpha_{32}, \alpha_{41}, \dots, \alpha_{k,k-1})'$ and $h_t = \log \sigma_{jt}^2$ for $j = 1, \dots, k$. Supposing the parameters in Eq. (4-7) follow a random walk process as $\beta_{t+1} = \beta_t + u_{\beta t}$, $\alpha_{t+1} = \alpha_t + u_{\alpha t}$, $h_{t+1} = h_t + u_{ht}$, the gradual changes and structural breaks can be captured. The variance-covariance matrix of the model's innovations is a block diagonal:

$$\begin{pmatrix} \eta_t \\ \mu_{\beta t} \\ \mu_{\alpha t} \\ \mu_{ht} \end{pmatrix} \sim N \left(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_{\beta} & 0 & 0 \\ 0 & 0 & \Sigma_{\alpha} & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix} \right) \quad (4-9)$$

The above time-varying parameters are estimated by the Markov Chain Monte Carlo (MCMC) algorithm with 10,000 samplings, including a pre-burn of 1000 samplings.

4.4 Empirical Results

4.4.1 Internal volatility spillovers among shipping spot freight markets

To explore how average volatility spillovers in the shipping freight system have evolved dynamically across four main spot markets, particularly in light of the COVID-19 pandemic, the time path of the total spillover index- TSI_t over the past decade is estimated in Figure 4-4, which has been validated for robustness as shown in Figure C-1 in Appendix C. From 2010 to 2015, the total spillover remained stable, hovering around 15%, with just a brief surge above 20% during the Eurozone debt crisis in 2012. Between 2014 and 2019, as emerging economies slowed and investment activity declined—resulting in reduced seaborne demand and an oversupply of global fleets—the TSI_t index gradually fell to 10%. However, since the COVID-19 outbreak at the end of 2019, the total spillover increased sharply, peaking at nearly 40% within half a year. Then, from 2021 to 2023, amid ongoing conflicts like the Russia–Ukraine conflict, the TSI_t index persistently fluctuated around 20%. According to Sun et al. (2019) and Maitra et al. (2020, 2021), global events can exacerbate average spillovers in the shipping industry. Compared to other crises, COVID-19's port lockdowns and economic downturns have had more profound and lasting impacts on shipping.

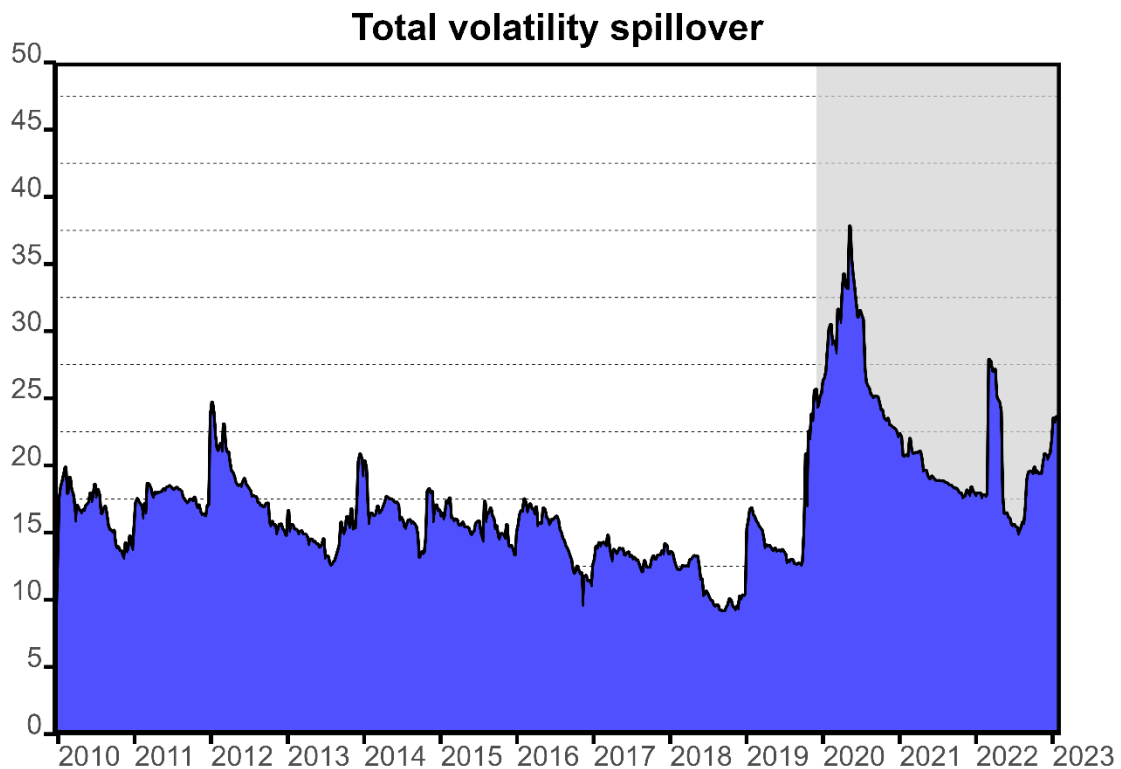


Figure 4-4 Dynamic movements of the total spillover in the shipping freight system.

Note: Total spillover index (TSI_t) is estimated 12 steps ahead of forecast error variance decomposition with the TVP-VAR model. The shaded area denotes the recent global crisis period of the COVID-19 pandemic.

Figure 4-5 illustrates the net total directional spillover across time to show the volatility relationship between individual markets and the entire shipping freight system. It depicts each market's net contribution to this system. The positive value of NS_{it} indicates that the corresponding market transmits more volatility to other markets in the system than it receives, and vice versa. Throughout the sample period in Figure 4-5, the role of any market alternates between being a net transmitter and a net receiver of volatility. Before the COVID-19 pandemic, from 2010 to 2019, the dry bulk market shifted from net transmitter to net receiver, while the container market exhibited the opposite trend. Both clean and dirty tanker markets changed roles with a high frequency. However, after the COVID-19 pandemic, the dirty tanker market became a significant net transmitter (over 10% spillover), while the dry bulk and container markets became critical net receivers. Notably, the clean tanker market was a net transmitter only in 2020 due to supply chain disruptions, and then also became a net receiver. All four markets experienced sharp increases in the NS_{it} index magnitudes.

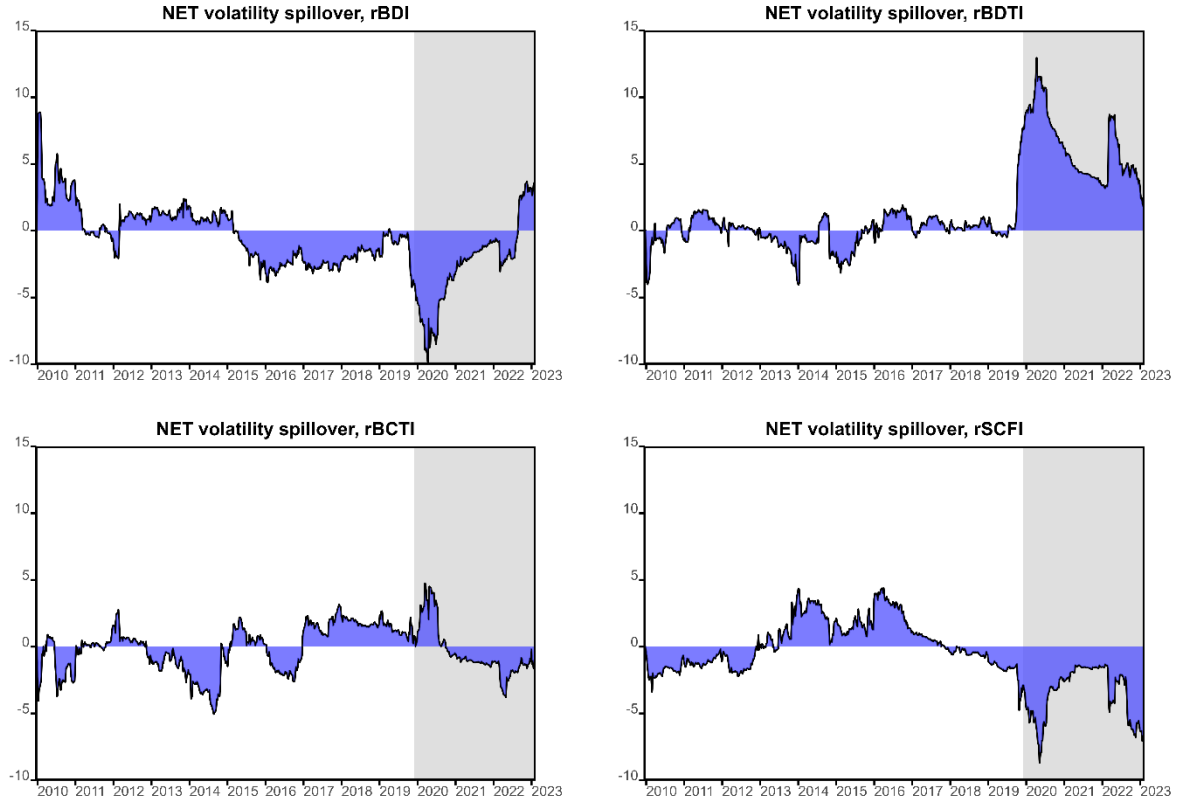


Figure 4-5 Dynamic net total directional spillovers for every shipping spot freight market

Note: The ahead-step of forecast error variance decomposition is $H=12$ for NS_{it} . The shaded area denotes the period of COVID-19.

Given COVID-19's significant impact on shipping spot markets, the samples are divided into pre-COVID-19 and post-COVID-19 periods to analyse average net pairwise total directional spillovers. Table 4-5 presents these spillovers with $NPS_{ij,t}$ values for each period. During the pre-COVID-19 period, the container market (0.77% of average net spillover, the same as below) and the dirty tanker market (0.42%) were net transmitters of volatility. In contrast, the dry bulk (-0.74%) and clean tanker markets (-0.45%) were net receivers. During this time, the overall volatility of the shipping freight system was not notable. The main net pairwise spillover originated from the container sector, following the path of $rSCFI \rightarrow rBDI$ & $rBCTI$ with the associated $NPS_{ij,t}$ values of 0.15% and 0.1%, respectively. During the post-COVID-19 period, the dirty tanker market (22.85%) emerged as the most dominant net transmitter of volatility, while the container market (-13.57%) became the only net receiver that was influenced by the other three markets. The main net pairwise spillover followed the path of $rBDTI \rightarrow rBDI$ & $rBCTI$ with $NPS_{ij,t}$ values of 2.12% and 2.84%. The COVID-19 pandemic has induced high volatility spillovers across four crucial spot markets and has shifted the role of the container freight market from a net transmitter to a net receiver.

Table 4-5 Average volatility spillovers among different shipping spot freight markets

Pre-COVID-19 period: 2009/10/23–2019/12/27					
	rBDI	rBDTI	rBCTI	rSCFI	FROM
rBDI	88.01	4.1 (0.07)	4.56 (-0.04)	3.34 (0.15)	12
rBDTI	3.8 (-0.07)	80.36	12.63 (0.03)	3.21 (-0.06)	19.64
rBCTI	4.74 (0.04)	12.51 (-0.03)	79.49	3.27 (0.1)	20.52
rSCFI	2.72 (-0.15)	3.45 (0.06)	2.88 (-0.1)	90.95	9.05
Contribution TO others	11.26	20.06	20.07	9.82	61.21
NET directional spillover	-0.74	0.42	-0.45	0.77	TCI
NPDC transmitter	1	2	1	2	15.3
Post-COVID-19 period: 2020/01/03–2023/03/31					
	rBDI	rBDTI	rBCTI	rSCFI	FROM
rBDI	80.45	11.65 (2.12)	7.25 (1.1)	0.65 (-1.15)	19.55
rBDTI	3.18 (-2.12)	78.17	17.79 (-2.84)	0.86 (-1.47)	21.83
rBCTI	2.84 (-1.1)	26.28 (2.84)	70.18	0.7 (-0.77)	29.82
rSCFI	5.25 (1.15)	6.75 (1.47)	3.78 (0.77)	84.23	15.78
Contribution TO others	11.27	44.68	28.82	2.21	86.98
NET directional spillover	-8.28	22.85	-1	-13.57	TCI
NPDC transmitter	1	3	2	0	21.75

Note: This table indicates the means of pairwise directional spillovers. The markets in column 1 are receivers, and those in row 1 are transmitters. The ‘FROM’ column indicates the average spillover from others. Similarly, the ‘Contribution to others’ row indicates the average spillover to others. The ‘Net directional spillover’ row reveals the total net spillover of each market. The numbers in the ‘NPDC transmitter’ row show the numbers as a net transmitter among all pairwise directional spillovers. The values of $NPS_{ij,t}$ are in the parentheses, and texts with the largest $NPS_{ij,t}$ within the focused periods are bolded.

4.4.2 Causal effects of external uncertainties

To link the external uncertainties to the internal spillovers among shipping spot freight markets, their causal relationships are first examined. As in Section 4.4.1, the pre-COVID-19 period and the post-COVID-19 period are checked, respectively. Table 4-6 reports EPU’s quantile Granger causal effects on spillover indices. During the pre-COVID-19 period, almost no Granger causality is observed. However, during the post-COVID-19 period, EPU has the

Granger causality with all spillover indices in specific quantiles. At the quantile range of [0.10–0.26] and [0.74–0.90], the overall spillover of the shipping freight system is Granger-caused by EPU. Net spillovers of four shipping spot markets are also Granger-caused by EPU. Changes in EPU after the pandemic have a strong predictive power for internal spillovers within maritime freight sectors because they represent the changes in global trade demand and supply balance (Nomikos and Tsouknidis, 2022). Compared with the sluggish recovery of tonnage supply, the transportation demand for goods rapidly increases. Accordingly, freight rate returns of different sectors fluctuate dramatically with interaction spillovers. Notably, at the high quantile range, net pairwise spillovers from the dry bulk and clean tanker markets to the container market are significantly Granger-caused by EPU. This means the demand volatilities of upstream raw materials and petroleum transport accumulate and hence enlarge in that of downstream (semi) manufactured products transport (Gong et al., 2020).

Table 4-7 reports GPR's quantile Granger causal effects on spillover indices. Similar to EPU, GPR becomes the main Granger cause during the post-COVID-19 period. At the quantile range of [0.10–0.26], the overall spillover of the shipping freight system is Granger-caused by GPR. For four shipping spot freight markets, only net spillovers of dirty tanker and clean tanker markets are Granger-caused by GPR. The potential fact is that changes in GPR reflect the evolution of energy commodity prices. An overlay of the COVID-19 pandemic and the Russia-Ukraine conflict has blocked seaborne lanes for energy commodities, and some countries use tanker ships for oil storage (Riaz et al., 2023). The scarcity of fleet supply and huge demand have pushed up energy commodity prices, which makes the spot freight rates of maritime oil transportation volatile. Results in Table 4-7 also show that at the low quantile range, net pairwise spillovers from two tanker markets to the dry bulk and container markets have significant Granger causality with GPR. It suggests that the volatilities caused by GPR in oil transportation markets can transfer to other shipping spot markets through the co-movements with bunker costs (Li and Yip, 2023).

Table 4-6 Granger Causality from EPU to spillover indices in different quantile ranges

Check ΔEPU with τ (sup-Wald test)	Pre-Covid-19 period						Post-Covid-19 period					
	[0.10- 0.26]	[0.26- 0.42]	[0.42- 0.58]	[0.58- 0.74]	[0.74- 0.90]	[0.10- 0.26]	[0.26- 0.42]	[0.42- 0.58]	[0.58- 0.74]	[0.74- 0.90]	[0.10- 0.26]	[0.26- 0.42]
Overall spillover	0.862	1.515	1.998	2.51	3.717	12.001 ***	2.162	2.903	1.768	9.169 **		
Net spillover for rBDI	5.292 *	0.708	1.494	1.54	2.168	3.226	4.759 *	0.203	3.639	5.206 *		
Net spillover for rBDTI	0.598	0.875	0.946	0.853	1.297	10.508 ***	4.561 *	1.236	0.573	6.457 **		
Net spillover for rBCTI	1.678	0.12	0.37	1.214	1.993	1.605	1.495	10.183 ***	6.262 **	3.740		
Net spillover for rSCFI	3.102	1.101	0.702	0.849	2.035	2.600	4.255 *	1.937	0.023	1.475		
Net spillover between rBDTI and rBDI	1.718	1.19	2.186	0.835	1.863	10.710 ***	5.303 *	0.611	0.956	2.251		
Net spillover between rBCTI and rBDI	2.097	0.505	0.735	0.949	1.281	1.262	3.432	3.742	7.405 **	2.573		
Net spillover between rBDTI and rBCTI	1.575	0.376	0.685	0.77	1.694	2.028	13.247 ***	5.928 *	0.744	2.761		
Net spillover between rBDI and rSCFI	0.582	0.978	1.16	0.565	0.287	0.119	0.662	0.578	2.081	12.167 ***		
Net spillover between rBDTI and rSCFI	1.937	2.051	1.472	1.036	1.097	3.344	1.488	5.952 *	2.627	2.602		
Net spillover between rBCTI and rSCTI	1.082	2.074	2.302	0.118	0.705	0.488	0.35	0.841	1.794	9.826 ***		

Note: The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively. The significant sup-Wald values are bolded.

