國立成功大學
交通管理科學系碩士班

碩士論文

不同經濟景氣海運碳權之分配

Carbon Allowance Allocation in the Shipping Industry under Different Economic Activities

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摘要

本研究透過美國聯邦政府利率，定義景氣循環之繁榮、平穩及衰退。並透過景氣循環之結果，分析油輪、貨櫃船與散裝船之海運費率。接著，結合碳排限額和碳交易之概念，提出考慮景氣循環與船舶是否依據 EEDI 情境之模型，來優化海運碳權分配之問題，進而建議決策者最小化免費碳權分配，與海運公司最小化其成本效益比率之目標。結果顯示，海運費率在景氣繁榮下較高。在不同景氣下，船舶高航速行駛，燃油成本對整體營收之占比較高；若比較不同景氣，船舶於景氣衰退下，燃油成本對整體營收之占比較高。在不同碳交易價格方面，船舶於高碳交易價格，其碳排成本對整體營收之占比亦較高；若比較不同景氣，在衰退景氣下，無論是碳交易價格之高低，海運公司碳排成本對整體營收之占比皆較低。在碳權分配方面，在船舶依據 EEDI 與無依據 EEDI 之兩種情境，海運部門在景氣繁榮環境中，因其排放量遠高於碳排限額，故須購買較多碳權，唯在景氣衰退之環境下，有多餘碳權可出售。最後，在成本效益分析方面，海運公司於景氣繁榮下，成本效益比率較低，表示其成本佔整體營收較低；於景氣衰退下，其成本效益比率較高。若比較船舶依據 EEDI 與無依據 EEDI 兩種情境中，海運公司於前者情境中，可有效降低其成本。因此，本研究建議海運公司於景氣衰退之環境下，可以透過降低船速，減少其成本；此外，海運公司使用 EEDI 所規範之船舶，亦能達到降低船舶排放，與減少成本之功效。

關鍵字：碳權分配、油輪、貨櫃船、散裝船、景氣

Abstract

This study utilizes the Federal Fund Rate to identify three business cycles in the field of international shipping: prosperous, steady, and sluggish. Then by combining the data regarding emission caps and the trade mechanisms, this study proposes models which consider two different scenarios for shipping vessels depending on whether they are in keeping with the EEDI or not during the different business cycles based on carbon allowance allocation problems (CAAP) in the shipping sector. For the CAAP, the critical issues for the decision maker is to decide the free carbon allowance level α to achieve the emission target set by the Paris Agreement. This is critical for shipping companies which want to follow the allocated free carbon allowance to minimize their cost-benefit ratio (CBR). The results show that the shipping freight rates during prosperous business cycles are higher. In addition, vessels which travel at higher speeds use more of their total profits for fuel costs. When comparing during the different business cycles, the proportion spent on shipping is higher in the sluggish business cycles. When comparing different carbon trading prices, vessels travel at higher trading prices the proportion of the emission costs of the total profit is higher. When comparing shipping costs during the different business cycles, the proportion spent by shipping companies during the sluggish business cycles is higher. Regarding carbon allowance allocation, for vessels keeping within the EEDI scenarios and for those without, the shipping companies need to buy more carbon allowance in the prosperous business cycle because vessels emit more CO_2, while in the sluggish business cycle the shipping companies can sell their allowances. Finally, for the cost-benefit analysis, during the prosperous business cycle, the shipping companies' cost-benefit ratio (CBR) is lower, indicating their expenditures as a percentage of total profits are lower. While in the sluggish business cycle, their CBR is higher. When comparing two scenarios in which companies follow or do not follow the EEDI, it was found that shipping companies can save more costs in the former scenario. Therefore, this study suggests that in the sluggish business cycles, shipping companies can cut cost by reducing vessel speeds. In addition, if shipping companies deploy the vessels in keeping with the EEDI, they can reduce both vessel emissions and operation cost.

Keywords: carbon allowance allocation, tanker, container shipping, bulk carrier, economic activities

致謝

時光荏苒，回首學習期間，無疑是一趟充實且精彩的旅程。內心激昂澎湃之際，心中浮現的是無限的感謝。本論文得以順利付梓，我最要感謝的，是我的指導教授張瀞之老師。感謝老師對我生活上與課業上滿滿的提攜與愛護，更感謝老師不遺餘力地協助我完成論文寫作。從一開始研究方向的擬定、到研究方法的建構、實證結果之問題釐清，到最後論文的結論、建議與定稿，那些頻頻往返於老師研究室與Lab 204-1 的日子，將會成為我最甜美與最難以割捨的回憶。此外，也感謝沈宗緯老師及謝金原院長兩位口委老師，在百忙之中撥冗擔任我論文口試委員，並給予我論文上諸多寶貴的建議，使得本論文更臻完整與嚴謹。

每次的啟程，都要記得自己的初衷與決定。回想當初念研究所的決定，是要磨念自己的學識、內涵與能力。經過兩年半充實的時光，從參與能測中心之研究、15th IAEE 歐洲研討會與 47th WDSI 研討會、8th CCP 聚陽小組，到擔任 5th 交管所所學會會長、系辦工讀生與財管與國貿課之課堂助教等，很幸運地我獲得的比想像中更多且豐富，也結交了許多朋友。感謝交管系每位老師廣博精深的學識涵養，讓我能深入探索學術領域的知識風景。感謝 Lab204-1 大家：明禧、又肇、有聞、Mbuso、昱偉、竺瑾、亦萱、佳翰的幫助，也給我許多鼓勵和信心。感謝 QQ 家兩位室友：欣儀和亭昀，在生活與課業上互相勉勵，還有一起熬夜瘋世足。感謝台南ㄘㄘ的同窗揖安、廷毅、令佳、宜庭、佳汎和雨萱，在研究生活的互相分享與勉勵。感謝 Allen、David 協助論文英文部分的校稿。感謝系辦助理：李助教、雅婷姊跟莊先生，在生活上的協助。感謝其他 Lab 的同學、學長姐、學弟妹們，還有身邊協助我許多的朋友，每次和大家的餐敘與聊天，都是我成長的動力與美好時光。

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誌於成大交管 204-1 研究室
中華民國 107 年 6 月

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Chapter 1 Introduction

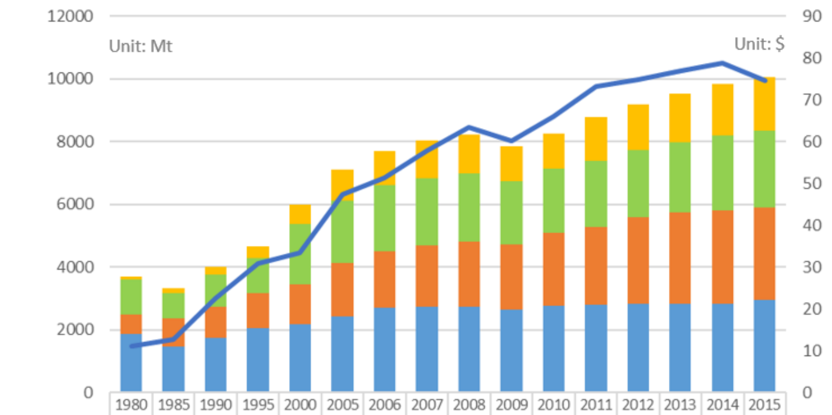
This chapter is divided into four parts. The first is research background, followed by research motivation, research objectives, and finally research flow.

1.1 Research Background

Based on the UNCTAD data for 2016, world seaborne trade volumes reached a new record and were estimated to have exceeded 10 billion tons in 2015, which was an increase of 1.6 percent over the volume in 2014 (Figure 1.1). At the same time, the heavy reliance on maritime transport translated into severe emissions of seaborne pollutants and greenhouse gases (GHG). According to ICCT (2017), international shipping emitted 812 million tons of CO_2, which was estimated at 2.6 percent of the world's total emissions.

According to UNCTAD (2017) as January 1, 2017, in total, the world seaborne fleet consisted of 93,161 vessels and reached 1.86 billion dwt. In addition, the sum of the top two seaborne fleet sectors, dry bulk carriers (42.8%) and oil tankers (28.7%) account for over 60% of dead-weight tonnage, followed by container ships (13.2%), other (11.3%), and general cargo ships (4%), as shown in Figure 1.2. However, among the seaborne fleet sectors, container ships emitted the highest CO_2 levels, accounting for 23% of total emissions, followed by bulk carriers and tankers with 19% and 13% of total emissions, respectively (ICCT, 2017). This is shown in Figure 1.3.

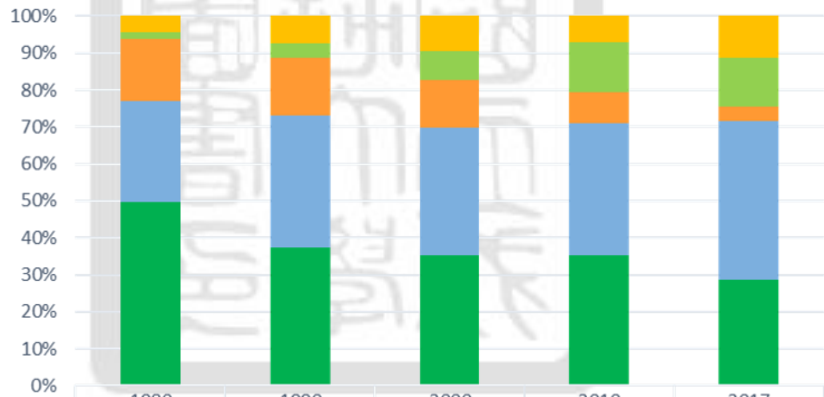
The Paris Agreement was adopted by the 195 members of United Nations (UN) under the Framework Convention on Climate Change (UNFCCC) on December 12, 2015 and was signed by 171 members on April 22, 2016. The main goal of the Paris Agreement is to keep the global average temperature from rising 2°C above pre-industrial levels, ideally limiting the temperature increase to 1.5°C. However, as the Paris Agreement under the UNFCCC does not include emissions from international shipping, the IMO and the UNFCCC have a critically important role for meeting these goals. The Marine Environment Protection Committee (MEPC) has been entrusted with finding solutions related to environmental issues in the international shipping sector within the IMO.