Table 4-7 Granger causality from GPR to spillover indices in different quantile ranges

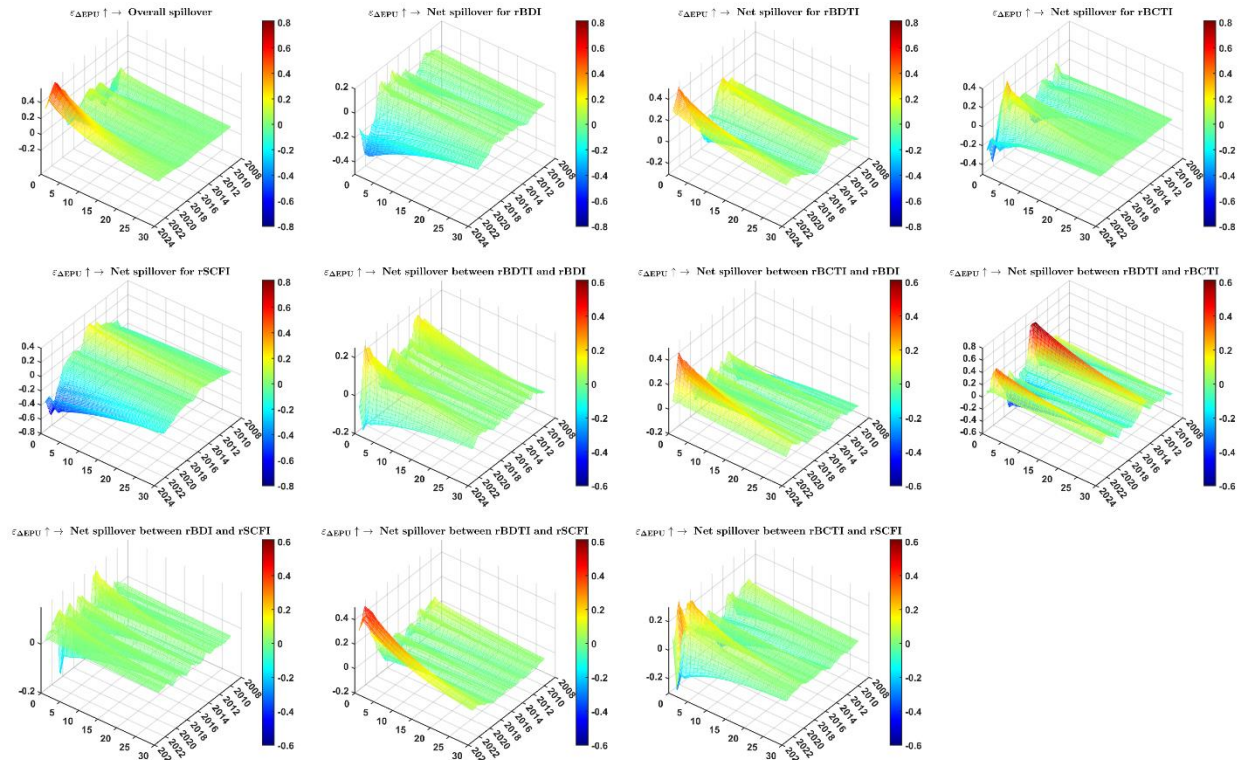
Check ΔEPU with τ (sup-Wald test)	Pre-Covid-19 period					Post-Covid-19 period				
	[0.10- 0.26]	[0.26- 0.42]	[0.42- 0.58]	[0.58- 0.74]	[0.74- 0.90]	[0.10- 0.26]	[0.26- 0.42]	[0.42- 0.58]	[0.58- 0.74]	[0.74- 0.90]
Overall spillover	0.77	0.87	0.627	0.365	0.916	4.407 *	0.051	0.337	0.929	3.564
Net spillover for rBDI	2.974	1.108	1.033	0.456	0.853	2.94	3.168	0.895	3.800	3.900
Net spillover for rBDTI	1.058	2.074	0.242	1.4	2.307	5.321 *	2.915	0.573	0.304	0.472
Net spillover for rBCTI	0.968	0.448	1.123	3.371	1.891	10.336 ***	5.835 *	6.338 **	5.906 *	2.364
Net spillover for rSCFI	4.026	1.412	1.454	4.165	4.086	2.918	0.591	0.032	0.197	0.171
Net spillover between rBDTI and rBDI	2.254	1.301	1.245	0.382	1.208	9.482 ***	0.41	0.276	0.087	2.82
Net spillover between rBCTI and rBDI	3.657	2.742	1.942	1.218	0.103	9.487 ***	1.033	0.250	3.088	6.273 **
Net spillover between rBDTI and rBCTI	5.614 *	4.027	0.538	0.467	1.087	10.175 **	3.112	7.644 **	13.741 ***	3.759
Net spillover between rBDI and rSCFI	1.03	0.586	2.138	3.276	3.547	0.746	0.394	1.157	0.252	3.916
Net spillover between rBDTI and rSCFI	1.948	1.189	1.535	1.624	0.716	6.083 *	1.188	2.315	1.156	1.843
Net spillover between rBCTI and rSCTI	0.77	0.87	0.627	0.365	0.916	4.407 *	0.051	0.337	0.929	3.564

Note: The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively. The significant sup-Wald values are bolded.

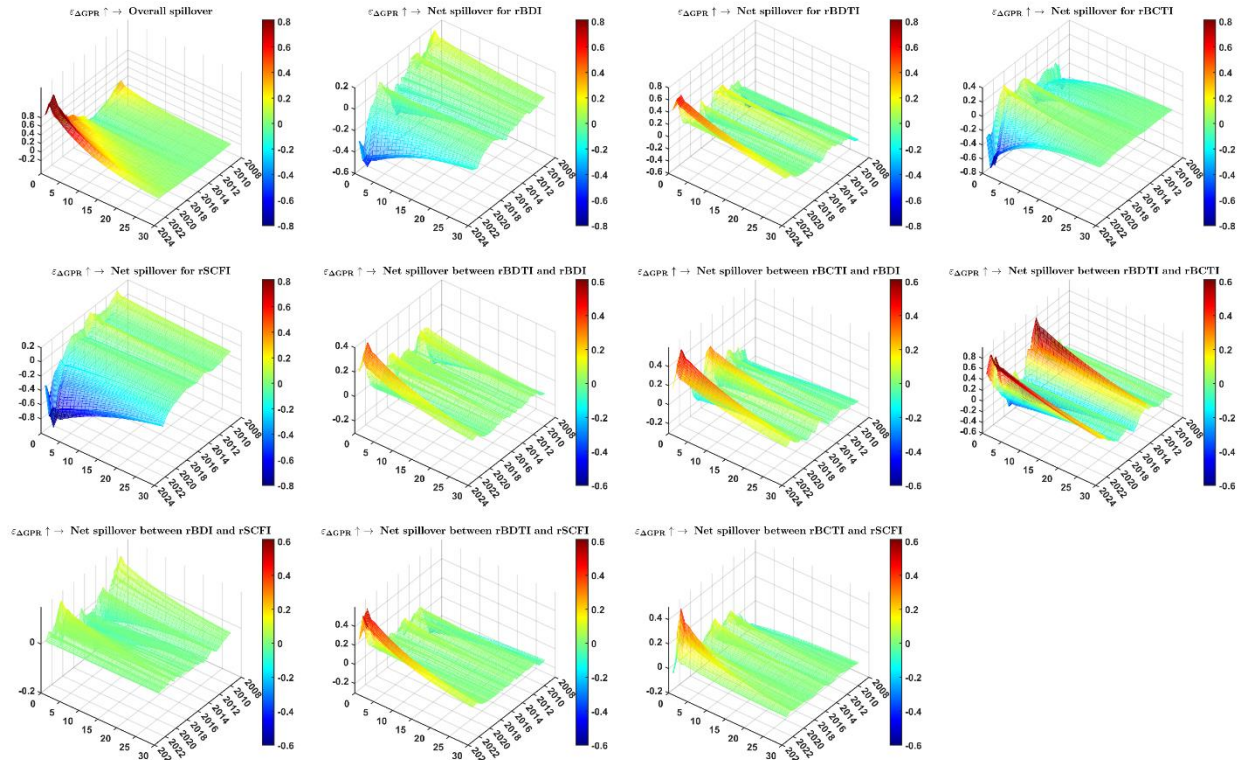
4.4.3 Shock effects of external uncertainties

To further capture the shock effects of external uncertainties on the internal spillovers among shipping spot freight markets, the evolution process between unit standard deviation changes (the impulses of EPU and GPR) and propagation mechanisms (the responses of spillover indices) is analysed (see Table C-1 in Appendix C for the MCMC sampling). Figure 4-6 shows the equal interval impulse and point impulse impacts of EPU and GPR. The size and persistence of impulse impacts are found to be time-varying and heterogeneous. Specifically, during the post-COVID-19 period, the maximum instantaneous responses of spillover indices occurred with a one-month lag. The overall spillover responses to EPU and GPR shocks can reach up to approximately 0.6 and 1.2, respectively. The cumulative shock effects of EPU and GPR can persist significantly for 0 to 10 months, exerting a long-term influence on freight rate volatility that is difficult to absorb for the market. The net spillover responses of the dirty tanker market to both shocks are positive, whereas other markets present negative responses. These response performances align with the roles of net spillover transmitters and receivers observed among these spot markets during the epidemic.

Notably, tanker markets are primary channels to exhibit external uncertainty variations in global crises, such as the lifting of the US crude oil export ban (2014–2016) and the Russia-Ukraine war (2022–2023). The net pairwise spillover between the two tanker markets responds sharply to uncertainty shocks and reaches as high as 0.8, which is difficult to recover even after 25 months. The net pairwise spillover responses from dirty and clean tanker markets to dry bulk and container markets exceed 0.4 and gradually disappear after 15 months in response to both EPU and GPR shocks. In contrast, the net pairwise spillover response from the dry bulk market to the container market remains relatively modest, at around 0.1, and diminishes within 5 months. Therefore, tanker markets enhance and spread EPU and GPR shocks into the broader shipping freight system (Bai, 2021; Khan et al., 2021). Their heightened sensitivity to uncertainty fluctuations offers valuable insights for forecasting volatility trends across various shipping freight sectors (Li et al., 2018).



(a) Impulse responses to EPU shocks.



(b) Impulse responses to GPR shocks.

Figure 4-6 Time-varying impulse responses of DY spillover indices to EPU and GPR shocks

4.5 Discussion

This study offers theoretical interpretations of volatility spillover dynamics among four shipping spot markets and their connections to external uncertainties, specifically EPU and GPR. Our findings answer the research questions posed in Section 4.1 with solid evidence, which will be discussed below.

First, evidence from the DY spillover index model reveals that internal spillovers among the four crucial spot freight markets exhibit high dynamics, significantly amplified by the COVID-19 pandemic. Notably, the volatility transmission paths changed markedly between the pre- and post-COVID-19 periods: before the pandemic, spillovers followed the path $rSCFI \rightarrow rBDI \ \& \ rBCTI$, whereas they shifted to $rBDTI \rightarrow rBDI \ \& \ rBCTI$ after the pandemic. This structural transformation in volatility spillovers reflects the profound reshaping of the shipping industry following the crisis.

Interestingly, the COVID-19 pandemic reversed the container market's role from a major net spillover transmitter to a net spillover receiver among the four markets. This role reversal helps clarify the complex interactions of volatility spillovers across different maritime freight sectors. A plausible explanation is that between 2009 and 2019, frequent news on acquisitions (e.g. bankruptcy of Hanjin Shipping) and alliances (e.g. creation of ONE Alliance) in liner shipping influenced tramp shipping rate returns, primarily through investor sentiment (Ju et al., 2024; Papapostolou et al., 2014). In contrast, the container market remained largely insulated from volatilities in other markets due to its inelastic transport demand and persistent vessel oversupply (Tvedt and Hovi, 2024). However, the COVID-19 pandemic disrupted this stability. The lockdown pressures on the seaborne supply chain drove up a broad rise in spot freight rates. Unlike the tanker and dry bulk markets, due to the empty container imbalances and blank sailing increases (Kuźmicz, 2022), the industry concentration in liner shipping decreased, as indicated by the decline in the Herfindahl-Hirschman Index (Ju et al., 2024). From 2020 to 2022, various surcharges, such as demurrage and detention charges, heightened the risk exposures of container freight rate returns, making them more susceptible to excessive volatility from other freight sectors (Shi et al., 2023).

Second, evidence from the Granger causality in quantiles and the impulse response models shows that the COVID-19 pandemic further reinforced the links between external uncertainties and internal spillovers among shipping spot freight markets. From 2020 to 2023, EPU significantly Granger-caused spillovers across all spot markets at high quantiles, driven by changes in global trade supply and demand (Theodossiou et al., 2020). In contrast, GPR

primarily Granger-caused spillovers associated with dirty and clean tanker markets at low quantiles, driven by changes in the energy transport pathways and bunker costs amid geopolitical conflicts (F. Chen et al., 2024; Michail and Melas, 2020). More importantly, the shocks induced by EPU and GPR were not short-lived; rather, they exerted prolonged effects on shipping spot freight market spillovers. These spillover indices remained highly responsive to these external shocks for more than a year, indicating the enduring nature of uncertainty-driven disruptions in the shipping industry.

A particularly noteworthy point is that tanker markets are key mediators in reflecting the effects of EPU and GPR. Oil prices, widely recognised as composite indicators of commodity demand, trading activity, and fuel costs (Ahmadi et al., 2016; Sun et al., 2019), serve as a crucial conduit through which external uncertainties propagate. During the post-COVID-19 period, the dramatic fluctuations in oil price returns had a leverage effect on spillovers from tanker markets to other freight sectors, which intensified the volatility connectedness of the shipping freight system with external uncertainties (Pouliasis and Bentsos, 2023; Wei, 2019). This finding is particularly significant as it underscores the tanker market's dual role—not only as a volatility transmission channel but also as a potential early-warning mechanism for systemic risks arising from economic and geopolitical shocks (Ishizaka et al., 2018).

4.6 Conclusion and Policy Suggestions

The shipping industry plays a critical role in global trade, yet it faces increasing challenges due to external uncertainties stemming from economic policies and geopolitical conflicts. In this paper, we build the dynamic DY spillover indices to capture the interconnectedness of spot markets for container ships, dry bulkers, and dirty and clean tankers. Using data from 2009 to 2023, we assess the effects of EPU and GPR on these spillover indices from different dimensions. Our research indicates that the COVID-19 pandemic has significantly altered the roles of net volatility transmitters and receivers within the shipping spot freight markets. Moreover, we uncover distinct mechanisms through which EPU and GPR Granger-cause and facilitate volatility spillovers, with tanker markets emerging as key mediators that amplify uncertainty shocks.

These insights provide valuable implications for stakeholders to better manage risk in a volatile trade environment. Here, several important policy suggestions are proposed:

- (a). Strengthening regulatory oversight on volatility spillovers.

Maritime regulators should continuously monitor the spillover network across the four

major shipping spot markets and their sub-markets. A thorough assessment of volatility transmission pathways induced by EPU and GPR will enable the implementation of targeted freight rate regulations to stabilise market fluctuations (Gallagher, 2021).

(b). Developing risk management strategies.

Since tanker markets serve as primary channels for spillovers caused by external uncertainties, industry practitioners can use them to quantify the maximum extreme risk exposures of freight rates across various shipping markets. To mitigate potential losses from EPU and GPR shocks, shipowners and cargo owners should adopt risk-hedging instruments such as Forward Freight Agreements (FFAs) and diversified financial portfolios (Drobetz et al., 2010; Poulisis et al., 2018).

(c). Improving transparency and information-sharing mechanisms.

Governments should mandate greater operational transparency of shipping companies. By establishing an integrated information-sharing framework, policymakers can provide timely support to traders. For example, in response to rapid container freight volatility and record-high prices in 2021, the South Korean government intervened by offering a 20% freight subsidy and securing shipping space for domestic exporters (The Maritime Executive, 2021). Similar proactive measures can help maintain trade flows during uncertain conditions.

In an era of heightened uncertainty, proactive measures will be essential to ensuring the continued efficiency and stability of maritime transport services. As global seaborne trade evolves, new risks—such as climate change policies, decarbonization efforts, and technological disruptions—may further reshape shipping freight markets. Future research should explore these emerging challenges to provide deeper insights into the resilience and adaptability of the shipping industry.

Chapter 5: Study 3—People Pillar—Governance of Seafarers’ Rights: A Quantitative Assessment of Abandoned Seafarers’ Repatriation and Wage Rights Under the Maritime Labour Convention

5.1 Introduction

The transnational labour services of seafarers are a cornerstone of the shipping industry. When seafarers work onboard, they have to endure the visible harshness of the natural environment and face the unpredictable human-made risk of being abandoned (Mack, 2007). To protect the rights of seafarers as a globalised industry community, the International Labour Organisation (ILO) has developed and approved the Maritime Labour Convention, 2006 (MLC), also known as the Bill of Rights (ILO, 2013). The MLC emphasises seafarers’ fundamental rights to repatriation and elaborates on the legal details of repatriation arrangements (McConnell et al., 2011)¹⁹. The 2014 amendments to MLC (2014 MLC Amendments) have introduced insurance certification and established a financial security system covering up to four months of wages for abandoned seafarers (ILO, 2014)²⁰. The amended MLC has marked the formation of a solid and standardised international framework for seafarers’ human rights, serving as a beacon for the global maritime sector and seafarers (Chang and Khan, 2023).

However, the number of seafarer abandonment events has not decreased with the 2014 MLC Amendments entering into force on 18 January 2017. According to the ILO statistics, 828 abandonment events have been reported from 2004 to 2023. About 67% of events have happened after 2017, and nearly 8400 seafarers are involved, as shown in Figure 5-1. One important reason is the compromise in formulating MLC provisions and the flexibility in implementing the MLC by ratifying countries (Sampson, 2022). Another reason is that many countries have not accepted the MLC, such as the United Arab Emirates (UAE), Saudi Arabia, and Turkey (Gupta and Shanthakumar, 2023). These countries, along with China and India (see

¹⁹ The initial MLC sets out the order of responsibility for repatriation in clause 5 of Standard A 2.5: shipowner, flag state, port state and labour-supplying state.

²⁰ The 2014 MLC Amendments introduce supplementary provisions of the financial security system in Standard A 2.5.2.

Figure 5-1), contribute more than 35% of abandonment events. Overall, the MLC faces huge challenges and obstacles in international governance.

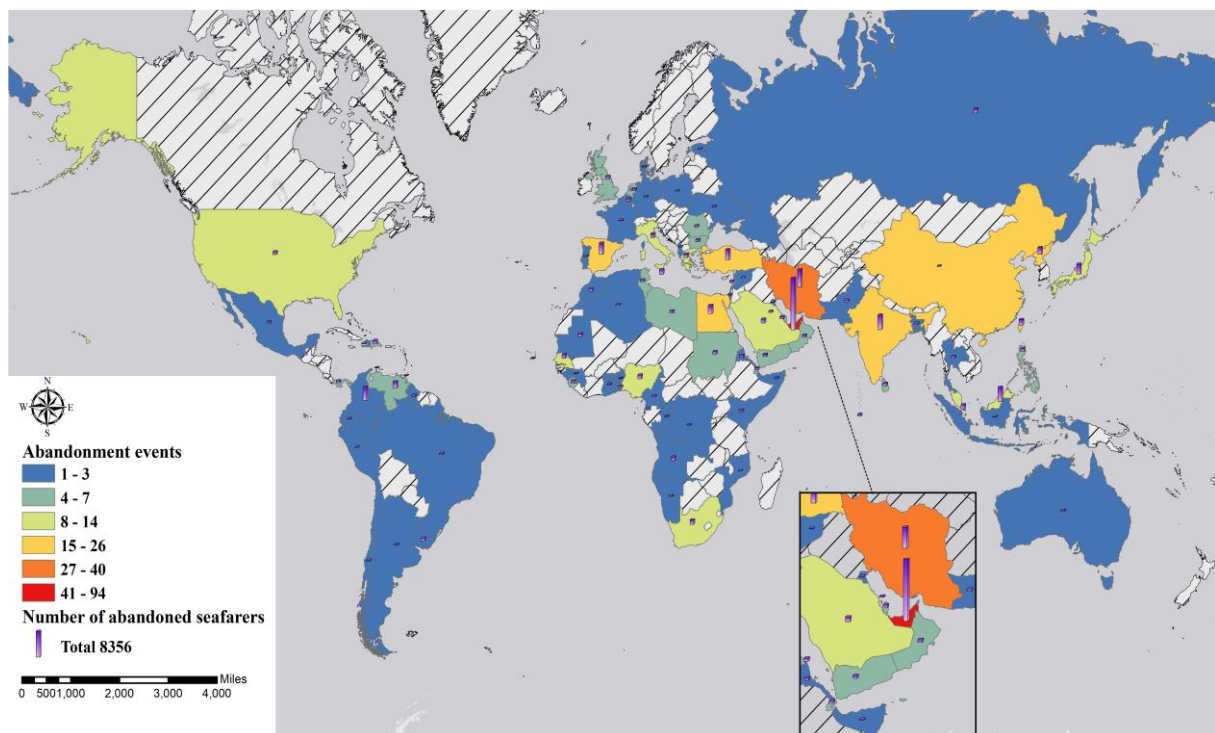


Figure 5-1 The heatmap of seafarer abandonment events for the period of 2017-2023

Source: Author.

Previous studies have focused on the MLC's policy, regulation and legislation. One group of scholars adopts the theoretical-doctrinal legal approach to review the MLC's comprehensive framework. Sampson (2022) discusses the MLC as a microcosm of global governance regulations, linking its importance to polycentric governance structures. Mantoju (2021) analyses the relationship between seafarers' real dilemmas and the MLC's provisions, emphasising the need for proper implementation. Exarchopoulos et al. (2018) critically examine welfare issues under the MLC, revealing its inadequacies in meeting seafarers' psychological needs and ensuring fair treatment. Another group of researchers focuses on national legislation aligning with the MLC. Camelia and Hastuti (2023) highlight Indonesia's insufficient supervisory mechanism for the MLC and prove the necessity of relevant legislation. Gupta and Shanthakumar (2022a) examine the judgments and orders of Indian admiralty courts and suggest legislative changes for quicker litigation disposal. Basurko (2018) discusses the connection between Spain's reform of financial security legislation and private protection regimes for seafarers.

However, these studies have gaps: (1) In terms of research view, most studies are limited to the theoretical jurisprudence field and only treat the MLC as a component of international

or domestic soft law. They focus on the detailed legal provisions and theories about seafarer abandonment, lacking an empirical view to test the MLC's effectiveness in protecting abandoned seafarers with convincing data. (2) In terms of research depth, only a few studies use simple statistics to illustrate the MLC's role in seafarer abandonment. They do not move further to the potential determining factors and the common difficulties in resolution. To fill these gaps, this study aims to address the following research questions:

RQ1: What critical factors related to the MLC's implementation should be identified and examined in constructing the new seafarer abandonment dataset?

RQ2: How can the effects of these factors on seafarers' repatriation and wage payment under the MLC be assessed?

To pursue answers to these questions, we collect the full text of abandonment reports from the ILO Seafarer Abandonment Database (ILO database) and conduct text mining (ILO, 2024)²¹. All text contents are reshaped to a uniform data format and manually extended to include more than 10 factors²². Then, based on literature about seafarer abandonment and the MLC, we focus on 6 critical factors influencing repatriation and wage rights: Port State Control (PSC), Abandonment region (geography of port States), Crew nationality, Flag State (whether the flag of convenience (FOC)), Protection and Indemnity (P&I) club, and Ship's age (see more information about FOC States and P&I clubs in Table D-1 in Appendix D). Finally, we use econometric approaches to assess the amended MLC's effectiveness and efficiency in protecting abandoned seafarers. The nested logit model assesses the choice probabilities of seafarers' repatriation and wage payment, allowing for correlated alternatives and establishing a hierarchy of repatriation and wage rights. The fixed effects model assesses the resolution time of abandonments, examining both repatriation and payment times in depth.

²¹ The ILO Seafarer Abandonment Database provides all abandonment reports, whose description can be found at <https://wwwex.ilo.org/ordspub/prdutf8p/f?p=63500:10> (last accessed in April 2025).

²² The abandonment reports are presented in text and have no uniform format for every item. A case may sometimes have contradictory text content in different items, such as the content of "Port of abandonment" in the case of the ship *Espemar Dos*, and the content of "Repatriation status" in the case of the ship *Century Bright*, both differ from those in "comments and observations". Therefore, we check and confirm the consistency of the text content case by case. Moreover, we search for more information on the features of an abandoned ship from the Clarksons Shipping Intelligence Network (Clarksons, 2024). Finally, we make a new dataset that includes the factors: *Ship name*, *7-digit IMO No.*, *Ship type*, *No. of seafarers*, *Repatriation status*, *Payment status*, *PSC*, *Flag State*, *Protection and Indemnity insurance*, *Crew nationality*, *Abandonment region*, *Built year*, *Ship's age (at date of abandonment)*, *GT*, *Repatriation time (days) of resolved scenario*, *Payment time (days) of resolved scenario*.

Our work has twofold contributions. First, it systematically collates abandonment reports and creates a new comprehensive dataset. The available dataset has enriched the research materials for scholars in related fields, covering the main factors related to the MLC's provisions. Second, it develops a new perspective to review the MLC with the data-based regression models. It integrates the abandonment-related factors that affect the seafarers' repatriation and wage rights into a framework. The empirical evidence of the MLC's deficiencies is provided, and feasible policy suggestions are discussed.

5.2 Factors Identification and Hypotheses Development

5.2.1 Critical factors in the MLC about seafarer abandonment

A range of literature focuses on the regulations and codes of the MLC regarding abandoned seafarers and analyses the critical factors needed to build a rational-legal system. Research on seafarer abandonment falls into two categories. The first category examines the MLC's content and addresses quantifiable factors in its provisions, such as FOC States and PSC (Doumbia-Henry, 2017; Gupta and Shanthakumar, 2022b; Vairavan and Ramaraju, 2024). The second category investigates part of the famous abandonment cases and summarises additional external factors related to the MLC, such as crew nationalities and ship age (López-Arranz et al., 2018; Ghaida and Ezra, 2022; Bolton, 2024). Focusing on the choice probability and time efficiency of the repatriation and wage payment rights for abandoned seafarers (response variables), Table 5-1 reports the related critical factors in the MLC (explanatory variables) within the above two categories of literature.

There are six recurring factors that play important roles in dominating the performance of the MLC. *Flag State* and *P&I club* represent the first responsible parties for repatriating seafarers and providing financial security assistance, as outlined in Regulation 2.5 of the MLC with the 2014 amendment. *Abandonment region* and *Crew nationality* (as proxies) represent the port State and labour-supply States. They act as secondary responsible entities for repatriating abandoned seafarers, according to Clause 5 of Standard 2.5.1 in the MLC. Additionally, the *PSC* serves as a backup “safety net” for flag State inspections to help with the repatriation. The *Ship's age* measures the residual sales values of ships for outstanding wage reimbursement.

Table 5-1 Critical factors in the literature affecting the MLC rights of abandoned seafarers

Critical factors	Abandoned seafarers' rights	References	Frequency
Flag State	repatriation and wage	Chang and Khan (2023); Exarchopoulos et al. (2018); Ghaida and Ezra (2022); Gupta and Shanthakumar (2023); Mantoju (2021); Sampson (2022)	6
PSC	repatriation	Chang and Khan (2023); Exarchopoulos et al. (2018); Ghaida and Ezra (2022); Gupta and Shanthakumar (2023); Mantoju (2021)	5
Abandonment region	repatriation	Chang and Khan (2023); Ghaida and Ezra (2022); Sampson (2022); Vuković et al. (2024)	4
P&I Club	repatriation and wage	Gupta and Shanthakumar (2023); López-Arranz et al. (2018); Sampson (2022)	3
Crew nationality	repatriation	Bolton (2024); Ghaida and Ezra (2022); Vuković et al. (2024)	3
Ship's age (sales values)	wage	Bolton (2024); Exarchopoulos et al. (2018); López-Arranz et al. (2018)	3
Shipowner	repatriation and wage	Bolton (2024)	1
International Transport Workers' Federation (coordinator)	repatriation and wage	Ghaida and Ezra (2022)	1
Admiralty court	wage	Gupta and Shanthakumar (2022a)	1
Recruitment and Placement Services	repatriation and wage	Mantoju (2021)	1
Seamen's Union (coordinator)	repatriation and wage	Vuković et al. (2024)	1

Source: Author.

5.2.2 Hypotheses development

Based on the critical factors and combining the previous studies and news articles, we propose a series of hypotheses to examine the positive or negative performances of MLC-related factors in seafarer abandonment. Figure 5-2 depicts the development of hypotheses around repatriation and wage payment rights. All these hypotheses are introduced as follows.

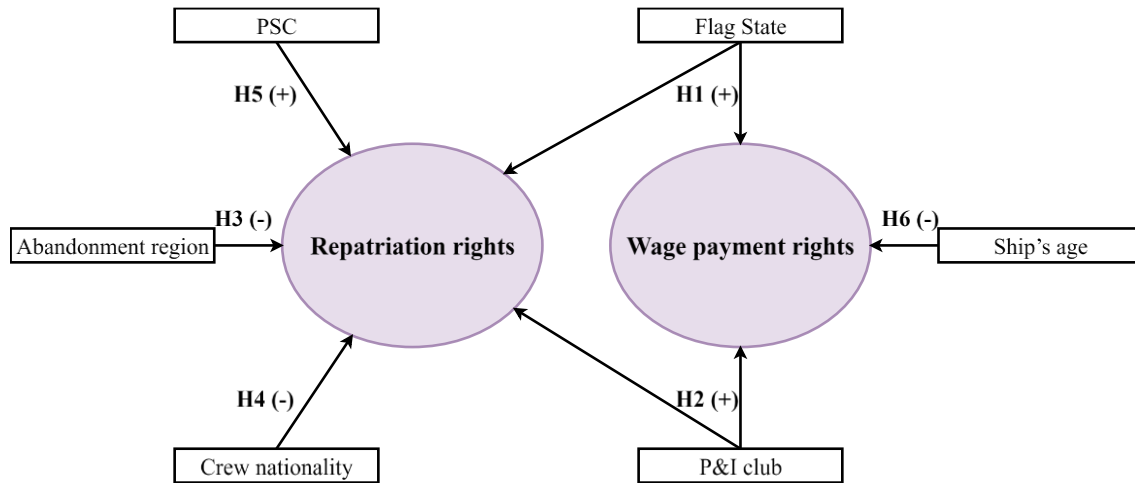


Figure 5-2 The hypotheses development of Study 3

Flag States are primarily responsible for implementing the MLC in abandonment events. When the abandoned seafarers complain to the International Transport Workers' Federation (ITF) or other concerned authorities, the informed flag States will require the registered shipowners to arrange the repatriation and pay the outstanding wages (Jing, 2023). If the shipowners fail to fulfil these duties, flag States should create a repatriation plan and assist crews in initiating the ship auction process to recover outstanding wages (ILO, 2014). Over 75% of ships are registered in the FOC States (Clarksons, 2024). These FOC States have gained extensive experience and developed effective administrative systems to manage abandonment events, largely due to monitoring by the ITF's campaign against FOC (McConnell et al., 2011; ITF, N.D.). According to Exarchopoulos et al. (2018), unlike traditional national flags, dominant FOC States view maritime business as a vital national industry and attract most newer ship registrations with owners in good financial health. Furthermore, Sampson (2022) notes that FOC States are more likely to engage in and expedite the resolution of abandonment events in line with the MLC's provisions than traditional national flags. Therefore, we have the hypothesis:

H1: FOC States can better guarantee the repatriation and wage payment than traditional flag States.

As the most commonly recognised organisation for financial security, P&I clubs play a key role in ensuring rapid repatriation and wage payment, serving as an additional safeguard for shipowners' responsibilities (Petrinović et al., 2017). Before issuing the Maritime Labour Certificate and Declaration (DMLC), flag States often require shipowners to obtain a financial security certificate from P&I clubs under the MLC (Zhang and Phillips, 2016). This certificate and its copies are posted in a visible place on board, accessible to the crew (ILO, 2014). The abandoned seafarers can directly provide evidence of unpaid wages to the P&I club and activate financial security without conditions, which is a quicker claims process (ILO, 2019). The P&I club will handle repatriation and pay up to four months' wages together (Vairavan and Ramaraju, 2024). The International Group of P&I Clubs (IG) covers P&I liability for over 90% of the world's ocean-going tonnage (Lielbarde, 2024a). The IG and its affiliated associations have sufficient resources to quickly provide direct access and financial assistance. So, we give the hypothesis:

H2: P&I clubs can somewhat benefit the process of repatriation and wage payment.

Port States have regional characteristics in handling onshore repatriation for abandoned seafarers. Due to the imbalance in global seaborne trade, busy shipping has led to the highest number of abandonment incidents occurring in Asia (McCarthy, 2021). According to the abandonment map by Ader et al. (2023), 51% of abandoned seafarers are in Asia, which is 34%, 31%, and 41% more than those in Africa, Europe, and other regions. Many Asian port States have not adopted the MLC and lack legislation to protect seafarers, affecting the success rate and timeliness of repatriation (ILO, 2013; Khan et al., 2024). News reports often highlight extreme abandonment events with long resolution times in Asia (Summers, 2024). Therefore, we propose the hypothesis:

H3: The Asian region has more unfavourable effects on repatriation than other regions.

Crews on an abandoned ship may be from different labour-supply States with mixed nationalities. Most countries rely on recruitment and placement services (RPS) agents to place seafarers with shipowners rather than using a national authority (Tang and Zhang, 2021). When repatriation can only be handled by labour-supply States, these states need to work with their RPS agents to access information about the abandoned seafarers (Zhao et al., 2016; Lielbarde, 2024c). However, seafarers' protection level varies widely between countries because of a lack of domestic legislation and ambiguous MLC provisions regarding manning agency liabilities (ILO, 2019). Some crews' nationality states and RPS agents take advantage of regulatory gaps to exploit abandoned seafarers by delaying travel documents and deducting air ticket costs to

prevent disembarkation (Mahmood, 2020; Galam et al., 2024). Consequently, crews with mixed nationalities are harder to fully repatriate than those with a single nationality (Grey, 2016; Chen and Shan, 2017). So, we assume that:

H4: Mixed nationality of seafarers adversely affects the repatriation.