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Containers	102	152	234	371	598	1001	1076	1193	1249	1127	1128	1393	1464	1544	1640	1687
Dry cargo other than main bulk commodities	1123	819	1031	1125	1928	1975	2112	2141	2173	2004	2022	2112	2150	2218	2393	2463
Main bulk commodities	608	900	988	1105	1295	1711	1814	1953	2065	2085	2335	2486	2742	2923	2985	2951
Oil and gas	1871	1459	1755	2050	2163	2422	2698	2747	2742	2642	2772	2794	2841	2829	2825	2947
GDP (current US$)	11.11	12.68	22.58	30.84	33.54	47.39	51.3	57.79	63.39	60.09	65.91	73.24	74.8	76.93	78.87	74.51

Figure 1.1 International seaborne trade and GDP, selected years

Source: UNCTAD (2016)



	1980	1990	2000	2010	2017
Other	4.5	7.5	9.4	7.2	11.3
Container ship	1.6	3.9	8	13.3	13.2
Gerneral cargo ship	17	15.6	12.7	8.5	4
Dry bulk carrier	27.2	35.6	34.6	35.8	42.8
Oil tanker	49.7	37.4	35.4	35.3	28.7

Figure 1.2 World fleet by principal vessel type, 1980–2017 (share of dead-weight)

Source: UNCTAD (2017)

The MEPC has already adopted the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) to address issues related to GHG emissions. The former provides compulsory energy efficiency standards for ships built after 2013, and the latter requires ships to develop a plan to monitor and possibly improve their energy efficiency. However, despite the EEDI, the SEEMP and market forces which have reduced emissions through efficiency improvements, the GHG emission from the international shipping industry is still projected to increase by 20% to 120% (Figure 1.4) by 2050 due to global economic growth and increased fossil fuel demand. These projections will make it extremely difficult to reach the Paris Agreements goals for emission reduction (IMO, 2015).

The EU emissions trading system (EU ETS) was set up in 2005 as the world's first major carbon market, and accounts for over 75% of international carbon trading. The goal of the EU ETS is to reach the GHG reduction goals set by the Kyoto Protocol. It works on the "cap and trade principle," through which a cap is set at a certain amount GHG that can be emitted by the system. By staying under this cap, companies can trade their unused emission allowances depending on their needs. The cap is designed to decrease over time to lessen the total emissions, a key part of the EU's strategy to reduce GHG emissions (European Commission, 2017).

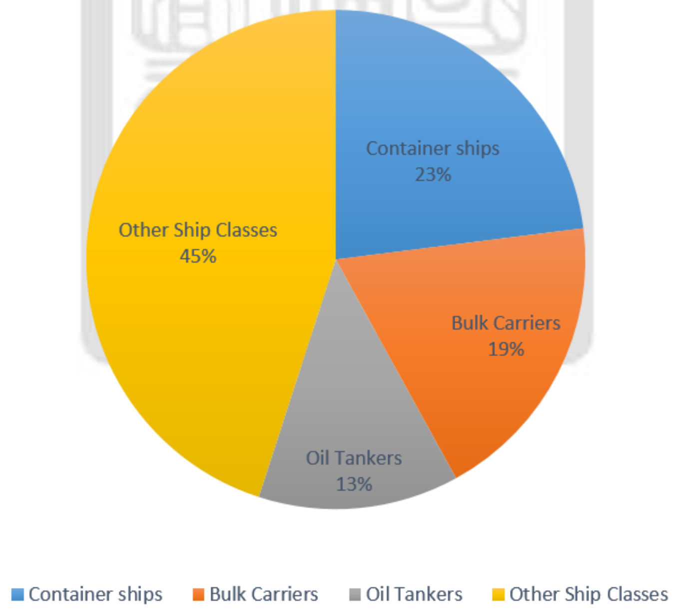


Figure 1.3 Share of CO_2 emissions by ship class, 2013–2015

Source: ICCT (2017)

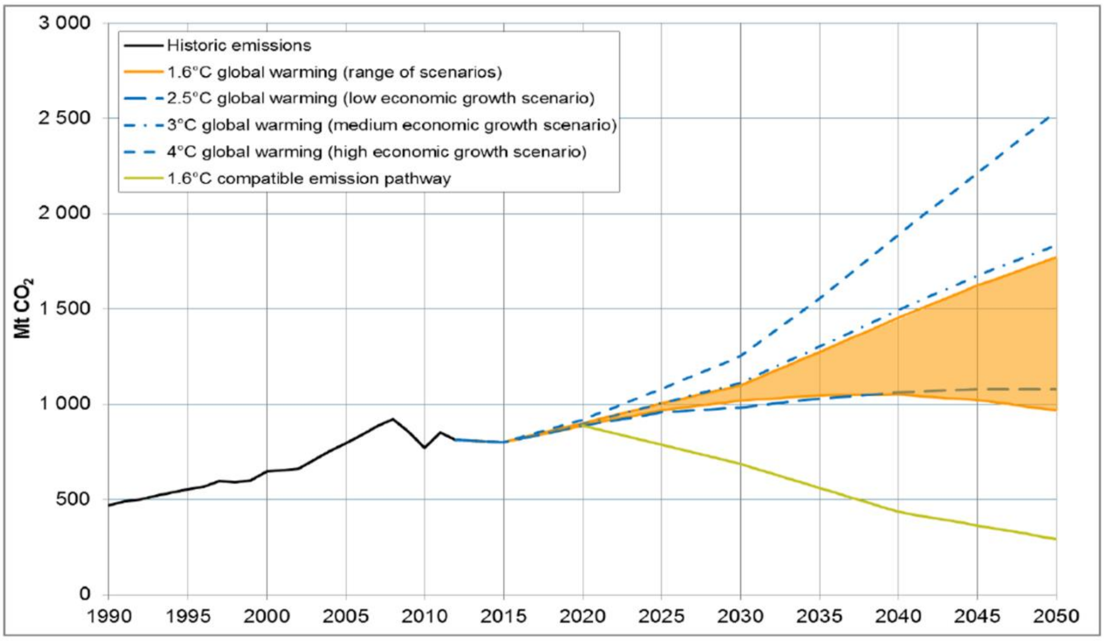


Figure 1.4 Historical and projected CO_2 emissions from shipping sector

Source: IMO 2015

The shipping industry carbon allowance allocation problem (CAAP) uses a complicated system negotiated between the decision maker and the shipping companies. Carbon allowance refers to the amounts of free and non-free carbon that the decision maker has authorized to be emitted into the atmosphere. If the free allowance of a shipping company is less than actual emissions, they need to buy additional emissions permission on the carbon trading market (i.e. the EU ETS). Thus, deciding the adequate initial allowance allocation is an important task for the decision makers.

According to the European Commission (2017), EU ETS is used by 31 countries, including all 28 EU countries plus Iceland, Liechtenstein, and Norway. This system limits emissions from more than 11,000 heavy energy-using installations and transportation systems, including airlines, between these countries. ETS brings flexibility that ensures emission reduction progresses smoothly while also promoting investment and development in clean and low-carbon technologies. Based on ETS requirements, EU Member States, working with the IMO, agreed to the establishment of market-based mechanisms (MBMs) in July 2011. These MBMs includes an emission trading schemes (ETS) and a global GHG fund. The overall goal is to tackle the problems of GHG emissions from international shipping (IMO, 2011). At the same time the European Parliament has been pushing the IMO to take more aggressive action and has stated that if no new agreement is proposed by the end of 2021, then the international shipping sector should be included under the EU ETS (European Parliament, 2017).

Apart from the environmental issues of the shipping industry, it must be remembered that the development of the seaborne trade is crucial to the world economy. According to the Word Bank's (2017) global GDP data from 1986 to 2016, the world economy has generally grown steadily over this period (Figure 1.5), except for 1997-1998 (the Asian Financial Crisis), 2001 (the internet Bubble), and 2009 (Subprime mortgage crisis), as well as a slowdown from 2012 to 2015 (The European debt crisis). These phenomena reflect the existence of business cycles in the world economy. Figure 1.1 illustrates the interaction between global GDP and seaborne trade; different business cycles, categorized as prosperous, steady, or sluggish, will also heavily influence the performance of seaborne trade (i.e. Subprime mortgage crisis of 2009). Thus, this study will focus on two interrelated aspects of the international shipping industry: environmental sustainability and the business cycles of the world economy.

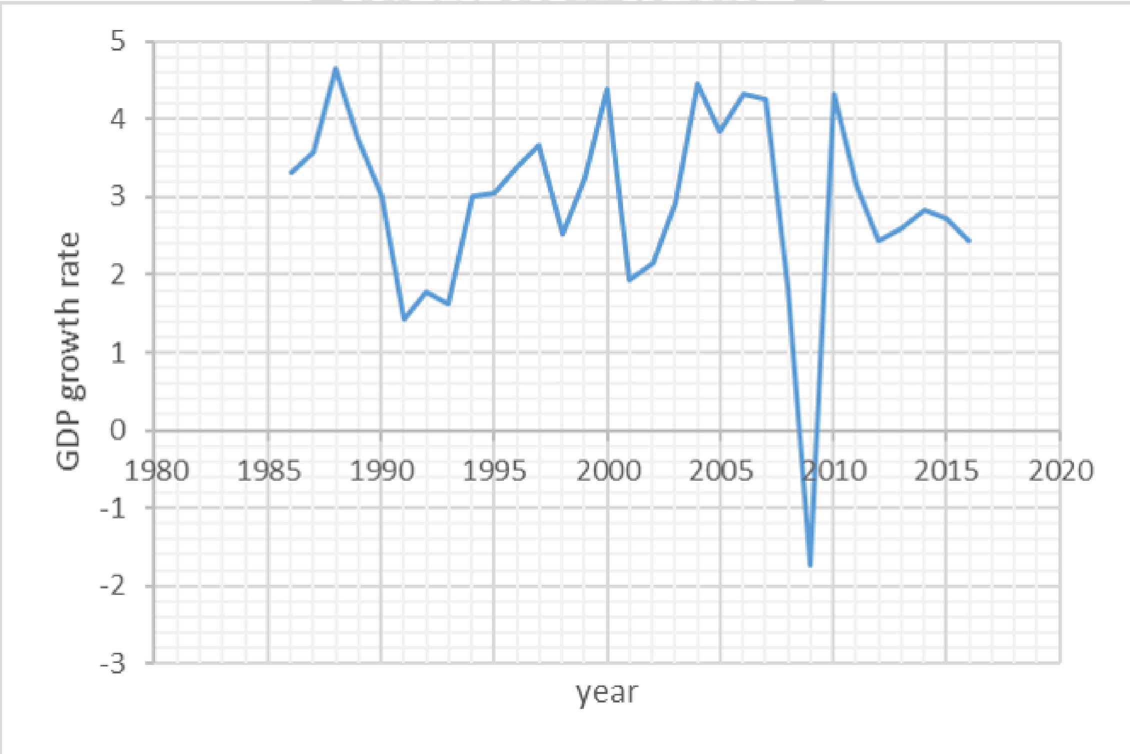


Figure 1.5 Global GDP (current US$) from 1986 to 2016

Source: World Bank (2017)

1.2 Research Motivation

World seaborne trade is highly correlated with the world economy, namely the business cycles of the world economy influence the world's seaborne trade. From an environmental viewpoint, due to the stable growth of seaborne trade, the GHG emissions from the international shipping industry are projected to increase by 250 percent by 2050 (OCED INSIGHT, 2016).

Unfortunately for the regulation of their emissions, the Kyoto Protocol and the Paris Agreement do not include controls for the international shipping industry in the member countries' national inventories, but instead left it to the IMO to deal with emission issues in this sector. Thus, pushed by the EU, a department within the IMO known as the MEPC has considered the implementation of MBMs such as a maritime industry ETS. However, when implementing a maritime transport ETS, the carbon allowance allocation problem (CAAP) is a priority issue which must be dealt with. Poorly informed decisions regarding allowances may not only fail to achieve GHG emission reduction targets but could lead to capacity supply shortages or even shipping industry downturns.

Therefore, this study will first analyze the relationship between the business cycles of the world economy and global seaborne trade and then utilize the Federal Fund Rate to identify business cycles as prosperous, steady and sluggish. This data will then be used to find an optimal solution for the shipping industry CAAP, after which, the impact of the CAAP on the shipping industry will be analyzed.

1.3 Research Objectives

Based on the above, the purposes of this paper are as follows:

1. Utilize the Federal Fund rate to identify business cycles as prosperous, steady and sluggish, and then examine how this relates to the shipping freight rates of tankers, container ships, and bulk carriers.
2. Analyze the proportion of fuel costs at different vessel speeds and in different business cycles to total profit, and then analyze carbon costs at different carbon trading prices and in different business cycles as a proportion of the total profit.
3. Propose a model which considers different business cycles to solve the shipping CAAP based on the target of the Paris Agreement. This model will focus on two parameters: decision maker's minimizing free carbon allocations and the shipping companies' optimal decision mode to minimize their cost-benefit ratio (BCR).

1.4 Research Flow

The research flowchart is shown in Figure 1.6. There are six stages in this study. The task of each stage is as follows:

1. **Background and Motivation**: List objectives, introduce trends of world economy, seaborn trade, and environmental issues.
2. **Problem Statement**: Based on the research background and motivation, define the explicit problem and research scope of this study.
3. **Literature Review**: This section will review the literature related to the shipping companies' decision making in regards to the carbon emissions trading system, the business cycle of the shipping industry and carbon allowance allocation problems in transportation, respectively.
4. **Model Formulation**: This section presents data description, research assumptions, and models for the CAAP.
5. **Empirical Analysis**: According to the hypotheses from the preceding section, the relationship between economic conditions and shipping industry CAAP will be analyzed. The proposed model will be amended if necessary.
6. **Conclusions and Suggestions**: Based on the empirical result, conclusions and suggestions which apply to the real maritime transport CAEEP are drawn.

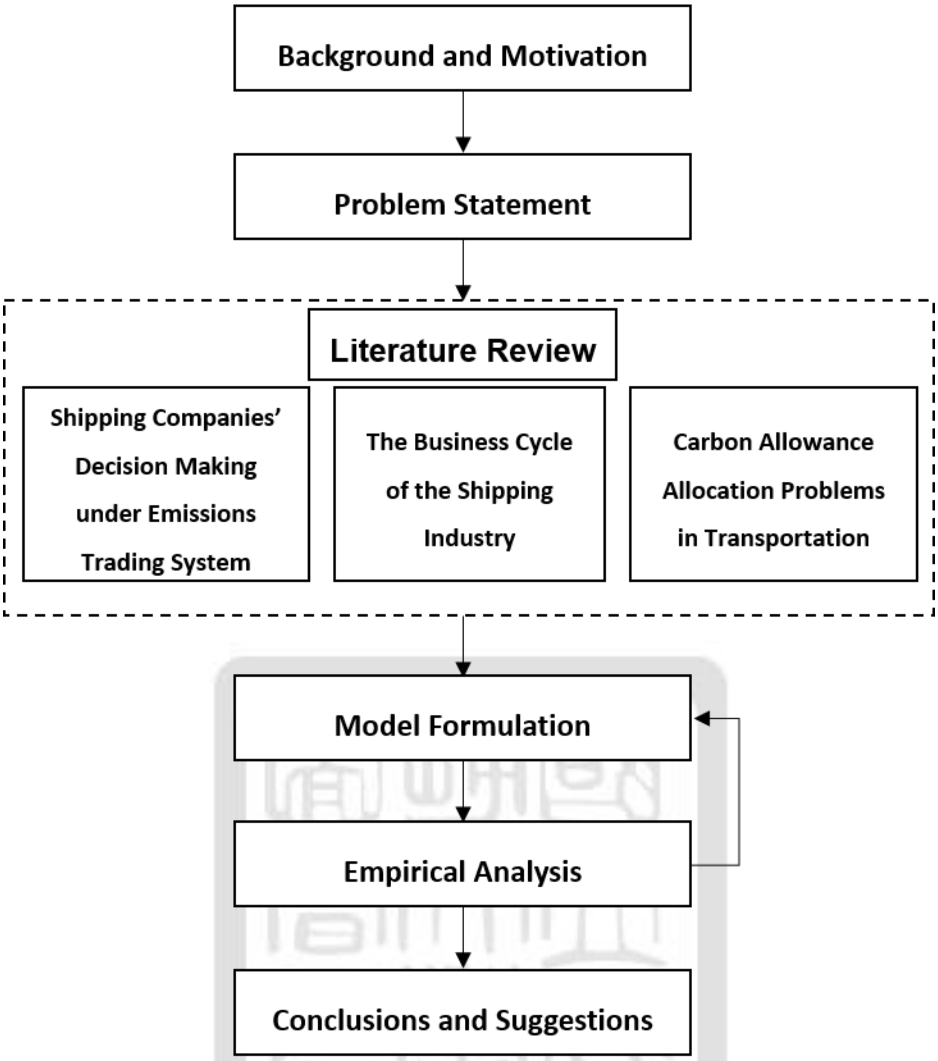


Figure 1.6 Research chart

Chapter 2 Literature Review

This chapter will review literature related to three different issues: first, the shipping companies' decision making in regards to the carbon emissions trading system; second, the business cycle of the shipping industry; third, carbon allowance allocation problems in transportation. The chapter concludes with a summary.

2.1 Shipping Companies' Decision Making under Emissions Trading System

Shi et al. (2013) predicted the potential programs from both the technical and the operational perspective and applied cost-benefit-analysis to assess the feasibility of GHG emissions trading (ET) for the Chinese shipping industry. Their results demonstrated that (1) the container sector emitted more CO_2 than the bulk sector, thus, it is possible that shipping companies between two sectors could have mutually beneficial transactions.; (2) CO_2 emission from shipping are relatively low compared with transport sectors such as road and rail, suggesting it is possible to work with other transport sectors to get emission quota.; (3) According to the result of cost-benefit analysis, the shipping sector will benefit from getting a large enough emissions quota as well as saving transportation cost by using the multimodal transport mode, however, this kind of reduction can only be practiced in inland waterway shipping. In addition, it is also not easy to conduct multimodal transport in mainland China.