Port State Control Officers (PSCOs) can proactively check and judge whether seafarers are abandoned via the DMLC list of 16 areas of working and living conditions (ILO, 2019). If abandonment is detected during a PSC inspection, the authorised officer can detain the ship and require the shipowner to repatriate seafarers within a specified period (Grbić et al., 2015; Doumbia-Henry, 2017). In order to avoid economic losses and high-risk ship ratings, the shipowner is motivated to speed up the repatriation process (Exarchopoulos et al., 2018; Mantoju, 2021). Therefore, we put the hypotheses:

H5: PSC inspection can provide positive support for the repatriation activity.

A court auction is the last hope for seafarers to recover outstanding wages in the worst situation that the shipowner and P&I club cannot afford. Abandoned seafarers appeal to the local admiralty court of the port State to arrest the ship and conduct a judicial sale (Gupta and Shanthakumar, 2022a). The ship's sale value decreases with age, and older ships have smaller auction proceeds. The per capita revenue from selling an older ship through multiple auctions is usually lower than the average outstanding wages, meaning only part of the unpaid wages can be recovered by abandoned seafarers (Bolton, 2024). Additionally, the ship's poor condition discourages potential buyers, who often withdraw from the purchasing process (López-Arranz et al., 2018). So, we propose the hypothesis:

H6: Older ships' auction values make it difficult to ensure wage payment and have a negative impact on payment speed.

5.3 Methodology

This section introduces two econometric approaches to assess whether the labour rights of abandoned seafarers are protected. Grounded in the ILO database, this study categorises abandonment treatments into three scenarios: resolved, disputed, and unsolved²³. Considering

²³ In our dataset, the resolved scenario represents the fulfilment of both rights to repatriation and wage. The disputed scenario represents only the fulfilment of the right to repatriation, and the unsolved scenario represents no rights have been fulfilled, or the case has been inactive. A tiny fraction of cases with these choice categories may not be the same as those marked in the raw data of the ILO database because an originally recorded case may have content that conflicts with its updated information.

the various choices of fulfilled rights and their correlation between different scenarios, the nested logit model is used to investigate the probabilities of seafarers' repatriation and wage payment choices. Only cases in the resolved scenario are considered when focusing on repatriation and payment times. Due to the possible influence of differences in ship types, the fixed effects model is used to eliminate this. Figure 5-3 shows the research framework that guides this study and tests the hypotheses.

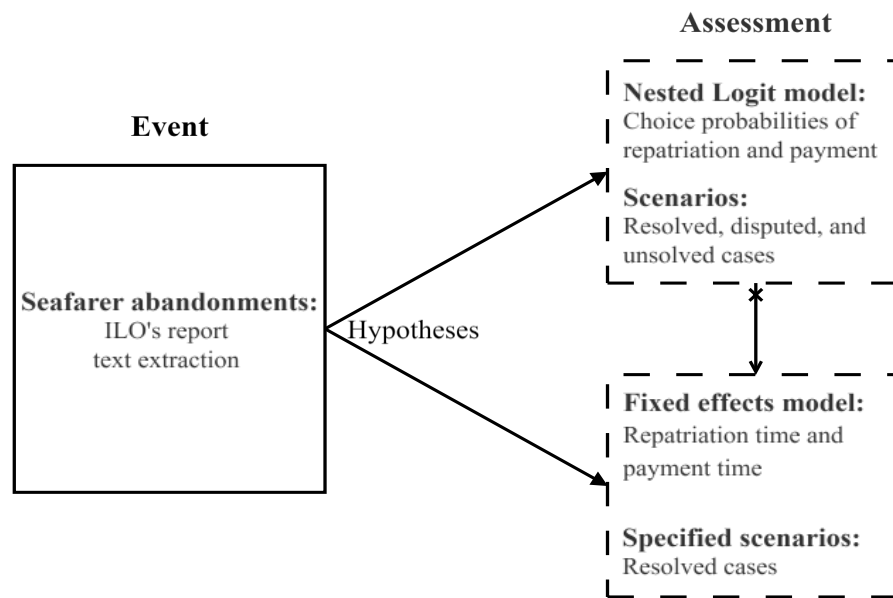


Figure 5-3 The research framework of Study 3

5.3.1 Specification of the nested logit model

Seafarers' repatriation and wage payment are crucial in judging whether the MLC is effective during abandonments. When abandoned, seafarers face three choices: (1) Repatriated and paid (resolved); (2) Repatriated and unpaid (disputed); (3) Not repatriated and not paid (unsolved). Obviously, this is a discrete choice problem, typically analysed using the Logit model. The Logit model family includes the multinomial logit model, the conditional logit model, and the nested logit model (McFadden, 1973; Wen and Koppelman, 2001). The first two models require the independence of irrelevant alternatives (IIA) assumption. The nested logit model relaxes this assumption, allowing alternatives within the same group to correlate while different groups remain independent.

In this study, the protection of seafarers' rights is prioritised differently. Many seafarers need repatriation before wage claims. When seafarers return home, some agree to discounted wages with shipowners, while some insist on full payment. This situation makes the protection boundary of wage rights unclear, meaning the two choices of repatriation with or without

payment of outstanding wages are correlated. Therefore, the nested logit model is more suitable and superior to other models. As shown in Figure 5-4, our nested structure has two levels. We assume repatriation rights are considered first, followed by wage rights. Type choices are at Level 1: repatriated (type P) and not repatriated and unpaid (type NP). More detailed mode choices are at Level 2: repatriated and paid (mode $P1$) and repatriated and unpaid (mode $P2$).

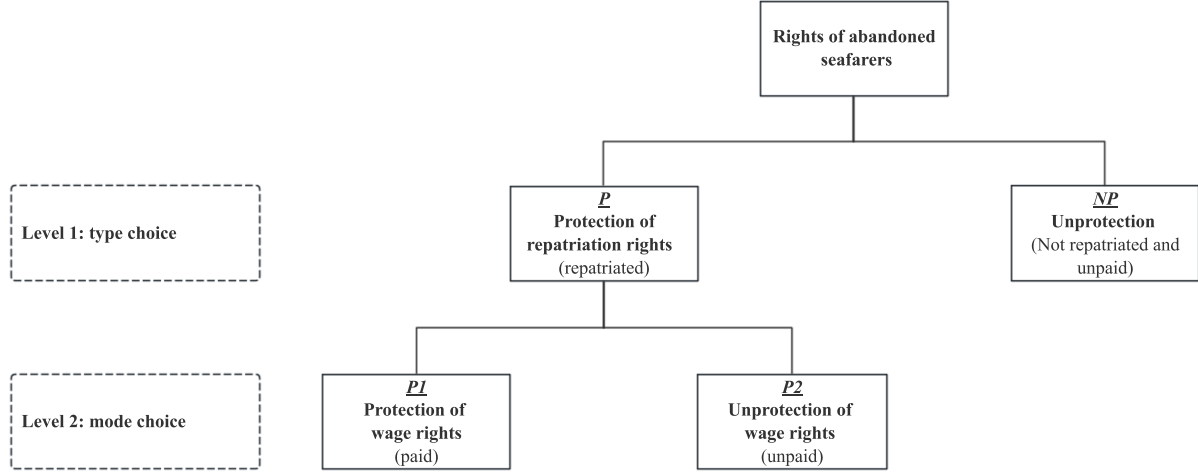


Figure 5-4 The choice structures of the nested logit model

Considering the random utility of each selection branch should follow Gumbel's multivariate distribution (Cascetta, 2009), the unconditional probability of mode k at level 2 can be:

$$P_k = P_j \times P_{k|j} \quad (5-1)$$

Within Eq. (5-1), the selection probability of type j at level 1 is expressed as:

$$p_j = \frac{\exp(z'_j \alpha + \tau_j I_j)}{\sum_{(P, NP)} \exp(z'_j \alpha + \tau_j I_j)}, \quad j = P, NP \quad (I_j = 0 \text{ for } j = NP) \quad (5-2)$$

where $\mathbf{z}_j$ is the factor vector [PSC , $Crew\ nationality$, $Abandonment\ region$] of level 1 with coefficient vector α , τ_j is the dissimilarity parameter, $I_j = \ln\{\sum_{l=1}^2 \exp(\omega'_{jl} \beta_j / \tau_j)\}$ is the inclusive value for nest j to achieve the maximum of the random utilities.

Then, the conditional probability of choosing alternative k conditional on choosing nest j is defined as:

$$P_{k|j} = \frac{\exp(\omega'_{jk} \beta_j / \tau_j)}{\sum_{l=1}^2 \exp(\omega'_{jl} \beta_j / \tau_j)} = \frac{\exp(\omega'_{jk} \beta_j / \tau_j)}{\exp(I_j)}, \quad k = 1, 2 \text{ when } j = P \quad (5-3)$$

where ω_{jk} is the factor vector [$P\&I\ club$, $Flag\ State$, $Ship's\ age$] of level 2 with coefficient vector β_j . The full information maximum likelihood technique is used to estimate the unknown coefficients of factor vectors (Louviere et al., 2000). Moreover, the IIA criterion can

be validated by the seemingly unrelated estimation test, which compares the difference between the restricted subset and the full set of alternatives (Greene, 2018).

5.3.2 Specification of the fixed effects model

Most seafarer abandonments happen due to the financial struggles of shipowners²⁴. Consequently, resolving repatriation and payment often takes several months. In the specific scenario of mode *PI*, reported abandonment cases are marked as resolved status when the ITF confirms that all abandoned seafarers have returned home and received their outstanding wages. Here, it is worth mentioning that the repatriation and payment times are identified and calculated by the item—“Abandonment date” and “Comments and observations”—in the ILO database.

According to Ghaida and Ezra (2022) and de Larrucea (2022), the ship type can affect repatriation and payment times. Shipowners’ operating and financial conditions vary with ship types and related seaborne markets. In fact, general cargo, bulk carrier, tanker, and tug are the top four ship types in reported abandonments, with proportions of 30%, 24%, 18%, and 10%, respectively²⁵. Therefore, the influence of ship types should be controlled and removed using a one-way fixed effects model.

Combined with the hypotheses, the time efficiency of repatriation and payment under MLC is assessed by the following models:

$$\begin{aligned} \text{Repatriation time}_{it} = & \delta_0 + \delta_1 PSC_{it} + \delta_2 Crew\ nationality_{it} + \delta_3 Abandonment\ region_{it} \\ & + \delta_4 P\&I\ club_{it} + \delta_5 Flag\ state_{it} + \theta_i + \varepsilon_{it} \end{aligned} \quad (5-4)$$

$$\text{Payment time}_{it} = \eta_0 + \eta_1 Ship's\ age_{it} + \eta_2 P\&I\ club_{it} + \eta_3 Flag\ state_{it} + \varphi_i + \sigma_{it} \quad (5-5)$$

where i is the ship type of abandonment cases, and t is the abandonment year. The vectors of δ and η are the coefficients of factors. θ_i and φ_i are the fixed effects of the ship type. ε_{it} and σ_{it} are the random error terms of the models.

²⁴ Under the MLC, the shipowner is described as “the owner of the ship or another organisation or person, such as the manager, agent or bareboat charterer, who has assumed the responsibility for the operation of the ship from the owner and who, on assuming such responsibility, has agreed to take over the duties and responsibilities imposed on shipowners in accordance with this convention, regardless of whether any other organisation or persons fulfil certain of the duties or responsibilities on behalf of the shipowner”(ILO, 2006).

²⁵ The MLC provides a broad definition of a ship, which also includes vessels operating in coastal waters, such as tugs.

5.4 Samples and Model Variables

Based on the constructed seafarer abandonment dataset, we have selected the samples from January 2017 to December 2023 to assess the MLC and its 2014 amendments. It includes 562 samples for the nested logit model and 304 for the fixed effects model. The detailed descriptions are presented as follows.

5.4.1 Response variables

For the nested logit model, Table 5-2 represents the nested tree of three alternatives for abandoned seafarers. As the response variable, these choices indicate the resolved, disputed and unsolved cases. A total of 315 abandonments are resolved with the fulfilment of both the repatriation and wage rights. For 117 disputed abandonment cases, seafarers can only return home but have no paid wages. There are 130 unsolved (pending) abandonments with neither repatriation nor payment provided, leaving seafarers in an unprotected situation.

Table 5-2 Descriptive statistics of response variables in nested tree structures

Response variable	Mode	Freq	Percent
Choices	P1 (%)	315	56.050%
	P2 (%)	117	20.818%
	NP (%)	130	23.132%

Type	N (type)	Mode	N (mode)	k
Protection of repatriation rights	1124	P1(wage paid)	562	315
		P2(wage unpaid)	562	117
Unprotection (Not repatriated and unpaid)	562	NP	562	130
		total	1686	562

k = number of times an alternative is chosen

N = number of observations at each level

Note: The format of the dataset is reshaped to long data when constructing the nested tree.

For the fixed effects model, Table 5-3 gives the response variables related to the resolution time in mode *P1*, including *Repatriation time* and *Payment time*. The average repatriation time is 184 days, and the average payment time is 222 days. The longer payment time implies that repatriation is prioritised, and some seafarers do not get their owed wages until they return home.

Table 5-3 Descriptive statistics of response variables on resolution time

Response variable	Obs (Freq.)	Mean	SD	Min	Median	Max
Repatriation time (days)	304	184.237	204.335	3	118.5	1602
Payment time (days)	304	221.678	224.270	3	145	1602

5.4.2 Explanatory variables

Table 5-4 describes the explanatory variables for the full samples of three modes. Only the variable of *Ship's age* is numerical, and the remaining variables of *Flag State*, *P&I club*, *Crew nationality*, *PSC*, and *Abandonment region* are categorical. All variables depict objective facts, which vary with every abandonment sample. More than 75% of abandonments happen on a vessel flying the FOC, and more than 66% of shipowners employ crews of mixed nationality. About half of the abandoned ships have financial security. Only 15% of abandonments are proactively detected by PSC. Notably, nearly 60% of abandonments occur in port States of the Asia region.

Table 5-4 Descriptive statistics of explanatory variables for the nested logit model

Explanatory variable	Obs (Freq)	Mean (Percent)	SD	Min	Max	Description
Ship's age	562	25.664	13.77 2	1	70	Serviceable life of the ship at the time of abandonment
Flag State	562	0.754	0.431	0	1	
<i>FOC (%)</i>	424	75.445%				1 if a ship is registered under an FOC, 0 for Non-FOC
<i>Non-FOC (%)</i>	138	24.555%				
P&I club	562	0.528	0.5	0	1	
<i>PI (%)</i>	297	52.847%				1 if the insurance certificate for seafarers' financial security is valid, 0 for an unknown situation
<i>Unknown (%)</i>	265	47.153%				
Crew nationality	562	0.66	0.474	0	1	
<i>Mixed (%)</i>	371	66.014%				1 if seafarers on a ship are of mixed nationalities, 0 for a single nationality
<i>Single (%)</i>	191	33.986%				
PSC	562	0.151	0.359	0	1	
<i>Yes (%)</i>	85	15.125%				1 if Port State control is involved, 0 for otherwise
<i>No (%)</i>	477	84.875%				

Abandonment region	562	2.11	0.8	1	4
<i>Africa (%)</i>	108	19.217%			
<i>Asia (%)</i>	328	58.363%			
<i>Europe (%)</i>	82	14.591%			
<i>Americas & Oceania (%)</i>	44	7.829%			

Geographic area location of abandonment: 1 for Africa, 2 for Asia, 3 for Europe, 4 for other regions

Note: (1) Full samples are for the nested logit model. Subsamples of the resolved scenario for the fixed effects model are not described repeatedly. (2) For abandoned ships with validated insurance certificates, the top 5 P&I clubs are Thomas Miller Specialty (9.09%), MS Amlin Marine (9.09%), The American Club (8.42%), West of England (8.08%), and Maritime Mutual Insurance Association (7.41%). They are all parts of the International Group of P&I Clubs. (3) For abandoned ships with only single nationality seafarers, the top 5 nationalities are India (30.89%), Indonesia (9.95%), Philippines (8.9%), Ukraine (7.85%), and Myanmar (6.81%).

Moreover, as shown in Table 5-5, the correlations among the above explanatory variables are measured to check the potential collinearity. Although some correlations are significant, their coefficients are below 0.3, and the effect of collinearity can be ignored for the IIA assumption. Therefore, all the explanatory variables are fully available in the nested logit model according to the hierarchical structures.

Table 5-5 Correlation table

Explanatory variable	Ship's age	Flag State	P&I club	Crew nationality	PSC	Abandonment region
Ship's age	1					
Flag State	-0.055**	1				
P&I club	0.229***	0.157***	1			
Crew nationality	-0.104***	0.071***	-0.023	1		
PSC	-0.013	0.001	-0.070***	0.022	1	
Abandonment region	0.039	-0.022	-0.099***	0.061**	0.203***	1

Note: The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

5.5 Results and Analyses

5.5.1 Estimation of the choice probabilities of repatriation and payment

Table 5-6 reports the estimation results from the nested logit model. The IIA assumption should be focused on first for model validation. The p-value of the LR (likelihood ratio) test within the model is 0.003. Additionally, the p-values of seemingly unrelated estimation by

deleting alternatives in mode *P1* or *P2* are 0.049 and 0.004, respectively. All these values reject the IIA assumption. The dissimilarity parameter of type *P* is not equal to 1 at a 99% confidence level. Therefore, the nested logit model is appropriate and effective.

How different factors affect choices of repatriation and wage payment is also examined. As shown in Table 6, the nest of type *NP* serves as the baseline for comparison. For the repatriation choices, the coefficient of *PSC* is 0.262 but not significant, suggesting *PSC* does not increase the likelihood of seafarers' repatriation. The coefficient of *mixed* nationality is significantly negative, indicating that complex nationalities among seafarers tend to decrease the probability of repatriation. Interestingly, when Europe is the benchmark, all remaining regions negatively impact repatriation. The *Asia* region has the lowest significant coefficient of -0.701, implying that abandoned seafarers in Asia face the most difficulty returning home.

For the wage payment choices under the premise of repatriation, the *Ship's age* has a significantly negative coefficient in mode *P1*. It suggests older ships have fewer sales values and are less likely to cover abandoned seafarers' unpaid wages. Notably, the coefficients of *P1* and *FOC* are significantly positive in mode *P1*, which are opposite to those in mode *P2*. This implies that the P&I clubs and FOC States are more likely to guarantee seafarers' repatriation and wage rights simultaneously. In contrast, a traditional national flag or a lack of financial security is more likely to lead to repatriation without paid wages.

Table 5-6 Results of the nested logit model

Variables	Choice		
	Type		
	Base: NP nest	P (Repatriated)	
PSC			
<i>Yes</i>	—	0.262 (0.274)	
Crew nationality			
<i>Mixed</i>	—	-0.377* (0.224)	
Abandonment region			
<i>Africa</i>	—	-0.223 (0.384)	
<i>Asia</i>	—	-0.701** (0.335)	
<i>Americas & Oceania</i>	—	-0.309 (0.476)	
	Mode		
	NP nest	P1 (Repatriated/Paid)	P2 (Repatriated/Unpaid)
Ship’s age	—	-0.016* (0.009)	-0.005 (0.013)
P&I club			

<i>PI</i>	—	0.580** (0.274)	-1.378** (0.637)
Flag state			
<i>FOC</i>	—	1.186*** (0.346)	-1.637** (0.648)
Model Fit			
Number of Observations	1686	Number of Cases	562
Log Likelihood	-541.755	Wald chi2 (11)	48.34
		Prob > chi2	0.000
Dissimilarity Parameters			
P_tau	3.046*** (0.711)	LR test for IIA (tau=1): χ^2	9.13
NP_tau	1	Prob > χ^2	0.003
Seemingly Unrelated Estimation Test			
Alternative deleted	χ^2	Prob	
P1	15.48	0.049	
P2	22.71	0.004	

Note: Robust standard errors are in parentheses. The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

5.5.2 Estimation of the repatriation and payment times

Table 5-7 reports the regression results of the fixed effects model for the resolution time of abandonment events. For repatriation time, the coefficient of *PSC* is not significant. It implies that the *PSC* cannot decrease the time cost of repatriation. In contrast, the *Asia* region has a positive and significant coefficient of 83.523, larger than the others, indicating that the seafarers repatriated from Asia need to wait longer before disembarkation. For payment and repatriation times, the coefficients of *PI* and *FOC* are significantly negative, which illustrates that P&I clubs and FOC States strictly perform the MLC regulations for repatriation and wage claims. Both P&I clubs and FOC States speed up the resolution process of abandonment. All these findings align with the results in section 5.5.1.

However, the coefficients of *Mixed* nationality and *Ship's age* indicate that they have no significant effects on the repatriation time and payment time, respectively. It implies repatriation activities and wage reimbursements are completed within a similar timeframe regardless of the nationalities of crews or the ages of ships.

Table 5-7 Results of the fixed effects model

Variables	Repatriation time	Payment time
PSC		
<i>Yes</i>	-27.776 (28.193)	—
Crew nationality		
<i>Mixed</i>	5.588 (24.016)	—
Abandonment region		
<i>Africa</i>	55.244 (48.772)	—
<i>Asia</i>	83.523* (44.930)	—
<i>Europe</i>	69.844 (48.645)	—
P&I club		
<i>PI</i>	-91.302*** (24.120)	-90.673*** (27.577)
Flag State		
<i>FOC</i>	-67.779** (29.795)	-61.498* (33.414)
Ship's age	—	0.049 (1.053)
Constant	227.346*** (54.630)	323.743*** (41.082)
<i>F</i> -test	4.29***	5.60**
<i>R</i> -squared	0.111	0.064
Observations	304	304

Note: Robust standard errors are in parentheses. The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Moreover, Table 5-8 lists the detailed repatriation and payment times based on individual variable groups. As mentioned, the *PSC*, *Mixed* nationality, and *Ship's age* cannot significantly affect the number of days for repatriation and payment. The average repatriation time of abandonments in Asia is about 1.5 months longer than in other regions. The P&I clubs and FOC States can shorten the average repatriation and payment times by 3 months and 2.5 months, respectively. Noticeably, the performance of FOC States shows that the campaign against FOC has yielded remarkable achievements in the maritime industry (Sampson, 2022; ITF, n.d.).

Table 5-8 The average repatriation and payment times by individual variable grouping

Average repatriation time by grouping individual variables										
Variable	PSC		Crew nationality		Abandonment region		P&I club		Flag State	
	<i>Yes</i>	<i>No</i>	<i>Mix</i>	<i>Single</i>	<i>Asia</i>	<i>Not Asia</i>	<i>PI</i>	<i>Unknown</i>	<i>FOC</i>	<i>Non-FOC</i>
Days	163	191	186	180	205	162	145	241	169	250
Δ days	-28		6		43		-96		-81	

Average payment time by grouping individual variables						
Variable	Ship's age		P&I club		Flag State	
	<23	>=23	PI	Unknown	FOC	Non-FOC
Days	228	217	184	276	209	279
Δ days	11		-92		-70	

Note: The median of ship age is 23. For an individual variable, Δ days are calculated by the value of the former group minus the value of the latter group.

5.5.3 Robustness check

As detailed in Table 5-9 and Table 5-10, we have conducted a series of additional robustness checks to guarantee the robustness of our empirical models. First, we adjust the number of explanatory variables for the nested logit model by removing specific ones. Specifically, Models 1~4 remove the variables of *PSC*, *crew nationality*, *P&I club* and *Ship's age* in turn. Second, we change the regression method and the study period for the fixed effects model, and add some control variables. Specifically, Models 5 and 8 use the OLS (ordinary least squares) regression, while Models 6 and 9 use samples from 2020 to 2023 during the COVID-19 pandemic. Models 7 and 10 add the control variables of *No. of seafarers* and *GT* (gross tonnage). In summary, the coefficients and significances of all the above models are consistent with those of the original models. The results from these robustness tests lend further assurance to the validity and reliability of our earlier findings.

Table 5-9 The robustness check for the nested Logit model and fixed effects model

		Choice probability of repatriation and wage payment rights			
Variable		Model 1	Model 2	Model 3	Model 4
Type P	PSC				
	Yes	/	0.248 (0.273)	0.256 (0.274)	0.272 (0.273)
	Crew nationality				
	Mixed	-0.370* (0.223)	/	-0.388* (0.224)	-0.411* (0.223)
	Abandonment region				
	Africa	-0.304 (0.375)	-0.274 (0.383)	-0.194 (0.382)	-0.212 (0.384)
	Asia	-0.789** (0.322)	-0.721** (0.335)	-0.668** (0.330)	-0.594* (0.327)
Mode P1	Americas & Oceania	-0.357 (0.474)	-0.329 (0.476)	-0.267 (0.474)	-0.3 (0.476)
	Ship's age	-0.016* (0.009)	-0.017** (0.009)	-0.013* (0.007)	/
	P&I club			/	

	<i>PI</i>	0.619** (0.278)	0.532** (0.262)		0.546** (0.251)
	Flag State				
	<i>FOC</i>	1.240*** (0.347)	1.082*** (0.331)	1.477*** (0.338)	0.902*** (0.265)
	Ship's age	-0.006 (-0.014)	-0.007 (0.012)	-0.011 (0.013)	/
	P&I club				
Mode P2	<i>PI</i>	-1.446** (0.651)	-1.272** (0.609)	/	-1.032* (0.54)
	Flag State				
	<i>FOC</i>	-1.735*** (0.651)	-1.514** (0.625)	-2.037*** (0.684)	-1.239** (0.559)

Note: Robust standard errors are in parentheses. The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

Table 5-10 The robustness check for the nested Logit model

Variable	Repatriation time			Payment time		
	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
PSC						
<i>Yes</i>	-16.764 (28.016)	-20.915 (20.249)	-27.676 (28.108)	/	/	/
Crew nationality						
<i>Mixed</i>	2.909 (24.177)	31.160* (17.631)	-1.036 (23.935)	/	/	/
Region						
<i>Africa</i>	65.176 (48.945)	39.197 (33.502)	24.995 (49.733)			
<i>Asia</i>	89.943** (44.597)	63.495** (30.747)	59.464* (36.445)	/	/	/
<i>Europe</i>	74.196 (48.680)	82.752* (39.611)	46.710 (49.004)			
P&I club						
<i>PI</i>	-85.312*** (23.543)	-63.770*** (17.391)	-97.931*** (24.328)	-88.613*** (27.068)	-79.998*** (25.486)	-97.800*** (27.604)
Flag State						
<i>FOC</i>	-61.082** (29.218)	-37.675* (22.531)	-70.863** (29.594)	-55.707* (32.333)	-37.954* (21.244)	-64.039* (33.152)
Ship's age	/	/	/	-0.408 (0.961)	-1.097 (0.970)	0.413 (1.051)
Gross tonnage (control variable)	/	/	-0.204 (0.161)	/	/	-0.055 (0.179)
No. of seafarers (control variable)	/	/	-2.409** (0.978)	/	/	-3.059*** (1.066)

Note: Robust standard errors are in parentheses. The symbols *, **, and *** indicate significance at 10%, 5%, and 1% levels, respectively.

5.6 Discussion

5.6.1 Interpretation of the hypothesis test by examples

Considering the importance of the amended MLC to the repatriation and wage rights of abandoned seafarers, we have proposed some hypotheses and adopted the nested logit and fixed effects models for assessment. Our research findings provide the evidence for the hypothesis test results in Table 5-11. Hypotheses 1~4 are supported, hypothesis 5 is rejected, and hypothesis 6 is partially supported. Combined with some detailed sample cases and legal provisions, we interpret the test results to highlight deficiencies under the MLC.

Table 5-11 The hypothesis test results

Hypotheses	Test results	Notes
H1: FOC States can better guarantee the repatriation and wage payment than traditional flag States.	Supported	In <i>H1</i> and <i>H2</i> , the average repatriation and payment times are still longer than 160 days and 200 days, respectively.
H2: P&I clubs can somewhat benefit the process of repatriation and wage payment.	Supported	
H3: The Asian region has more unfavourable effects on repatriation than other regions.	Supported	/
H4: Mixed nationality of seafarers adversely affects the repatriation.	Supported	/
H5: PSC inspection can provide positive support for the repatriation activity.	Rejected	/
H6: Older ships' auction values make it difficult to ensure wage payment and have a negative impact on payment speed.	Partially supported	/

For **H1** and **H2**, financial security from P&I clubs and corresponding supervision from FOC States are effective but inadequate. The wage security of up to four months does not cover the outstanding amounts or convince seafarers to sign off. In extreme cases, like *Avlemon* and *Sanad* vessels, seafarers remain unpaid for 2-3 years. The conflict of interests between the insurance providers and shipowners also causes payment delays, which need FOC States to reconcile (Gupta and Shanthakumar, 2023).

For **H3**, non-ratification of the MLC by many Middle Eastern countries contributes to the frequent abandonment in Asia, leaving seafarers exploited and stranded at sea. Despite some countries like the UAE and Turkey having promised compliance with the MLC standards to the maximum extent since 2018 (ITF, 2019a), they tend to have fewer obligations. For instance,

in the cases of vessels *M/V Aegean Princess* in 2018 and *Ocean Trader* in 2021, the UAE port authority showed little interest in helping abandoned seafarers.

For **H4**, scattered and unregulated RPS agents disadvantage seafarers of mixed nationalities. Many unregistered and dishonest RPS agents charge for positions and offer the SEAs (Seafarer Employment Agreements) wages below ILO minima, as illustrated in the cases of vessels *Larobon*, *Faridah*, and *Tahsin*. When abandoned, some RPS agents, like the agents of *Oriental Emerald* and *Ultra Tatio* vessels, cannot provide all crew documents for repatriation and forge bank accounts to receive outstanding salaries. In fact, not all countries have specialised systems to support the MLC's recruitment and placement regulations²⁶. In addition, repatriation activities are uniformly organised in batches and conducted in roughly the same time, which is not affected by the national composition of the seafarers.

For **H5**, PSC inspections fail to fulfil the MLC's duty to facilitate repatriation for two reasons. First, PSCOs have flexibility in following MLC guidelines on complaints (Mantoju, 2021; ILO, 2022). A typical case is the abandoned ship named *Archon* in 2021. Due to understaffing over the weekend and a lack of willingness, PSCOs in Barcelona, Spain, did not address seafarers' complaints and missed the repatriation solution. In another case from 2019, Turkey port officers chose to remove the ship called *Abo Alyssa* from the port area rather than respond to repatriation requests. The second reason is the minimum crew requirements of SOLAS (International Convention for the Safety of Life at Sea). Cases involving vessels like *Miss Gaunt*, *Marvin Confidence*, *Marvin Faith*, *Sky Fortune*, and *Evolution* show how PSC's minimum safe manning requirements prevent crew disembarkation and repatriation plans offered by financial security providers and flag States. Clauses 7 and 8 of Standard A2.5.1 in the MLC state that port States should facilitate repatriation and cannot prevent it due to the shipowner's financial condition or inability to replace the crew. However, these clauses do not clarify where the responsibility lies for providing replacement crews (Gupta, 2023).

For **H6**, these ships have low sales values and are repeatedly abandoned to avoid paying wages (Bolton, 2024). Some are abandoned over three times, such as ships with IMO numbers "9046784, 7504598, 9144184". Moreover, in certain cases, when old ships' values are sufficient to cover all the owed wages, they will be auctioned by the maritime court and the auction process will delay payment time. However, even for newer ships, shipowners rarely

²⁶ Seafarers on a ship often come from different countries, especially developing ones. Only the Philippine Overseas Employment Administration and the India Directorate General of Shipping can provide professional recruitment and placement services.

settle all wages at once because they are bankrupt, resulting in further payment delays of subsequent wages. Consequently, payment speed shows no clear difference between old and new ships.

To summarise the interpretation: (a) Although FOC States and P&I clubs uphold the basic force of the MLC, the average resolution time still exceeds six months. (b) Seafarers abandoned in the Asia region and those of mixed nationalities face lower probabilities of being fully repatriated. (c) PSC does not comply with the MLC's repatriation facilitation provisions as expected. (d) Low sale values and lack of insurance for older ships are major obstacles to reimbursing seafarers' outstanding wages.

5.6.2 Policy suggestions

Drawing upon the current procedures of MLC's members and third-party organisations, some policy suggestions are provided to address these deficiencies.

(a). P&I clubs should expand the scope of financial security, and flag States should set up a welfare fund to cover repatriation fees and extra unpaid wages.

The average repatriation and payment times exceed six months due to inadequate financial security. Four months' wages and repatriation subsidies cover only a small percentage of abandoned seafarers (Sampson, 2022). Many still struggle with unpaid wages and repatriation costs. One solution is for P&I clubs to extend the covered wage months. Another is for flag States to create a welfare fund as complementary financial security. Flag States can collect risk deposits before registration from owners of older ships and those listed in the ITF Seafarers' Breach of Rights Index as funding sources²⁷.

(b). ITF should work with Middle Eastern governments to share information on abandonment.

In Asian abandonments, Middle Eastern ports do not allow the existence of seafarers' unions. The ITF Arab World and Iran Network coordinator cannot directly participate or meet captains face-to-face (Ghaida and Ezra, 2022), making it hard to manage seafarers' repatriation needs. Therefore, cooperating with local governments through a memorandum of understanding (MOU) could help ITF establish a better communication channel with crews (ITF, 2019b).

²⁷ To tackle the exploitation and abuse of workers at sea, ITF has launched a new online Seafarers' Breach of Rights Index at <https://www.itfseafarers.org/en/directories/seafarers-breach-of-rights> (last accessed in March 2025).

(c). An international alliance of RPS agents should be established.

This international RPS alliance can quickly facilitate the sign-off and repatriation of mixed nationality crews, and its operation is not limited by national borders. Moreover, according to standard A1.4 in the MLC, this alliance can help abandoned seafarers file complaints about unpaid wages and claim the outstanding amounts on their behalf (Lielbarde, 2024b).