Dessens et al. (2014) combine the E3MG and global atmospheric model, p-TOMCAT, to explore the effects of decarbonizing international shipping and aviation on climate mitigation and air pollution. The former assesses the impact of the global emission trading scheme (GETS) on international aviation and shipping GHG emissions between 2000 to 2050, and latter examines the air pollution and climate effect of GETS. The results show that GETS reduces the CO_2 and non-CO_2 emissions of international shipping and aviation by up to 65% compared to the business as usual scenario (BAU scenario), in which CO_2 and NO_X emissions increase by 367% and 49%, respectively between 2000 and 2050. However, there is a smaller increase of 68% in CO_2 emissions and a 40% reduction in NO_X in the GETS scenario. Furthermore, despite the 7% reduction in demand for international aviation and shipping, due to the increase in investment in R&D, GETS will also result in a 1.9% increase in global GDP.

Hermeling et al. (2015) use the Basic World Input-Output Database computable general equilibrium model (Basic WIOD CGE model) to evaluate the effect of a European maritime emission trading scheme (EUMETS) aimed at reducing the emissions of the international shipping industry from both the economic and legal points of view. The results show that from the economic viewpoint, since shipping routes are mainly within EU territorial waters, limiting the scope of a maritime ETS provokes distortions and puts a higher burden on routes featuring a high share of regulated emissions as well as impeding cost-efficiency in emission reduction among regulated ships. Therefore, policy makers should work on an international agreement in emission reduction in the shipping sector rather than resorting to a regional (European) scheme. From a legal viewpoint, the ETS is not compatible with international law due to the lack of international legislative jurisdiction; the World trade law is infringed, while IMO would not have its acts impeded in the market-based mechanisms (MBM) against global warming.

Wang et al. (2015) analyze the benchmarks for an open emissions trading scheme (ETS) and compare it to a Maritime only ETS (METS) for international shipping. They find that for both ETS and/or METS, ship speed, carrier output and fuel consumption all decrease for both the container and bulk shipping sectors. However, under the ETS, the reduction in shipping volume will be more severe when shipping costs are higher, while under the METS, the emission reduction objective will not be altered by the trade of permits. However, the market structure of the METS will have a more significant impact than an open ETS. In addition, according to the calibration results which predict that the container sector under the METS will buy emission permits from the dry bulk side, one sector will cause spill-over effects on the other sector when the METS has a high degree of competition. Specifically, when trading is more competitive, the equilibrium permit price will rise.

Although many studies have investigated the impact of emission policy on the maritime sector, there is little discussion of the impact on ship operations and the costs. Koesler et al. (2015) assesses the potential implications of a maritime emission trading scheme (ETS) on the organization and operations of shipping companies with a case study interview approach. The interview questions can be divided into five topics: (1)General design issues of a possible regulation; (2)Supply of allowances – Basic allocation and trading of allowances; (3)Monitoring, reporting, verification of emissions; (4)Carbon management and mitigation; (5)General aspects. The results show that since the international shipping industry is known to be a highly cyclical sector, within an ETS set a fixed amount of supplied emission allowances, variation and uncertainty in the demand for allowances can strongly affect the price of emissions. In addition, the linking and banking of emission allowances should only be permitted under strict situation to avoid the risk of some firms never actually reducing emissions. However, maritime ETS does have the potential to push the international shipping sector towards cost-efficient emission reduction practices.

2.2 The Business Cycle of the Shipping Industry

Kavussanos and Alizadeh (2001) examined patterns in seasonal (deterministic and stochastic) dry bulk freight markets, and measured and compared freight rates for different vessel sizes (Capesize, Panamax and Handysize), contract duration (spot, 1-year and 3-year charters) and market conditions (peaks and troughs). Their results reveal that shipping freight rates exhibit pronounced seasonal variations. In addition, seasonal fluctuations in dry bulk freight market are sharper and more obvious during market recovery. Furthermore, spot rates for larger vessels are prone to higher seasonal fluctuations than for smaller vessels, while differences in seasonal fluctuation between sectors are eliminated as the contract duration increases. Thus, it is suggested that during the peak season, shipowners should maximize their long-term revenues by entering into the time-charter market; when freight rates are expected to fall, shipowners could put their ships in dry-dock.

Slack and Gouvernal (2011) have investigated linear shipping freight rates (including base rates and surcharges) and compared the surcharge differences for terminal handling charges (THC), bunker adjustment factor (BAF), currency adjustment factor (CAF), among others. They found that a growing number of surcharges are being applied to the shipping routes, which has changed and complicated the nature of freight rates. They also found that shipping distance and BAF surcharges are positively related for the same period of time. During the world economic crisis, ocean freight rates fell proportionately to surcharges because of the lack of trading volume.

Dai et al. (2015) applied the BEKK parameterization of the multi-variate GARCH model (BEKK GARCH) to investigate the volatility transmission effects across the vessel market (including the newly built and secondhand vessel markets) and the freight market for global dry bulk shipping. They found a pronounced bilateral and unidirectional interaction between the freight rate market and vessel market. In addition, after the 2008 world financial crisis, the global dry bulk shipping market was totally distorted, with the secondhand market causing a spillover into the freight market.

Tsouknidis (2016) adopted a DCC-GARCH model using the volatility index developed by Diebold and Yilmaz (2012, 2009) to capture the effects of dynamic volatility spillover within and between the dry-bulk and tanker freight markets. The volatility spillover index measures include the total spillover index, the directional spillover effects on each market, the net spillover effect, and the net pairwise spillover effect. The results show that there is time-varying volatility spillovers across the shipping freight markets, and these were larger during and after the global financial crisis. In addition, compared to the dry-bulk market, volatility spillovers within the tanker market are larger, with smaller vessels carrying volatility spillovers to larger vessels during the global financial crisis.

2.3 Carbon Allowance Allocation Problems in Transportation

Xu et al. (2016) proposed a bi-level multi-objective model for the air passenger transport carbon allowance allocation problem (CAAP) using an interactive fuzzy logic controlled genetic algorithm (IFLC-GA). This system has two levels: the upper level is a government level that attempts to minimize the maximal carbon intensity and maximize the minimal allocation satisfaction, while the lower level is the airlines level that focuses on their maximal economic benefit with optimal aircraft selection decisions. The results show that the cap and trade mechanism as well as carbon allowance allocations have significant effects on mitigating carbon emission. In addition, the results also suggest that the free emission level should be between 85% and 95%. This is a vital part of low-carbon air passenger transport management.

Qiu et al. (2017) combined a cap-and-trade mechanism and a carbon tax mechanism to create a mixed mechanism that adopts a bi-level multi-objective model to seek the optimal solution for the air passenger transport carbon allowance allocation problem (APTCAAP). Since an interactive evolutionary mechanism is useful for finding the best solution for the multi-objective bi-level problem, a bi-level interactive genetic algorithm (BIGA) was designed to find the most balanced solution for the proposed model. According to the computational results, a mixed mechanism can greatly help reduce carbon emissions for air passenger transport, and can play an important role in the low carbon planning management.

Zhu et al. (2018) have proposed using a stochastic programming model to investigate the potential impact of a maritime emission trading system (METS) on containership operator's CO_2 emission reduction and fleet renewal strategies. In total, 12 scenarios using different carbon allocation methods and varied bunker and CO_2 prices are and compared. In addition, the scenario settings of the carbon allowance is based on the EU ETS standards for the aviation industry, in which 82% of the allowance is granted for free, 15% is auctioned, and the remaining 3% is flexible balance per year. The results show that METS should encourage containership operators to deploy more energy-carbon-efficient ships, and even lay up less energy-efficient ships. In addition, when the bunker price is higher, there is a greater reductions in CO_2 emissions. However, even when the bunker price is high, the CO_2 price does not seem to be a key factor in compelling operators to reduce bunker consumption. In fact, tightening the allocation of the free CO_2 allowance only has a significant impact on emission reduction when there is a high bunker price.

2.4 Summary

The shipping industry is a key player in the world economy. In the dry bulk and tanker markets, a number of studies investigated the business cycles of the shipping industry by modeling the volatility of shipping freight rate and exploring potential volatility spillovers across different freight rate segments and sub-segments (Kavussanos and Alizadeh, 2001; Dai et al., 2015; Tsouknids, 2016). When studying the container market, previous literature has focused on comparing the surcharges to the base rates, but few studies have utilized the international index to define the business cycle of global shipping.

The shipping emissions trading system (ETS) has proven to be a powerful motivator for emissions reduction; as the carbon trading prices get higher, there is an increased reduction in carbon emissions (Dessens et al., 2014; Wang et al., 2015; Koesler et al., 2015; Xu et al., 2016; Qiu et al., 2017; M. Zhu et al., 2018). However, when the trading price level is too high, it leads to a significantly negative impact on the world economy. In addition, the gap between the supply and demand in the carbon allowance allocation sectors leads to critical trade-offs in the carbon allowance allocation problem (CAAP) in maritime transport. However, the CAAP is an important issue for implementing ETS in the international shipping industry; a poorly estimated allowance may not only fail to achieve GHG emission reduction targets but may also lead to capacity supply shortages or even shipping industry downturns. Previous related literature has focused on the relationship between the implementation of ETS and emission reduction in the international shipping industry (Dessens et al., 2014; Koesler et al., 2015; Wang et al., 2015), as well as the shipping companies' cost-benefit (Zhu. 2018). Literature regarding the interaction of carbon allocation within the shipping industry, however, tends to focus on spill-over effects (Shi et al., 2013; Wang et al., 2015). Only a few studies have applied the EU standard for the aviation industry when investigating the potential impact of the shipping industry on CO_2 emission reduction (Zhu. 2018) or have analyzed the optimal free carbon allowance of the CAAP for air passenger transport management under the ETS (Qiu et al., 2017; Xu et al., 2016). There is a distinct lack of research investigating the optimal free carbon allowance for the CAAP in the shipping industry based on the Paris Agreement emission targets.