(d). PSC should unconditionally accept complaints from abandoned seafarers and be responsible for arranging local replacement crews.

Many shipping companies, like *Palmali Holding* and *CNAN-MED*, exploit the weaknesses of PSC to maximise profits by abandoning ships worldwide despite seafarers' complaints²⁸. To reduce this behaviour, PSCOs must accept complaints with more detailed inspections (PARIS MOU, n.d.) and help connect seafarers with authorised officers for onshore handling procedures. Additionally, PSC has the geographic advantage of quickly finding available seafarers and recovering expenses from the auction proceeds of detained ships. Therefore, crew changes by local seafarers will not burden port States.

5.6.3 Limitations and future directions

Several limitations of this work suggest avenues for future research. First, our dataset only considers the direct factors relevant to the repatriation and wage provisions in the MLC. The mediating effects of indirect factors, such as charity organisations and abandonment causes, on the MLC still need to be investigated. Second, econometric models could be combined with machine learning approaches to evaluate the MLC more rigorously and accurately. Third, our study does not address other rights of abandoned seafarers beyond repatriation and wage rights. Seafarers' psychological health and medical care will be a focus of future research. It can be achieved by collecting questionnaires and listening to the voices of those experiencing abandonment.

5.7 Conclusion

As a central expression of human rights law at sea, the MLC is greatly important to the shipping industry (Papanicolopulu, 2023). This bill is flexible enough to balance maritime

²⁸ See ILO Seafarer Abandonment Database. Palmali Holding company has more than ten abandoned ships, and ships of the CNAN-MED company are mainly detained in European ports for unpaid wages. Part of the IMO numbers of these ships are 9435325, 9437775, 9356957, 9557795, and 9697337.

jurisdiction and international governance (Sampson, 2022). However, this flexibility has led many commentators to question the MLC's performance in various aspects of labour standards. How to complete and promote the MLC to ensure the smooth operation of global trade is an ongoing and vital task for industry and academia.

We look at the frequent cases of seafarer abandonment in recent years. Econometric approaches with critical factors are used to assess the repatriation and wage rights of abandoned seafarers under the MLC. Our work reveals four issues of concern. First, the obligations of PSC to assist with repatriation are not clearly defined in the MLC, and the conflicts between the MLC and SOLAS limit the positive roles of PSC. Second, the cases of abandonment happening in Asia require third-party intervention, such as cooperation between ITF and local governments. Third, crews with mixed nationalities need an international RPS alliance to supervise their agents and provide quick assistance in cases of abandonment. Fourth, the financial security system covers too few wage months, leading to long resolution times of over half a year. Our work demonstrates that there is a long way to go for strengthening seafarers' understanding and confidence in the MLC. All stakeholders should recognise that seafarers are not victims of the games from all sides in shipping but are engaged in a dignified profession.

Chapter 6: Conclusions

Taking sustainable shipping management at the core, based on the triple bottom line and extended resource-based view, this thesis innovatively proposes a coherent three-dimensional analytical framework about ballast water, market volatility, and seafarers' rights to address important issues in the sustainable development of the maritime industry. This research framework provides a new perspective on multiple integration and dynamic evolution for understanding the complexity of the SSM. All the work across different topic dimensions fills the significant theoretical and managerial gaps in the SSM literature.

6.1 Summary of Study Findings

The three research questions and objectives in Chapter 1 are achieved by the findings in the above studies. Specifically, we summarise the main findings as follows.

(1) Major findings of Study 1.

By designing a new ballast water volume estimation and risk assessment approach, the BW discharge volumes from 2017 to 2020 in ten Chinese seaports are accurately forecasted, and the NIS risks of these seaports in 2020 are evaluated. Through an analysis of model results, we discern that ports in the Yangtze River Delta and Bohai Rim received the most ballast water, especially the Ningbo-Zhoushan Port, as a high-risk region receiving about 65 million tonnes per year. Due to differences in ship sizes between dry bulk and liquid bulk commodities for export transport in China, at a per-unit capacity of cargo throughput, a tanker usually has a higher ballast water discharge potential than a bulker. Chinese ports face a probability of more than 0.9 of non-indigenous species introduction. The findings offer an available decision support tool for assisting port officers with implementing the BWMC in real scenarios.

(2) Major findings of Study 2.

Using the Diebold-Yilmaz spillover indices and VAR-based causal inferences, mixed-frequency time series in the period 2009–2023 are analysed for the internal spillovers among container, dry bulk, dirty, and clean tanker spot (freight) markets and their linkages to external uncertainties. Special attention is given to the post-COVID-19 period in this study. We demonstrate that the epidemic has shifted the roles of net spillover transmitters and receivers within the four markets, while also intensifying the causality effects and shock impacts of EPU and GPR on internal spillovers of spot markets. Our findings also reveal that EPU and GPR influence spillovers through distinct mechanisms, with tanker markets serving as key mediators that amplify uncertainty shocks. This study addresses the driving forces and impacts of external

uncertainty factors on internal spillovers within the shipping freight system and attempts to convey valuable policy implications to shipping stakeholders.

(3) Major findings of Study 3.

Based on the text-to-data conversion with abandonment reports from the ILO, a new dataset is first created covering 16 factors. This research identifies 6 critical factors involved in the MLC during the period of 2017–2023 and uses the nested logit model and fixed effects model to quantitatively examine these critical factors' effects on the repatriation and wage rights of abandoned seafarers. We observe that Asia as the abandonment region and crew's mixed nationalities negatively affect repatriation probability, while the older age of a ship negatively affects the payment probability. Notably, PSC cannot meet the MLC's expectation to either increase the likelihood of or decrease the time of repatriation. Although the P&I clubs that preserve the financial security system and FOC States help resolve abandonment issues, the average time for repatriation and payment still exceeds six months. The findings rate the MLC's effectiveness and possible dysfunctions, providing policy suggestions for the improvement of abandoned seafarers' interests through detailed examples.

6.2 Research Implications

Although we have discussed the implications and policy suggestions in three chapters of sub-studies, they still lack an integrative presentation. Hence, in this section, we summarise the contributions to existing literature in the theoretical implications and to current SSM regimes in the managerial implications.

6.2.1 Theoretical Implications

This thesis contributes to the existing literature in several important aspects. Specifically, the theoretical implications of the three studies are as follows.

Focusing on the purpose of **forecasting**, Study 1 develops a new ballast water discharge estimation model based on the assumptions about port ballast water operation processes. Extending the BWM literature, this study adds the statistical variables of *Exports* and *Imports* into the IMO and GloBallast Project's traditional estimation model that only depends on the variable of *DWTs*, and adopts the LASSO technique in machine learning to ensure the out-of-sample forecasting performance. This model offers a measurement tool for developing countries and small island states without ballast water records to rapidly compute the accumulated discharge volumes and match them with appropriate port treatment infrastructures.

Study 1 also modifies the risk assessment model to more easily predict the risk probabilities, including the non-indigenous species risk, introduction risk, establishment risk, and comprehensive spread risk at the port level. Accordingly, Study 1 broadens theoretical boundaries and conditions of ballast water analysis through a generic approach of discharge estimation and risk assessment.

Drawing from the purpose of **causal inference**, Study 2 unveils how external uncertainty factors' stimuli break the dynamic equilibrium of internal spillovers among shipping spot freight markets. Extending the shipping volatility literature, this study provides evidence that, during the COVID-19 pandemic, the variation of shipping spot markets' spillover indices is Granger-caused by the EPU and GPR, and verifies that the tanker markets are the primary channels to spread the EPU and GPR shocks to other spot markets. By monitoring the movement trends of EPU and GPR, participants can judge the changes in volatility transmission directions and magnitudes for their strategic planning. Based on the judgment, carriers may restructure the charter types or look for profit opportunities in the second-hand ships and demolition markets, while shippers may optimise the inventory holdings and ordered parcel sizes or seek transport alternatives. Additionally, governments can also give subsidies and resource support for their shipping industry. Therefore, this study lays a foundation for a deeper understanding of external uncertainties' macro effects on the shipping freight system's volatility.

Drawing upon the purpose of **policy evaluation**, Study 3 sheds light on the performance of MLC in protecting the fundamental repatriation and wage rights of abandoned seafarers. Extending the MLC literature, this study highlights the critical factors involved in abandonment solutions to reveal both shortcomings and advantages of MLC's regulations. The counterintuitive truths are that PSCs have no facilitating action in resolving abandonment due to contradictions in different legal provisions like SOLAS, but the FOC states accelerate the resolution time of repatriation and wage payment by positive communication with P&I clubs and abandoned seafarers. Besides, the extension of four-month financial security and the establishment of an international alliance of RPS agents deserve attention by the ILO's Special Tripartite Committee. Consequently, Study 3 brings new insights through quantitative analysis to the literature on MLC's effectiveness and provides the basis for further amendment of relevant maritime laws.

6.2.2 Managerial Implications

The research outcomes of this thesis can provide managerial implications for sustainable

shipping according to the TBL, including three pillars of planet (environmental dimension), profit (economic dimension), and people (social dimension). These implications are specifically outlined as follows.

At the **Planet pillar**, IMO's maritime treaty on the BWMC marks an essential milestone in achieving the sustainable development of marine resources and maintaining the natural biodiversity of the Earth's environment. In study 1, the precisely estimated ballast water discharge volumes and associated discharge potentials of different ship types benefit managers in planning the construction of emergency BW treatment facilities while consuming the least shore power. These facilities can prevent the regrowth of organisms surviving the treatment process on intake, especially for those ballast water management systems without secondary disinfection during the transition phase from D-1 standard to D-2 standard. Moreover, the convenient and fast assessment of the NIS risk helps managers develop the specimen collection strategies for port biological baseline surveys and the monitoring strategies of the introduced marine pests and harmful pathogens that will threaten human health. With the execution of these strategies, commercial port officers can also conduct stricter additional requirements than the D-2 standard for ships.

At the **Profit pillar**, freight rate volatility is the central content of UNCTAD's maritime transport report that aims to encourage the sustainable shipping trade. In study 2, the uncertainty mechanisms and underlying causes of EPU and GPR dominate the upside- and downside-variations of spillovers among shipping spot freight markets. It sets new requirements for stakeholders' economic management abilities. On the one hand, they should build advanced digital freight management platforms. For example, by real-time analysis of external uncertainty indices, these platforms can help update optimal online rate index-linked contracts and rearrange capacity and route deployment. On the other hand, they should strengthen cross-sector cooperation with the finance industry to obtain greener ship financing and supply chain support loans for resistance against uncertain impacts, especially those related to oil prices and national trade commodity policies. Furthermore, governments of maritime-power countries have the duty to enhance information sharing and market transparency and establish global shipping regulatory summits, which will provide officially approved guidelines for all parties.

At the **People pillar**, the ILO-advocated MLC amendment embodies the international responsibility and social welfare to protect seafarers' rights. In study 3, the exhaustive statistical and empirical investigations offer unique evidence about the MLC's enforcement deficiencies in dealing with cases of abandonment for maritime lawmakers. The failure of the PSC's role in

assisting abandoned seafarers requires that legislators clearly explain the conflicting provisions of different laws and clearly delineate the overlapping jurisdiction of the port State and the flag State. Financial security also requires a new legal basis and social credit, making it possible for innovative technologies such as Blockchain to promote the traceability and immediacy of repatriation and wage payment. More importantly, the RPS agents in different countries need to be overseen by international organisations to ensure fair employment agreements for crews in cases of abandonment.

6.3 Limitations and Future Research Directions

Undoubtedly, the thesis does not cover all aspects of ballast water, market volatility, and seafarers' rights. There are still some research points deserving study in the future to reinforce the understanding of sustainable shipping.

First, regarding the limitations in Study 1 on the discussion of invasive species control in ballast water and sediment, future research can focus on the species invasion and spread risk networks and the maintenance of ballast water treatment systems in the future. Along with the rise of shipborne electronic ballast water record books and port NIS sampling systems, the development of a comprehensive risk assessment framework, including invasion and secondary spread networks, will be a promising direction. In the high-order invasion network, how to select treatment protocols for ports in ecosystem-fragile regions (e.g., the Arctic Ocean) with different priorities is not explored. Similarly, in the secondary spread network, how to detect all potential colonisations and model the risk weights is not well developed for secondary invasions by rivers, ocean currents or hinterland transport. In addition, as the BWTSs are equipped on all vessels by the 2024 deadline, the maintenance of treatment systems will be important for ship operators. The trade-off problem to balance the ballast water policy compliance costs and subsequent economic profits needs to be solved. The technical selection and upgrade of BWTSs also need to be considered.

Second, regarding the limitations in Study 2 on the roles of other kinds of external uncertainties in the shipping industry, future research can focus on the climate policy uncertainty and the natural disaster uncertainty. Under the backdrop of maritime carbon emission reduction, the climate policy uncertainty brings many opportunities. For investors to avoid the carbon tax uncertainty, the optimal hedge ratios between the carbon credit futures and freight markets and the optimal carbon capture value decision between the CO₂ ship and pipeline need to be studied. For companies to mitigate the bunker price uncertainty, the best

transitional options for zero-carbon alternative fuels and decarbonisation pathways need a deeper examination. Moreover, with the growth of meteorological disasters, canals and ports face escalating challenges. The barge rate volatility and delivery schedule variation in drought disasters still lack examination for inland canals like the Mackenzie and Mississippi rivers. The problems of ports' berth allocation and recovery capability are not well investigated when encountering extreme weather such as hurricanes and tides.

Third, regarding the limitations in Study 3 on the broader rights for seafarers as well as fishers in the MLC and similar conventions, future research can focus on the seafarers' health rights and the fishers' fair employment rights. With the hazardous nature of working at sea and the medical care constraint on board, seafarers' health rights still have room for enhancement. Considering the seafarers' poor educational level, the training and certification of self-first-aid knowledge and the uniform guidelines of telemedical advice need to be further completed. Meanwhile, the insufficient medical repatriation support from port-based welfare services is an urgent issue to solve. The provisions to encourage personal protective equipment also need to be explored. Due to the differences in jurisdiction between the fisheries and maritime sectors, small-scale fishing is excluded from the MLC. The parallel Work in Fishing Convention, 2007 (C188) is not enough to protect fishers from exploitation and fatigue. A systematic comparison of the C188 with the MLC has not been well researched to detect the gaps and promote completeness and ratification of the C188 across additional countries.

6.4 Concluding Remarks

With the requirements of Sustainable Development Goals 14, 8, and 16 in the 2030 Agenda, this thesis seeks to explore novel angles for revisiting the issues in terms of ballast water, market volatility, and seafarers' rights. From the angle of methodological innovation, through scientific assumptions and detailed data, a generic ballast water discharge and risk assessment tool is proposed, revealing the far-reaching ramifications of harmful invasive species in ballast water on marine ecosystems. From the angle of conceptual in-depth understanding, causal relationships from the EPU and GPR to the spillover effects across shipping spot freight markets are demonstrated, profoundly dissecting how external uncertainty is transmitted and amplified within the shipping freight system. From the angle of jurimetrics rigour, concentrating on the point of human-centred care, the contradiction between the textual design and the actual implementation of the MLC provisions is quantitatively analysed, calling on the international community to face up to the structural barriers behind the problem of

seafarer abandonment.

This thesis provides a comprehensive picture to address the significance of sustainable shipping management. The results provide theoretical and managerial implications for policymakers to enhance the maritime resource allocation and the responsibility for sustainability. More importantly, this thesis also paves the way for future research to enrich the understanding of sustainable shipping. Ultimately, this thesis hopes to attract more attention to continuous innovation, empirical monitoring, and coordinated governance for the balance between environmental preservation, economic efficiency, and human welfare in a rapidly changing global maritime context.

Appendix A: PRISMA Analysis and Scientometric Mapping of Topic 2 and Topic 3

The keywords, authorship and countries relationships, theme evolution, and theme words co-occurrence networks of Topic 2-market volatility and Topic 3-seafarers' rights are shown as follows. And the PRISMA analysis of three thesis-related topics is also presented.