To help fill this gap, this study utilizes the Federal Fund Rate to identify three business cycles as prosperous, steady and sluggish and then proposes models which take business cycles into consideration when allocating optimal free carbon allowances and measuring the shipping companies' cost-benefits against the Paris Agreement stipulations. The summary of the literature review in this study is listed in Table 2.1.

Table 2.1 The summary of the literature review

Research direction	Author (year)	Research Topics	Methodology
2.1 The Shipping Companies' Decision Making under Carbon Emissions Trading System	Shi et al. (2013)	Actions applied by Chinese shipping companies under greenhouse gas emissions trading scheme.	Intergrated mathematical modelling, Cost-benefit-analysis
	Dessens et al. (2014)	Effects of decarbonising international shipping and aviation on climate mitigation and air pollution.	E3MG model, Global atmospheric model, and p-TOMCAT,
	Wang et al. (2015)	Modeling the impacts of alternative emission trading schemes on international shipping.	Economic modeling
	Koesler et al. (2015)	Course set for a cap? A case study among ship operators on a maritime ETS.	Case study interview approach
2.2 The Business Cycle of the Shipping Industry	Kavussanos and Alizadeh (2001)	Seasonality patterns in dry bulk shipping spot and time charter freight rates.	ARIMA and VAR model
	Slack and Gouvernal (2011)	Container freight rates and the role of surcharges	Case study
	Dai et al. (2015)	An empirical analysis of freight rate and vessel price volatility transmission in global dry bulk shipping market.	BEKK parameterization of the multi-variate GARCH model (BEKK GARCH)
	Tsouknidis (2016)	Dynamic volatility spillovers across shipping freight markets	Multivariate DCC-GARCH model

Table 2.1 The summary of the literature review

2.3 Carbon Allowance Allocation Problems in Transportation	Xu et al. (2016)	Carbon allowance allocation with cap and trade mechanism in air passenger transport.	Bi-level multi-objective model, Interactive fuzzy logic controlled genetic algorithm (IFLC-GA)
	Qiu et al. (2017)	Carbon allowance allocation with a mixed mechanism in air passenger transport.	Bi-level interactive genetic algorithm (BIGA)
	Zhu et al (2018)	Impact of maritime emissions trading system on fleet deployment and mitigation of CO_2 emission	Stochastic programming model

Chapter 3 Research Methodology

This chapter is divided into three parts. The first part is a description of the data; the second part describes the notation and the models used for the CAAP in the shipping sector, and final part is the summary.

3.1 Data Description

3.1.1 Vessels' Data

The relationship between fuel consumption and vessel speed is often approximated as a cube, indicating that when the vessel speed increases one knot, it produces about three times the emissions. Based on Figure 1.3, the proportion of the CO_2 emissions in the shipping sector for container ships, bulk carriers, and tankers are 23%, 19% and 13% respectively, which covers nearly 55% of the total emission. Hence, to provide more practical and comprehensive results, this study chooses the best representative vessel types as the research target for tankers, container ships and bulk carriers.

3.1.1.1 Tanker

Compared with 2014, the global crude oil trade in 2015 increased 3.8% and is estimated to have reached 1.77 billion tons, accounting for more than half of tanker trade (55%), followed by refined petroleum products with 1.17 billion tons (37%) and natural gas with 338.3 billion cubic meters (8%), which can be seen in Figure 3.1. The top three oil importers are China, America, and India.

Since China imports the most oil, the WAF - China route is used as the research route for tankers (Figure 3.2). The route is estimated to be 23,548 nm, departing from Ningbo, China and finally arriving in Bonny Offshore, Nigeria. In addition, the 260,000 mt VLCC vessel is deployed in this route, and the sailing time is estimated to be 70 days.

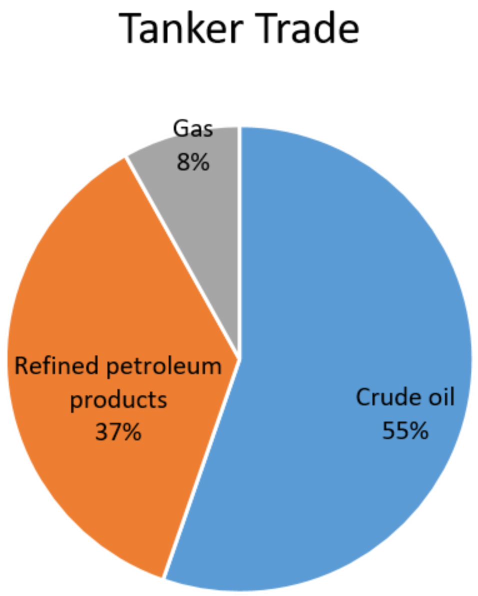


Figure 3.1 Percentage share of major trade for tankers

Source: UNCTAD (2015)

Figure 3.2 WAF - China tanker shipping route

Source: Ports.com (2017)

3.1.1.2 Container Ships

Based on UNCAD data, global containerized trade increased to a 3.1% faster rate in 2016 as compared with 2015, which is mainly due the recovery in Asian-European trade and the continuing growth in China's demand (UNCTAD, 2017). The Ocean Alliance was proposed by the COSCO Container Lines and was founded on April 20, 2017. The members of the Ocean Alliance include COSCO Container Lines, CMA CGM, the Evergreen Line, and the Orient Overseas Container Line (which merged with COSCO), currently account for most of the market share in global container capacity.

The Asia-Northern Europe route is the biggest trade route of the Ocean alliance, with 33% market share, as shown in Figure 3.3 (CMA CGM, 2017). Thus, this study applies the AEU2 as the main research route, with 186,470 mt ULCV vessels, for which the total distance and sailing days are approximately 24,978 nm and 52 days, departing from Tianjin, China and arriving at Le Harve, France. In addition, the AEU2 route also calls at Pusan - Qindao - Shanghai - Ningbo - Yantian - Singapore - Algeciraas - Southampton - Dunkirk - Hamburg - Rotterdam - Zeebrugge – Le Havre - Khor Fakkan - Port Kelang - Xiamen, as shown in Figure 3.4 (COSCO, 2017).

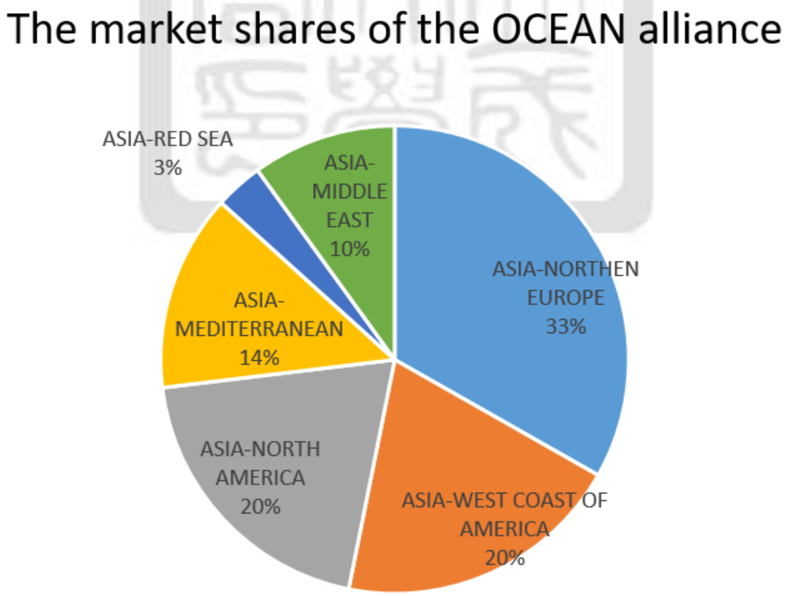


Figure 3.3 The maket shares of the Ocean Alliance

Source: CMA CGM (2017)

Figure 3.4 AEU2 container shipping route

Source: COSCO (2017)

3.1.1.3 Dry Bulk Carrier

In the dry bulk market, the five major bulk cargos are iron ore, coal, grain, bauxite/alumina, and phosphate. The market share of both iron ore and coal make up 80% of bulk cargo, as can be seen in Figure 3.5. China imports the most dry bulk goods, such as iron ore and coal, imported mainly from Brazil. Thus, the bulk carrier route from Qingdao to Tubarao using Capesize dry bulk carriers are adopted as the benchmark for this study, with a shipping route of approximate 27,228 nm over 81 sailing days, as shown in Figure 3.6.

The characteristics of the different vessel types, including tankers, container ships and bulk carriers, used in this study are presented in Table 3.1.