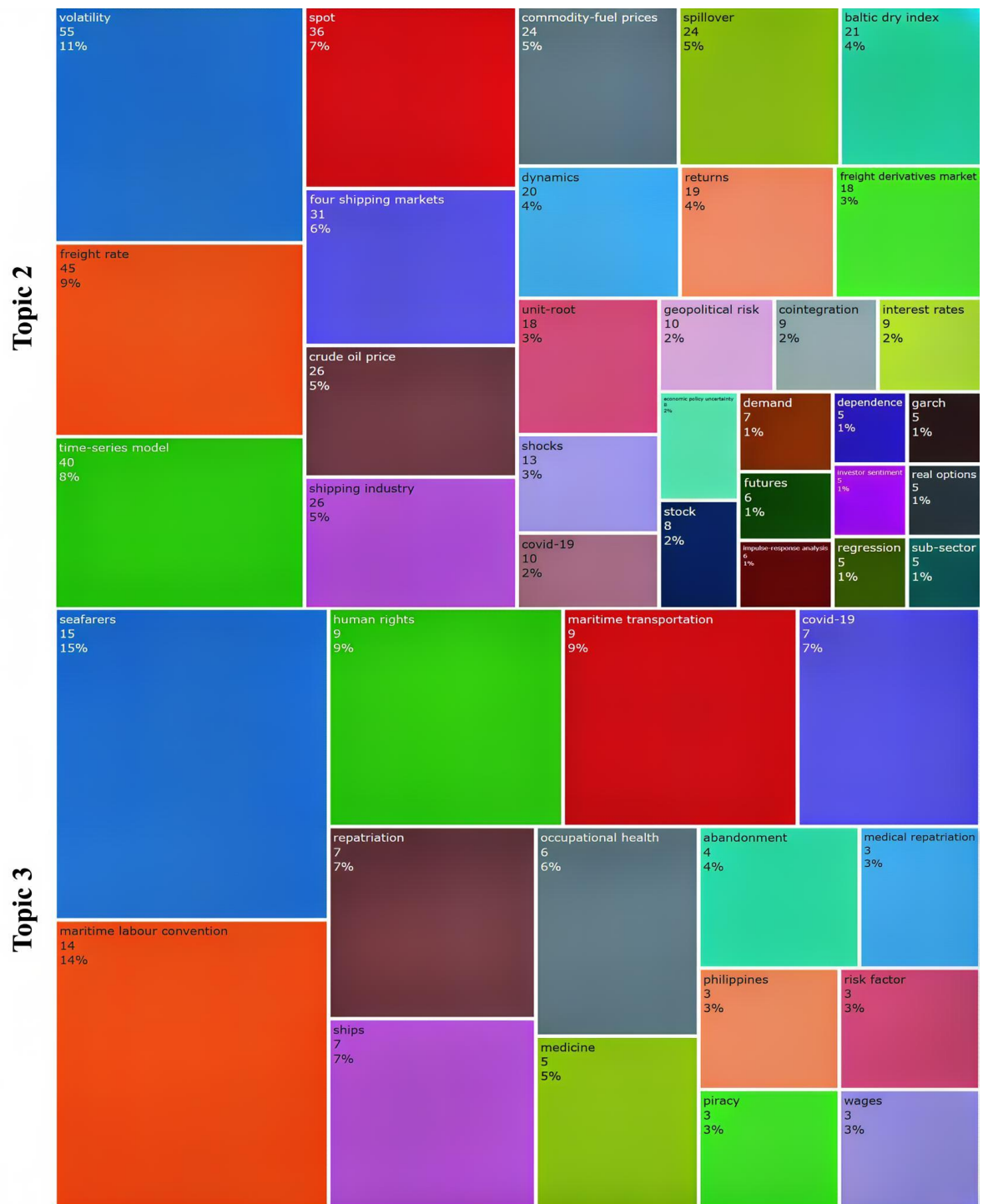


Figure A-1 The keyword trees of Topic 2 and Topic 3

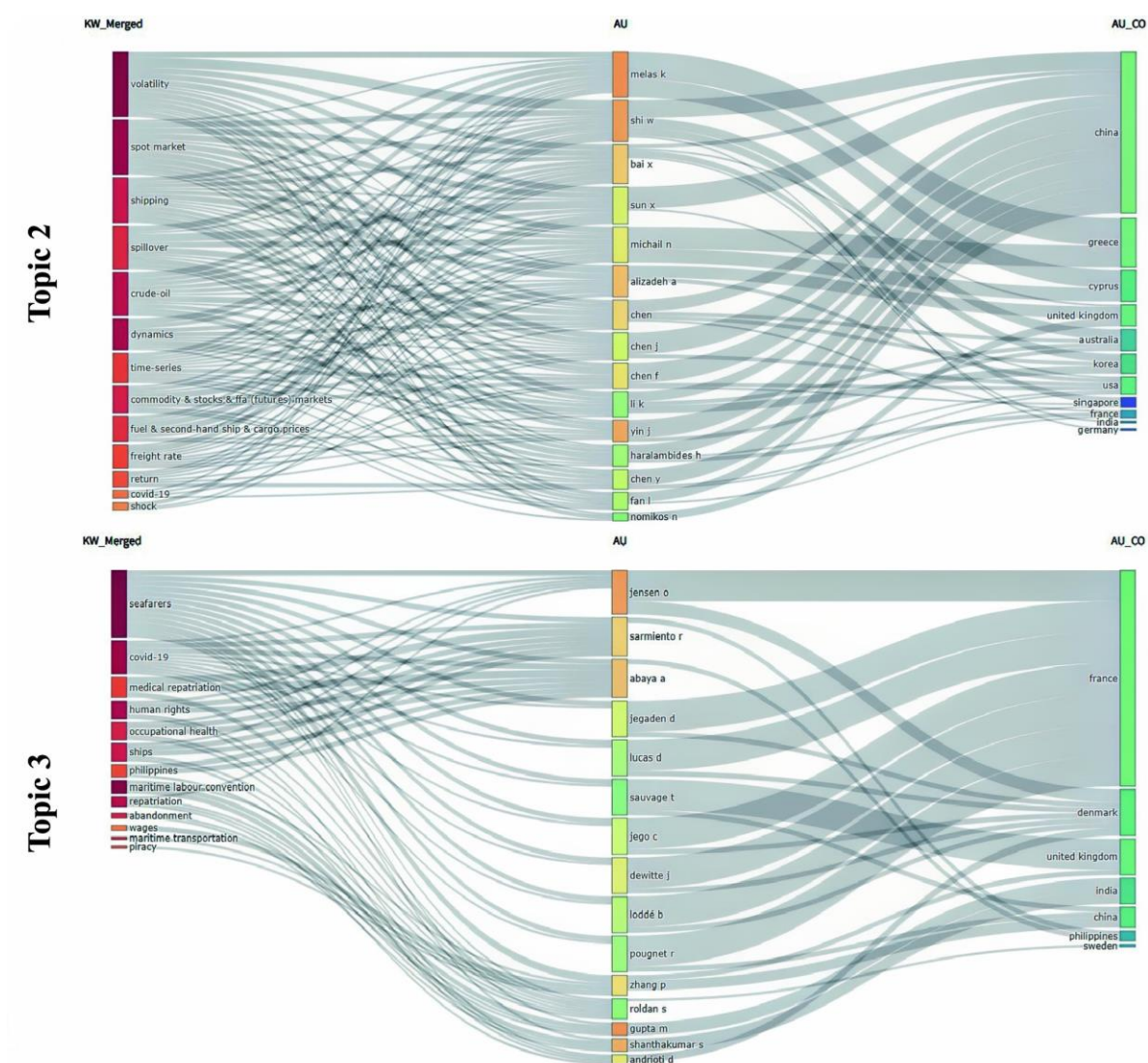


Figure A-2 The development of authorship and countries' relationships according to keywords of Topic 2 and Topic 3

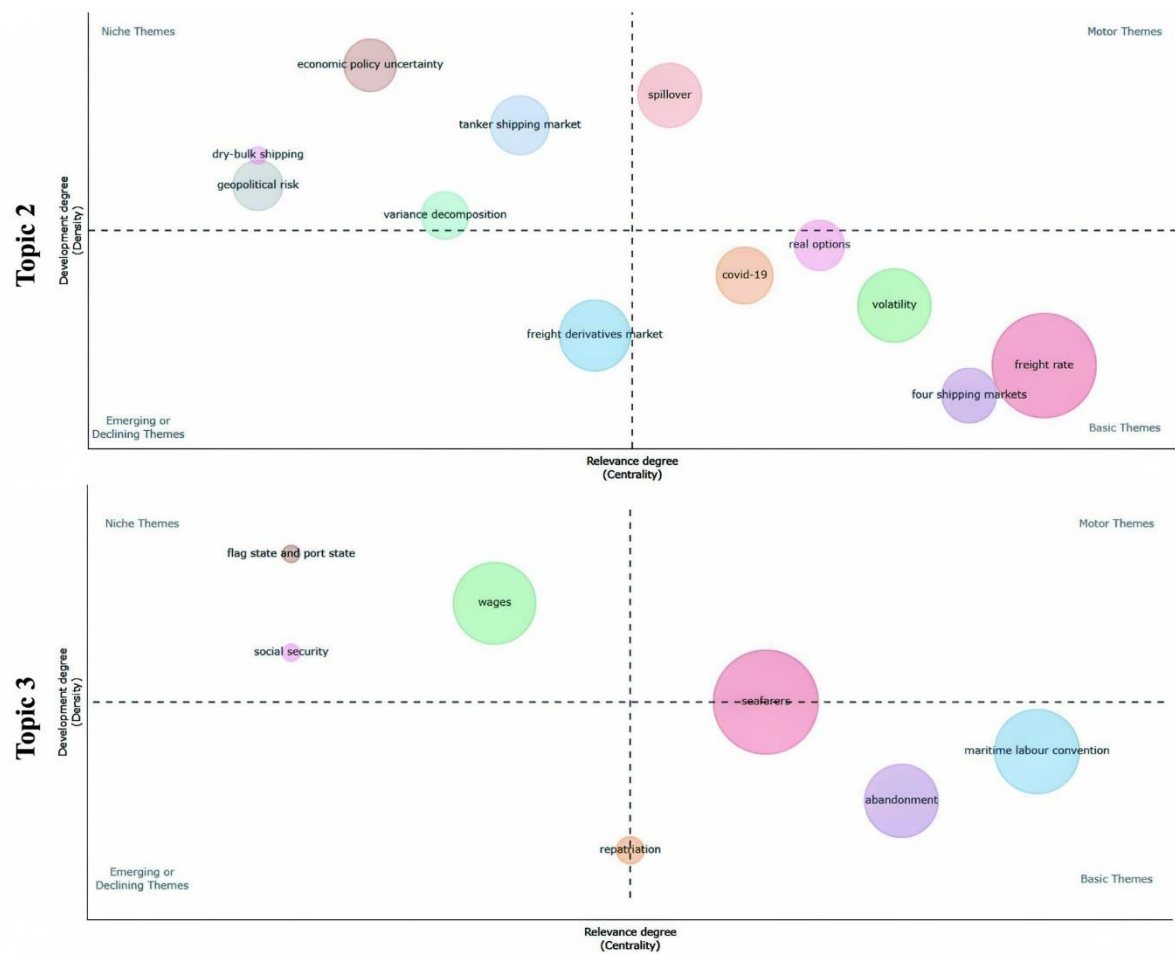


Figure A-3 The theme evolution for Topic 2 and Topic 3

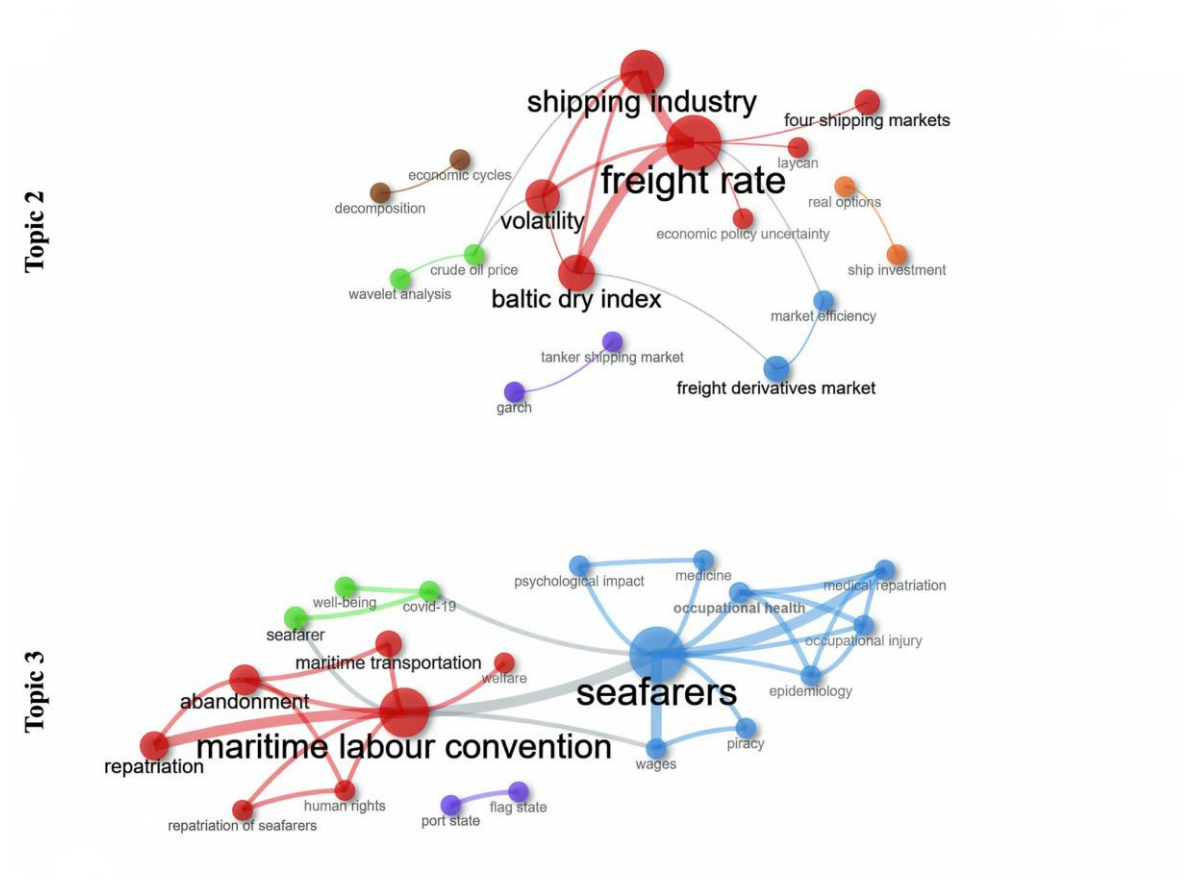


Figure A-4 The theme words co-occurrence networks of Topic 2 and Topic 3

Table A-1 Search strings, restrictions and results

Thesis-related topic	Search Engine	Strings and refinements	Retrieved paper	Added paper
Ballast water topic	Scopus	TITLE-ABS-KEY ((“ballast water” OR “ballast water management convention”) AND “estimation*”) OR TITLE-ABS-KEY ((“ballast water” OR “ballast water management convention”) AND “risk assessment*”) Refined by: PUBYEAR > 2009 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (LANGUAGE , “English”))	159	15
		TS= ((“ballast water” OR “ballast water management convention”) AND “estimation*”) OR TS= ((“ballast water” OR “ballast water management convention”) AND “risk assessment*”) Refined by: Article (Document Types) and 2010-2024 (Publication Years)	151	
	Selected	124	Ineligible	17
	Total	107		
Market volatility topic	Scopus	TITLE-ABS-KEY (“shipping” AND “volatility*”) OR TITLE-ABS-KEY (“shipping” AND (“economic policy uncertainty*” OR “geopolitical risk*”)) Refined by: PUBYEAR > 2009 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (LANGUAGE , “English”))	232	3
		TS= (“shipping” AND “volatility*”) OR TS= (“shipping” AND (“economic policy uncertainty*” OR “geopolitical risk*”)) Refined by: Article (Document Types) and 2010-2024 (Publication Years)	287	
	Selected	127	Ineligible	9
	Total	118		
Seafarers’ rights topic	Scopus	TITLE-ABS-KEY (“seafarer” AND “abandonment*”) OR TITLE-ABS-KEY (“seafarer” AND (“repatriation*” OR “financial security*”)) Refined by: PUBYEAR > 2009 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (LANGUAGE , “English”))	33	12
		TS= (“seafarer” AND “abandonment*”) OR TS= (“seafarer” AND (“repatriation*” OR “financial security*”)) Refined by: Article (Document Types) and 2010-2024 (Publication Years)	16	
	Selected	43	Ineligible	7
	Total	36		

Appendix B: Ballast Water Management Report and Port Discharge Frequency

When a ship plans to discharge ballast water at a port, as shown in Figure B-1, a general situation is that the number of tanks discharged is less than or equal to the number of tanks in ballast, although they are equal in most ballast water report forms.

Ballast Water Management Report

Vessel Information

Vessel Name **Kodiak Island**
 ID number **IMO number 9726190**
 Country of Registry **Hong Kong**
 Owner/operator **Kodiak Island LTD/Pacific Basin Shipping (HK) Ltd**
 Type **Bulk carrier** Gross Tonnage **23275**
 Ballast water volume units **cubic meters**
 Total ballast water capacity **14966.0** Number of tanks on ship **22**
 Onboard BW Management System **162.060/12/1**
 Last drydock date **2022-05-24**

Voyage Information

Arrival port (port and state) **Long Beach CA**
 Arrival date **2024-09-12**
 Last port (port and country) **New Westminster CA**
 Next port (port and country) **Santa Rosalia MX**
 Total ballast water on board **10777.9** Number of tanks in ballast **22**
 Number of tanks discharged **16**

Certificate of accurate information

Certification **Yes**
 Report type **New report**

Ballast Water History

Tank name/number	FPT	Tank capacity	636.78
Event type	Date	Event location(s)	Volume
Discharge+ Treatment			0
Source+ Treatment	12-Mar-2024	IWAKUNI, JAPAN	0.9
Empty-refill+ Treatment	19-Aug-2024	32-05.9N; 155-32.3E / 32-06.4N; 155-34.1E	0.9
Reason BW management was not conducted			

Tank name/number	WBT 1P	Tank capacity	407.78
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Figure B-1 An example of a ballast water management report submitted to the National Ballast Information Clearinghouse (NBIC)

Based on the NBIC's reports, the monthly discharge frequencies of main US ports are collected in Table B-1.