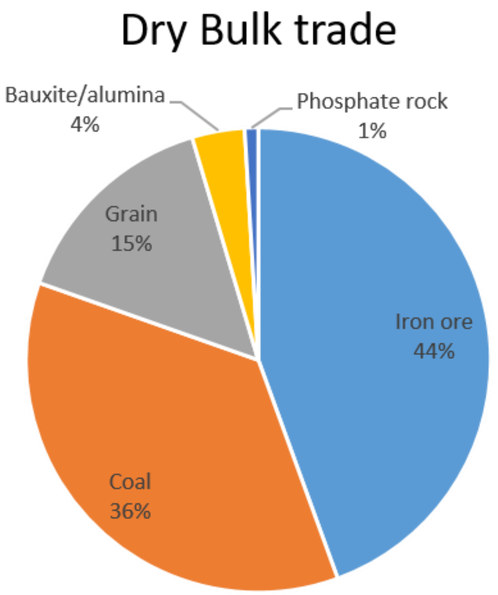


Figure 3.5 Percentage share of major trade in dry bulk cargo

Source: UNCAD (2017)

Figure 3.6 Qingdao - Tubarao dry bulk shipping route

Source: Ports.com (2017)

Table 3.1 The characteristic of different vessel type in this study

Vessel type Characteristic	Tanker VLCC	Container Ship ULCV	Dry Bulk Carrier Capesize
Deadweight (mt)	260,000	186,470 (16,022 TEU)	207,812
Design speed (knots)	15.9	25	14.7
Steaming Days	70 (at 14 knots speed)	52 (at 20 knots speed)	81 (at 14 knots speed)
Distance (nm)	23,548	24,978	27,228
Route	Ningbo to Bonny Offshore	Far East to North Europe	Qingdao to Tubarao
Route Name	WAF - China	AEU2	–

Source: (Lorentzen & Stemoco, 2015; MAN Diesel & Turbo, 2014; marine insight, 2017; Marine Traffic, 2017; Tankers International, 2017; Wahl & Kristoffersen, 2012)

3.1.2 Business Cycle of Shipping Industry

Variables for defining business cycles include Federal Fund Rate, bulk freight rate (NHH, 2014), China Containerized Freight Index (MacroMircro, 2018), and tanker freight rate (NHH, 2013). The monthly data of the Federal Fund Rate include 360 observations taken from January 1987 to December 2017. Freight data for tankers, containers, and bulks are from 2000 to 2013 (tankers), 1988 to 2017 (containers), and 1999 to 2014 (bulk carriers), respectively. The time periods listed above are significantly larger than 6–7 years, which is the typical length of a shipping business cycle (Stopford, 2009).

3.1.3 Carbon Trading Price

The initial carbon price (*IP*) is according to the MARKETS INSIDER (2018) data, which includes daily data from the 26th of October 2009 to the 2nd of March 2018 for a total of 1,744 observations.

3.1.4 Caps on CO_2 Emissions

The mitigation target of the Paris Agreement is to reduce the CO_2 emissions of the shipping sector by at least 40% by 2050 as compared to 2005 levels (European Parliament, 2017). In this study, the emission mitigation target is set to reduce emissions by 50% by 2050. The mitigation data used in the calculations used in this research is initially based on the data given in Figure 1.3, clarifying the share of CO_2 emission for international shipping by ship class. Then, according to the actual emission data from OECD (2010), Eide et al. (2007), IMO (2015), and ICCT (2017), the mitigation targets for specific periods can be set.

3.1.5 Research Assumptions

Before constructing models for the maritime transport CAAP, the following two assumptions were adopted:

(1) CAAP is a highly complicated, non-deterministic polynomial-time hard (NP-hard) system. Therefore, to simply the calculations for container ships, a shipping route with a single origin and single destination is used.

(2) Both decision makers and shipping company sides behave rationally and with a full understanding of their objectives and the inherent constraints. In addition, to ensure completeness of the carbon trading market, the shipping companies buying or selling of the allowances on the market, if there are free allowances, will be inconsistent with the actual emissions, and each shipping company's allowances and emissions will be offset at the end of the period.

3.2 Notation and Models

3.2.1 Notation

The mathematics notations for parameters, variables and functions of the carbon allowance allocation problem (CAAP) are shown in Table 3.2.

Table 3.2 Notations for parameters, variables and functions

Index			**Description**
I			Index of vessel type *i*, where *i* = 1~3 (1= tanker, 2 = container ship, 3 = bulk carrier)
J			Index of economic conditions, where *i* = 1~3 (1= prosperous, 2 = steady, 3 = sluggish)
A			The ratio of free emission allowances
Parameters		**Unit**	**Description**
Decision maker	FM_i	ton/ single route	The fuel consumption of the main engine of vessel type *i*
	FA_i	ton/ single route	The fuel consumption of the auxiliary engine of vessel type *i*
	FP_i	ton/ single route	The fuel consumption of vessel type *i* during the port operation
	VAS_i	Knot	The actual speed of vessel type *i*
	VMS_i	Knot	The maximal speed of vessel type *i*
	h_i	Nm	The distance of the shipping route for vessel type *i*
	M_i	ton/day	The fuel consumption for main engine of vessel type *i*
	D_i	Day	The sailing days of vessel type *i*
	P_i	kW·h	The average installed engine power of vessel *i*
	ML_i	0 ≦ ML ≦1	The main engine load of vessel type *i*
	$SFOC_i$	kg/kW·h	The specific fuel oil consumption of vessel type *i*
	DW_i	Ton	The gross deadweight of vessel type *i*

Table 3.2 Notations for parameters, variables and functions

Shipping companies	R_{ij}	\$/ton	The freight rate of vessel type *i* in business cycle *j*
	VOL_i	ton or TEU	The capacity volume of vessel *i* in single route
	U_i	$0 \leqq U_i \leqq 1$	The capacity load of vessel type *i*
	TC_i	\$	The total operating cost of vessel *i*
	TFC	\$	The total fuel cost of vessel type *i*
	TCC_i	\$	The total carbon cost of vessel type *i*
	TCR_i	\$/day	The time charter rates of vessel *i* (where *i* = 1, 3)
	X_i	Vessels	The fleets of vessel *i* in the specific route
	FP	\$/ton	The fuel price
	IP	\$/ton	The initial carbon price
	r	$0 \leqq r \leqq 1$	The supply-demand fluctuation coefficient
Fuctions			**Description**
Decision maker	FC_i	ton/ single route	The total fuel consumption of the vessel type *i*
	FM_i	ton/ single route	The main engine fuel consumption of vessel type *i*
	M_i	ton/day	The fuel consumption for main engine of vessel type *i*
	P_i	kW·h	The main engine power of vessel type *i*
	E_i	Kg	The actual carbon emissions for vessel type *i*
	Z	Kms/Perg	The maximal free carbon allowance allocation for the international shipping
Shipping companies	π_j	\$	The economic benefit volume of vessel type *i* under *j* business scenario
	CTV_j	Kg	The carbon trading volume of vessel *i* under *j* business scenario
	$p(CTP_i)$	\$	The actual carbon trading price of vessel *i*
	CBR_j		The cost-benefit ratio of vessel *i* under *j* business scenario

3.2.2 Model Formulation

3.2.2.1 The Concept for the CAAP

In this study, the carbon allowance allocation problem (CAAP) of the shipping sector is a "Leader-follower relationship" problem between the decision maker and the shipping companies. The relationship of the CAAP can be seen in Figure 3.7. The first critical issue for the decision maker is to decide the permitted free emission level α to regulate the free carbon allowance allocation for each vessel. The shipping company will bases decisions on the allocated free carbon allowance to minimize their cost-benefit ratio (CBR).

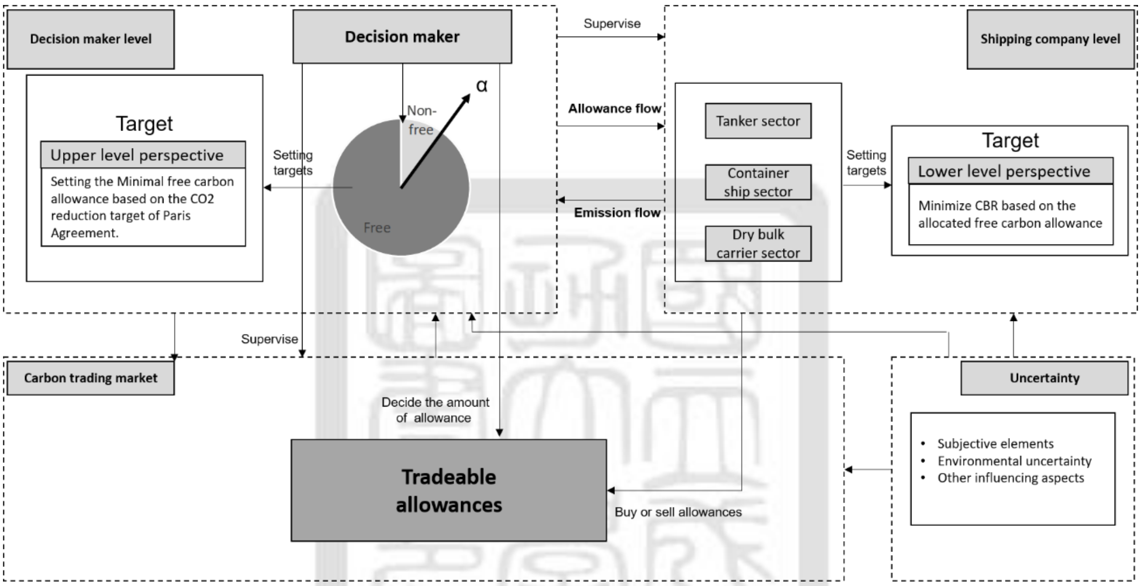


Figure 3.7 Concept map for the CAAP of the shipping industry

3.2.2.2 Decision Maker's Carbon Allowance Allocation

In general, the power of a ship comes from the main and auxiliary engines. When a vessel is at sea, the power is from the main engine (FM_i), while the vessel calls at port, the power is from the auxiliary engine. Endresen et al. (2003) point out that fuel consumption while in port (FA_i) and during port operations (FP_i) are approximately 10% and 5% of the main engine's consumption in a single route, respectively. Thus the relationship of the fuel consumption (FC_i) can be formulated as Eq. (1), which is composed of the fuel consumption of main engine, auxiliary engine and port operation.