Table B-1 The frequency distribution of monthly ballast water data for both ship types

Bulk Carrier				Tanker Ship			
port	Freq.	Percent	Cum.	port	Freq.	Percent	Cum.
Baltimore	120	2.74	2.74	Baltimore	120	2.73	2.73
Houston	120	2.74	5.48	Baton Rouge	120	2.73	5.45
Jacksonville	120	2.74	8.22	Corpus Christi	120	2.73	8.18
Long Beach	120	2.74	10.96	Houston	120	2.73	10.91
Los Angeles	120	2.74	13.7	Lake Charles	120	2.73	13.63
Mobile	120	2.74	16.44	Long Beach	120	2.73	16.36
New Orleans	120	2.74	19.18	Los Angeles	120	2.73	19.09
Savannah	120	2.74	21.92	Mobile	120	2.73	21.81
Tacoma	120	2.74	24.66	New Orleans	120	2.73	24.54
Tampa	120	2.74	27.4	New York	120	2.73	27.27
Seattle	119	2.71	30.11	Pascagoula	120	2.73	29.99
New York	118	2.69	32.8	Philadelphia	120	2.73	32.72
Newark	118	2.69	35.49	Port Arthur	120	2.73	35.45
Philadelphia	117	2.67	38.16	Port Everglades	120	2.73	38.17
Boston	116	2.64	40.8	Richmond	120	2.73	40.9
Corpus Christi	116	2.64	43.44	San Juan	120	2.73	43.63
Port Arthur	116	2.64	46.08	Savannah	120	2.73	46.35
Port Everglades	115	2.62	48.7	Texas City	120	2.73	49.08
San Francisco	115	2.62	51.32	Beaumont	119	2.7	51.78
Wilmington (DE)	115	2.62	53.94	Boston	119	2.7	54.49
Wilmington (NC)	115	2.62	56.56	Freeport	119	2.7	57.19
Detroit	113	2.58	59.14	Jacksonville	119	2.7	59.9
Baton Rouge	112	2.55	61.69	Newark	119	2.7	62.6
Lake Charles	112	2.55	64.24	Brownsville	116	2.64	65.24
Oakland	112	2.55	66.79	Galveston	116	2.64	67.87
San Juan	108	2.46	69.25	Detroit	115	2.61	70.48
Beaumont	101	2.3	71.55	San Francisco	111	2.52	73.01
Chicago	99	2.26	73.81	Wilmington (NC)	109	2.48	75.48
Toledo-Sandusky	99	2.26	76.07	Wilmington (DE)	98	2.23	77.71
Panama City	96	2.19	78.26	Anchorage	95	2.16	79.87
Portland1	92	2.1	80.36	Tampa	89	2.02	81.89
Providence	82	1.87	82.23	Honolulu	86	1.95	83.84
Gulfport	77	1.76	83.99	Seattle	82	1.86	85.71
Stockton	70	1.6	85.59	Port Canaveral	80	1.82	87.53
Albany	68	1.55	87.14	Anacortes	76	1.73	89.25

Freeport	64	1.46	88.6	Paulsboro	72	1.64	90.89
Portland	59	1.34	89.94	Portland	71	1.61	92.5
Portsmouth	58	1.32	91.26	Tacoma	70	1.59	94.09
Vancouver	52	1.19	92.45	Bellingham	56	1.27	95.36
Cleveland	41	0.93	93.38	Portland1	43	0.98	96.34
Honolulu	41	0.93	94.31	Portsmouth	38	0.86	97.21
New Haven	38	0.87	95.18	Ponce	33	0.75	97.96
Longview	34	0.78	95.96	West Palm Beach	19	0.43	98.39
San Diego	31	0.71	96.67	New Haven	14	0.32	98.7
Ponce	30	0.68	97.35	Searsport	12	0.27	98.98
West Palm Beach	26	0.59	97.94	Chicago	11	0.25	99.23
Port Canaveral	18	0.41	98.35	Oakland	8	0.18	99.41
Brunswick	15	0.34	98.69	Vancouver	6	0.14	99.55
Anchorage	12	0.27	98.96	Albany	4	0.09	99.64
Brownsville	8	0.18	99.14	Toledo- Sandusky	4	0.09	99.73
Galveston	8	0.18	99.32	Green Bay	3	0.07	99.8
Searsport	7	0.16	99.48	Cleveland	2	0.05	99.84
Redwood City	6	0.14	99.62	Longview	2	0.05	99.89
Milwaukee	4	0.09	99.71	Port Angeles	2	0.05	99.93
Fall River	3	0.07	99.78	Providence	2	0.05	99.98
Camden	2	0.05	99.83	San Diego	1	0.02	100
Pascagoula	2	0.05	99.88				
Port Huron	2	0.05	99.93				
Texas City	2	0.05	99.98				
Beaufort- Morehead City	1	0.02	100				
Bridgeport	1	0.02	100.02				
Gary	1	0.02	100.04				
Total	4,387	100		Total	4401	100	

Appendix C: Robustness of DY Spillovers and MCMC Algorithm

Parameter Sampling

To validate the robustness of DY spillovers, the decay factor (k_1) and forgotten factor (k_2), as well as the forecast horizons, are changed. As an illustration of the total volatility spillover index in Figure C-1, the overall patterns of dynamic measurements remain the same, and the average error does not exceed 5%. Notably, the best forgotten factor should keep the value of 0.99.

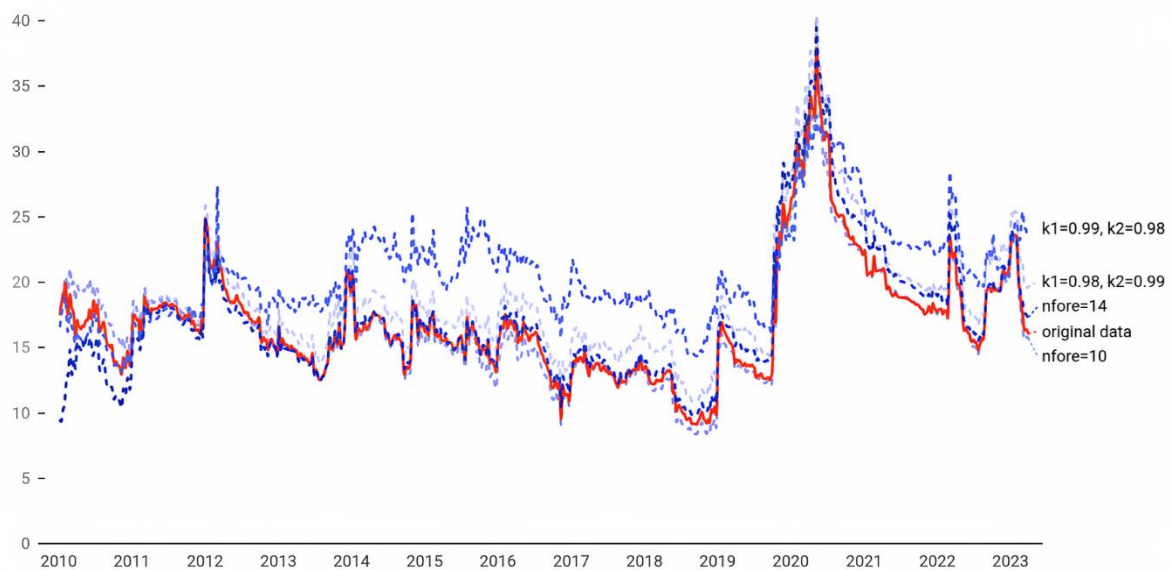


Figure C-1 Robustness of DY spillovers using the total volatility spillover index

The time-varying parameters estimated by the MCMC algorithm are reported in Table C-1. It shows that the estimated posterior means of all selected parameters are included in the 95% confidence intervals with small standard deviations. Geweke statistics are less than 1.96, and inefficiency factor values are lower than 100, which means the null hypothesis of parameter convergence to the posterior distribution cannot be rejected at the 5% significance level. Hence, the MCMC algorithm is efficient in generating posterior draws for TVP-VAR models.

Table C-1 The selected parameter estimations for the TVP-VAR with stochastic volatility

Parameter	Mean	Std.Dev.	95%U	95%L	Geweke	Inef.
Model 1: Time-varying impulse response test for Overall spillover						
($\Sigma\beta$)1	0.0023	0.0003	0.0018	0.0028	0.007	2.38
($\Sigma\beta$)2	0.0023	0.0003	0.0019	0.0029	0	2.78
($\Sigma\alpha$)1	0.0058	0.0016	0.0035	0.0095	0	6.52
($\Sigma\alpha$)2	0.0051	0.0014	0.0032	0.0084	0.005	22.64
(Σh)1	0.0058	0.0036	0.003	0.0127	0	59.89
(Σh)2	0.0058	0.0015	0.0037	0.0096	0	8.1
Model 2: Time-varying impulse response test for Net spillover for rBDI						
($\Sigma\beta$)1	0.0023	0.0003	0.0018	0.0029	0.148	3.58
($\Sigma\beta$)2	0.0023	0.0002	0.0018	0.0028	0	15.66
($\Sigma\alpha$)1	0.007	0.0053	0.0035	0.0274	0	35.3
($\Sigma\alpha$)2	0.0044	0.0008	0.0031	0.0062	0	5.84
(Σh)1	0.0077	0.0098	0.0035	0.0408	0	46.13
(Σh)2	0.0063	0.0063	0.0033	0.0243	0	50.34
Model 3: Time-varying impulse response test for Net spillover for rBDTI						
($\Sigma\beta$)1	0.0023	0.0003	0.0018	0.0029	0.001	12.31
($\Sigma\beta$)2	0.0023	0.0003	0.0018	0.0029	0.37	4.53
($\Sigma\alpha$)1	0.0065	0.0063	0.0032	0.028	0	42.84
($\Sigma\alpha$)2	0.0041	0.0007	0.0029	0.0057	0.125	6.14
(Σh)1	0.0068	0.0046	0.0035	0.0216	0	45.09
(Σh)2	0.0064	0.0023	0.0034	0.0121	0	61.19
Model 4: Time-varying impulse response test for Net spillover for rBCTI						
($\Sigma\beta$)1	0.0023	0.0003	0.0018	0.003	0.015	1.3
($\Sigma\beta$)2	0.0023	0.0003	0.0017	0.003	0	18.25
($\Sigma\alpha$)1	0.007	0.0056	0.0037	0.0284	0	77.86
($\Sigma\alpha$)2	0.0051	0.0012	0.0035	0.008	0.8	20.63
(Σh)1	0.0076	0.0051	0.0039	0.021	0	55.85
(Σh)2	0.0057	0.0024	0.0034	0.0141	0	43.29
Model 5: Time-varying impulse response test for Net spillover for rSCFI						
($\Sigma\beta$)1	0.0022	0.0002	0.0018	0.0028	0.855	14.24
($\Sigma\beta$)2	0.0023	0.0003	0.0018	0.0029	0	3.22
($\Sigma\alpha$)1	0.0086	0.0088	0.0033	0.0399	0	92.9
($\Sigma\alpha$)2	0.0044	0.0009	0.003	0.0066	0.466	10.25
(Σh)1	0.0056	0.003	0.0034	0.01	0	20.23
(Σh)2	0.01	0.0097	0.0037	0.0305	0	52.47
Model 6: Time-varying impulse response test for Net spillover between rBDTI and rBDI						

($\Sigma\beta$)1	0.0023	0.0003	0.0019	0.0029	0	5.18
($\Sigma\beta$)2	0.0023	0.0003	0.0019	0.003	0.017	7.86
($\Sigma\alpha$)1	0.0092	0.0165	0.0032	0.0728	0	51.95
($\Sigma\alpha$)2	0.0038	0.0007	0.0027	0.0051	0	30.63
(Σh)1	0.0056	0.0017	0.0034	0.0098	0	60.3
(Σh)2	0.0061	0.0029	0.0035	0.0127	0	55.88

Model 7: Time-varying impulse response test for Net spillover between rBCTI and rBDI

($\Sigma\beta$)1	0.0023	0.0002	0.0018	0.0028	0.165	5.89
($\Sigma\beta$)2	0.0022	0.0003	0.0018	0.0028	0.152	7.4
($\Sigma\alpha$)1	0.0126	0.0201	0.0036	0.0776	0	98.54
($\Sigma\alpha$)2	0.004	0.0007	0.0028	0.0057	0	28
(Σh)1	0.0054	0.0014	0.0037	0.0094	0	49.35
(Σh)2	0.0297	0.0717	0.0032	0.2848	0	90.07

Model 8: Time-varying impulse response test for Net spillover between rBDTI and rBCTI

($\Sigma\beta$)1	0.0038	0.0063	0.0019	0.0152	0	26.79
($\Sigma\beta$)2	0.0027	0.0009	0.0019	0.0041	0	19.7
($\Sigma\alpha$)1	0.0131	0.0224	0.0034	0.0819	0	99.88
($\Sigma\alpha$)2	0.0041	0.0007	0.003	0.0056	0.68	17.59
(Σh)1	0.0058	0.0022	0.0035	0.01	0	35.66
(Σh)2	0.0073	0.0085	0.0034	0.0295	0	45.02

Model 9: Time-varying impulse response test for Net spillover between rBDI and rSCFI

($\Sigma\beta$)1	0.0023	0.0003	0.0019	0.003	0.869	6.09
($\Sigma\beta$)2	0.0022	0.0003	0.0018	0.0028	0.545	4.36
($\Sigma\alpha$)1	0.0073	0.0067	0.0036	0.0322	0	83.08
($\Sigma\alpha$)2	0.0033	0.0005	0.0025	0.0045	0	23.08
(Σh)1	0.0074	0.0069	0.0034	0.0349	0	58.54
(Σh)2	0.0064	0.0031	0.0033	0.0152	0	95.22

Model 10: Time-varying impulse response test for Net spillover between rBDTI and rSCFI

($\Sigma\beta$)1	0.0023	0.0003	0.0018	0.0029	0.002	3.59
($\Sigma\beta$)2	0.0022	0.0003	0.0018	0.0028	0.91	2
($\Sigma\alpha$)1	0.0069	0.0066	0.0036	0.0336	0	48.03
($\Sigma\alpha$)2	0.0037	0.0006	0.0028	0.0048	0	23.11
(Σh)1	0.0061	0.0053	0.0033	0.0203	0	45.38
(Σh)2	0.0053	0.0019	0.0032	0.0088	0	26.19

Model 11: Time-varying impulse response test for Net spillover between rBCTI and rSCFI

($\Sigma\beta$)1	0.0023	0.0003	0.0019	0.0029	0.592	4.24
($\Sigma\beta$)2	0.0023	0.0003	0.0018	0.0029	0.003	5.43
($\Sigma\alpha$)1	0.007	0.0056	0.0034	0.0268	0	56.03
($\Sigma\alpha$)2	0.0039	0.0007	0.0028	0.0054	0	18.27
(Σh)1	0.0096	0.0122	0.0035	0.0494	0	98.17
(Σh)2	0.006	0.0024	0.0035	0.0125	0	15.95

Appendix D: Directory of Flag of Convenience States and Protection and Indemnity (P&I) Clubs

Based on the ITF seafarers and the International Group of P&I Clubs, the countries that have been declared FOCs and the affiliated clubs are listed in Table D-1.

Table D-1 List of FOC States and principal P&I clubs in the group

FOC States			
Antigua and Barbuda	Equatorial Guinea	Marshall Islands	St Vincent
Bahamas	Faroe Islands	Mauritius	Sri Lanka
Barbados	French International Ship Registry (FIS)	Moldova	Tanzania (Zanzibar)
Belize	German International Ship Registry (GIS)	Mongolia	Togo
Bermuda	Georgia	Myanmar	Tonga
Bolivia	Gibraltar	North Korea	Vanuatu
Cameroon	Honduras	Palau	Cambodia (until 2016)
Cayman Islands	Jamaica	Panama	Netherlands Antilles (until 2010)
Comoros	Lebanon	San Marino	
Cook Islands	Liberia	São Tomé and Príncipe	
Curacao	Malta	Sierra Leone	
Cyprus	Madeira	St Kitts and Nevis	
Principal P&I clubs in the group			
American Steamship Owners Mutual Protection and Indemnity Association, Inc.		The Shipowners' Mutual Protection & Indemnity Association (Luxembourg)	
The Britannia Steam Ship Insurance Association Limited		Assuranceforeningen Skuld (Gjensidig)	
Gard P.&I. (Bermuda) Ltd		The Steamship Mutual Underwriting Association (Bermuda) Limited	
The Japan Ship Owners' Mutual Protection & Indemnity Association		Sveriges Ångfartygs Assurans Förening / The Swedish Club	
The London Steam-Ship Owners' Mutual Insurance Association Limited		The United Kingdom Mutual Steam Ship Assurance Association Limited	
NorthStandard Limited		The West of England Ship Owners Mutual Insurance Association (Luxembourg)	

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