$$FC_i = FM_i + FA_i + FP_i = FM_i + (10\% \times FM_i) + (5\% \times FM_i) \tag{1}$$

The model of the fuel consumption, (FC_i), is based on data from Corbett et al. (2009) and Psaraftis and Kontovas (2009), who assert that the relationship between fuel consumption and sailing speed follows the Propeller Law, which indicates that fuel consumption is in a positive cubic relationship with the ratio between the actual speed and the maximal speed ($\left(\frac{V_{AS}}{V_{MS}}\right)^3$). The function of the fuel consumption of the vessel main engine in a specific route is shown as Eq. (2).

$$FM_i = M_i \times \left(\frac{V_{AS}}{V_{MS}}\right)^3 \times \frac{h_i}{24V_{AS}} = M_i \times \left(\frac{V_{AS}}{V_{MS}}\right)^3 \times D_i \quad (2)$$

Therefore, the model for daily fuel consumption can be formulated as Eq. (3). Based on Endresen et al. (2003) and Cariou (2011), the fuel consumption of the main engine of a vessel type *i* per day (M_i) is calculated by the main engine power (P_i) multiplied by the main engine load (ML), the specific fuel oil consumption ($SFOC$), and finally, changing the units from kg / *kW·h* into ton / *kW·h*.

$$M_i = 24 \times P_i \times ML \times SFOC \times 10^{-3} \quad (3)$$

In addition, the engine power for different vessel types are different. The relationship can be formulated into a nonlinear model as Eq. (4). In addition, the deadweight and the main engine power of a vessel are in a positive relationship depending on coefficients γ and ω (Endresen et al., 2003).

$$P_i = \gamma \times DW_i^{\omega} \quad (4)$$

The value of the main engine load (ML) will be between 0 and 1. According to Cariou (2011), the level of $SFOC$ is best when around 0.180 to 0.195 kg/kW·h. Then, by putting Eq. (3) and Eq. (4) into Eq. (2), the fuel consumption of the main engine of a vessel type *i* in a single route can be formulated as Eq. (5). When we further put Eq. (5) into Eq. (1), the total fuel consumption of the vessel type *i* in a single route can be formulated, which can be seen as Eq. (6). Finally, the relationship between the fuel consumption and the CO_2 emission (E_i) can be formualted as Eq. (7).

$$FM_i = M_i \times \left(\frac{V_{AS}}{V_{MS}}\right)^3 \times \frac{h_i}{24V_{AS}} = P_i \times ML \times SFOC \times 10^{-3} \times \left(\frac{V_{AS}}{V_{MS}}\right)^3 \times \frac{h_i}{V_{AS}} \quad (5)$$

$$FC_i = FM_i + (10\% \times FM_i) + (5\% \times FM_i) = 115\% \times FM_i \quad (6)$$

$$E_i = 0.8645 \times \frac{44}{12} \times FC_i = 3.17 \times FC_i \quad (7)$$

The actual carbon emission (E_i) represents the CO_2 emission from the engine of the vessel type *i* in a single route. And the value is multiplied by the carbon ratio of the shipping-used fuel (0.8645), in a ratio ($\frac{44}{12}$) in transforming carbon (C, atomic weight is

12 atom) into CO_2 (CO_2, molecular weight is 44 amu), and the total fuel consumption (FC_i). We can simplify this equation by using 3.17 (0.8645 multiplied by $\frac{44}{12}$) multiplying FC_i, which has 3.17 as a common ratio to evaluate the current CO_2 emission of the vessel's main engine currently (Endresen et al., 2007; Psaraftis and Kontovas, 2009).

Finally, the decision maker must aggregate the total CO_2 emission of the vessels in the j_{th} business cycle. The corresponding function is shown as Eq. (8).

$$Z_j = \alpha \times \sum_{i=1}^{3} Ei(x_{ij}), \forall j = 1 \sim 3 \tag{8}$$

3.2.2.3 Cost-benefit analysis of the Shipping Companies

The revenue of shipping companies is based on the free carbon allowance allocated by the decision maker. Thus, the goals for the shipping companies are based on the free allowance to minimize their cost-benefit ratio (CBR). Corbett et al. (2009) made a formula by which the shipping companies' revenue (π_i) is calculated using the freight rate (R_{ij}) multiplied by the capacity volume of the vessel (VOL_i), and the capacity ratio (U_i) in the j_{th} business cycle, as shown in Eq.(9). The total cost (TC_j) is composed of the total time charter cost, the total fuel cost (TFC), and the total carbon cost (TCC_j). To simplify the calculation, in this study the time charter cost is not included, thus the function of the total cost (TC_j) can be formulated as Eq. (10).

$$\pi_j = R_{ij} \times Vol_i \times U_{ij} \tag{9}$$

$$TC_j = TFC + TCC_j \tag{10}$$

The relationship of the total fuel cost (TFC) is calculated by the fuel price (FP) multiplied by the vessel's total fuel consumption ($115\% \cdot FM_i$), as shown in Eq. (11).

$$TFC = \sum_{i=1}^{3} FP \times (115\% \times FM_i) \tag{11}$$

The total carbon cost of the vessels during different business cycles (TCC_j) is calculated by the actual carbon trading price ($p(CTP_i)$) multiplied by its trading volume (CTV_{ij}), which can be seen in Eq. (12). In addition, the trading price ($p(CTP_i)$) is composed of the initial carbon trading price (IP) and the supply-demand fluctuation (Fudenberg & Tirole, 1991), in which the fluctuation is composed of the supply-demand fluctuation coefficient (r) and the carbon trading volume ($\sum_{i \in I}\{CTV_{ij}^{+} - CTV_{ij}^{-}\}$), as shown in Eq. (13). The trading volume is the gap between the actual emission (E_i) and the cap of carbon allowance allocation (CEA) i.e. $CTV_{ij} = E_i(x_{ij}) - CEA.$ If there is a positive value (CTV_{ij}^{+}) it denotes that the free allowances for the shipping companies are insufficient; while a negative value (CTV_{ij}^{-}) indicates that the free allowances are more than the actual emission. Thus, CTV_{ij}^{+} and CTV_{ij}^{-} can seen as the volume of the carbon emission allowances bought and sold from the shipping companies, respectively (Xu et al., 2016).

$$TCC_j = \sum_{i=1}^{3} E_d(p(CTP_i)) \times E_d(CTV_{ij}) \tag{12}$$

$$p(CTP_i) = IP + r \times \sum_{i=1}^{3} \{CTV_{ij}^{+} - CTV_{ij}^{-}\} \tag{13}$$

Finally, according to the above, the shipping companies' cost-benefit ratio (CBR) based on the allocated carbon allowance, can be formulated as Eq. (14).

$$\min CBR_j = \frac{TC_j}{\pi_j} \tag{14}$$

3.2.2.4 The Fitting Models for the CAAP

For a workable emission trading system, the volume of the trading allowances must be well regulated. First, the carbon trading volume of the allowances must equal the sums bought and sold. Second, the decision maker should ensure the volume of allowances bought and sold for each shipping company is only allowed in one situation. Third, the volume of the allowances bought and sold cannot be negative, and the free allowance (FEA_i) allocated by the decision maker should exceed the sold volume of allowances. Finally, the total non-free allowances allocated by the decision maker should exceed the sum of all bought and sold allowances (Xu et al., 2016), as shown as Eqs. (15) - (18), respectively.

$$E_d(CTV_j) = \sum_{i=1}^{3} (E_d(CTV_{ij}^{+}) - E_d(CTV_{ij}^{-})), \forall j = 1 \sim 4 \tag{15}$$

$$E_d(CTV_{ij}^{+}) \times E_d(CTV_{ij}^{-}) = 0, \forall j = 1 \sim 4 \tag{16}$$

$$0 \leq E_d(CTV_{ij}^{+}), 0 \leqq E_d(CTV_{ij}^{-}) \leqq FEA_j, \forall j = 1 \sim 4 \tag{17}$$

$$E_d(CTV_{ij}^{+} - CTV_{ij}^{-}) \leqq N\_TEA_j, \forall j = 1 \sim 4 \tag{18}$$

3.3 Summary

The carbon allowance allocation problem (CAAP) of the shipping sector is a "Leader-follower relationship" problem between the decision maker and the shipping companies. The CAAP evaluation procedure with the proposed models contains 3 phases, including setting the emission cap for the shipping industry and calculating the actual emission of the vessels for different business cycles (Phase 1: step 1-3), calculating the gap between the emission cap and the actual emission to decide the free allowance allocation level α (Phase 2: step 4), and, finally, the shipping companies following the allocated free carbon allowance to minimize their CBR. The trading volume of the carbon allowance is designed to complement the regulations (Phase 3: steps 5-6). The evaluation procedure for the CAAP has been created as follows:

Step 1 Set the emission cap for the shipping industry;

Step 2 Calculate the emission of the i_{th} vessel in the j_{th} business cycle using Equations (1) to (7);

Step 3 Aggregate the emissions of the vessels in the j_{th} business cycle using Equation (8) to obtain the total emissions of the vessels Z_j;

Step 4 Calculate the gap between the emission cap and Z_j to decide the free allowance allocation level α;

Step 5 Based on α, calculate the shipping companies' cost-benefit ratio in the j_{th} business cycle (CBR_j) using Equations (9) to (14);

Step 6 Check the model's fit using Equations (15) to (18).

Figure 3.8 illustrates the evaluation process when conducting free carbon allowance allocation in the shipping industry, as described in the previous steps.

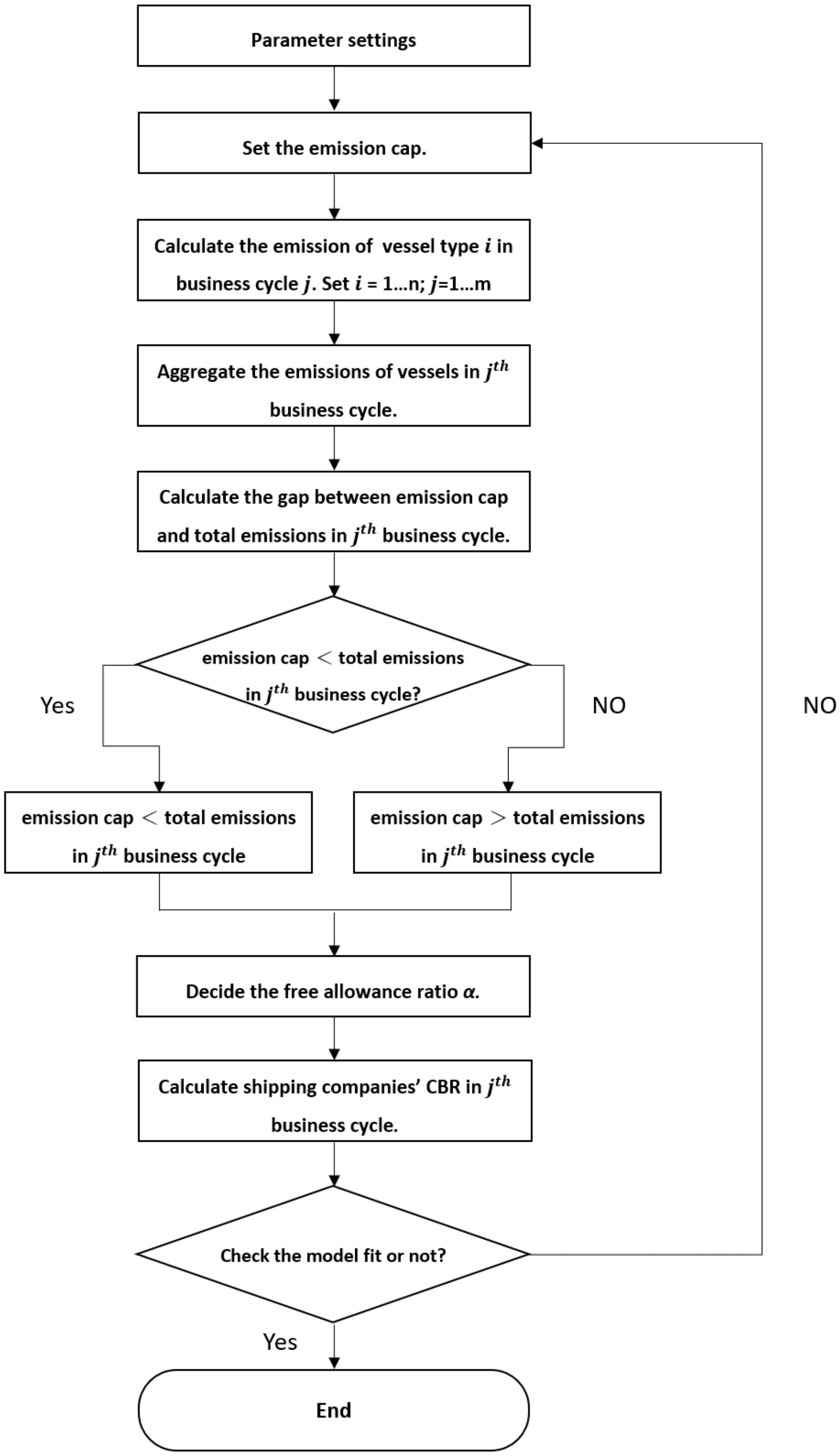


Figure 3.8 Flowchart for CAAP in shipping industry

Chapter 4 Empirical Result

This chapter is divided into five sections. The first is data analysis, the second is the analysis of vessels' emissions and emission cap, the third is an examination of the proportion of fuels cost at different vessel speeds and the emissions cost at different trading prices as a proportion of the total profit. The fourth section consists of carbon allowance allocations and cost-benefit analysis and, finally, the conclusion.

4.1 Data Analysis

The business cycles of the shipping industry are identified as prosperous, steady, and sluggish according to the criteria of the Monetary Policy with the Federal Fund Rate. If the government adopts a tight monetary policy, the business cycle is more likely to be defined as prosperous, whereas during a period of expansionary monetary policy it would be defined as sluggish. However, between tight and expansionary is defined as steady. The results can be seen in the block of Figure 4.1 with red (prosperous), green (steady) and blue (sluggish).

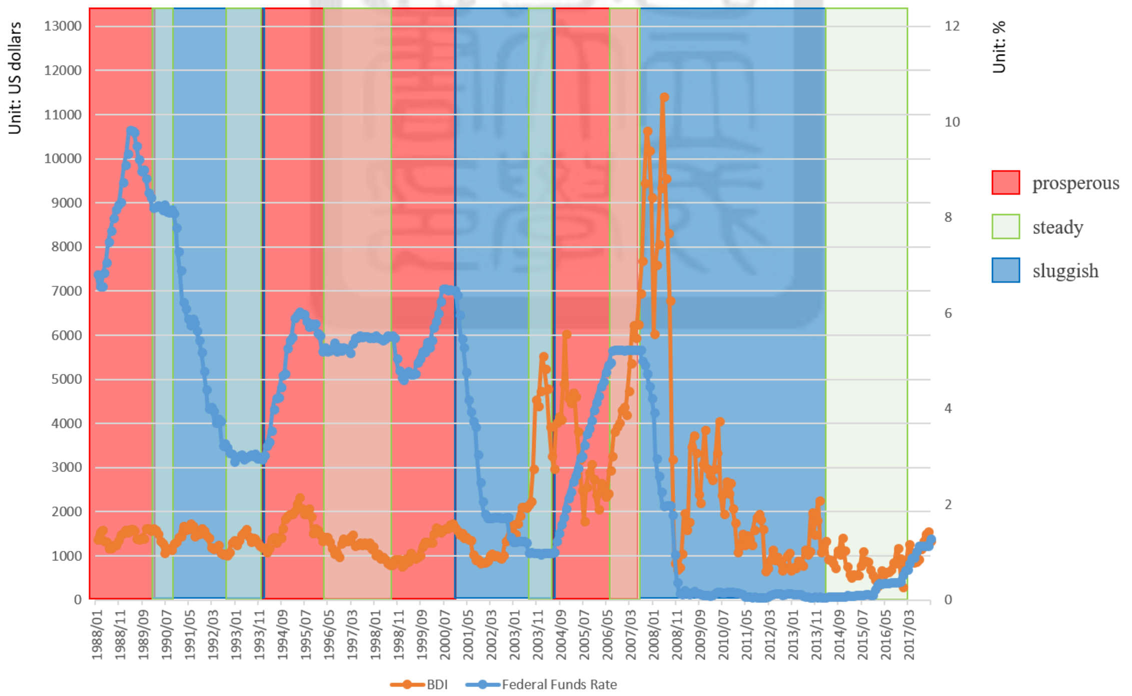


Figure 4.1 The business cycle defined by the Federal Fud Rate

After the 2008 world financial crisis, the global dry bulk shipping market has been totally distorted (Dai et al, 2015) and seasonal fluctuations are sharper and more pronounced during market recovery (Kavussanos and Alizadeh, 2001), so the business cycles of the shipping industry since the financial crisis should be discussed individually. In this segment, the implement period of quantitative easing (QE) is adopted to define the business cycles since 2008. The U.S. Federal Reserve System used QE following the global financial crisis of 2007–08, and this has mitigated some of the economic problems since the crisis. Thus, because the Federal Reserve ended QE in January of 2014, the period from the middle of 2007 to the end of 2013 is defined as sluggish, while the periods before and after can be considered steady.

In this part of the paper, the average freight rates for tankers, container ships, and dry bulk carriers are calculated for different business cycles based on the definitions in Figure 4.1 and the data of freight rates listed in Table 4.1.

Table 4.1 The shipping average freight rate for the different business cycles

	Bulk (Ton/ $)	Container (TEU/$)	Tanker (Ton/ $)
Prosperous	27.63	1,115	16.83
Steady	25.38	1,051	12.43
Sluggish	21.41	1,038	13.53

4.2 Analysis of Vessels' Emissions and Emission Cap

In this section, the fuel consumption and CO_2 emissions of the vessels used in this study are first calculated, and then the emission cap which would be necessary for the shipping industry to cut emission in 2050 to half of the 2005 rate are set and analyzed.

4.2.1 The Fuel Consumption and Energy Emissions of the Vessels

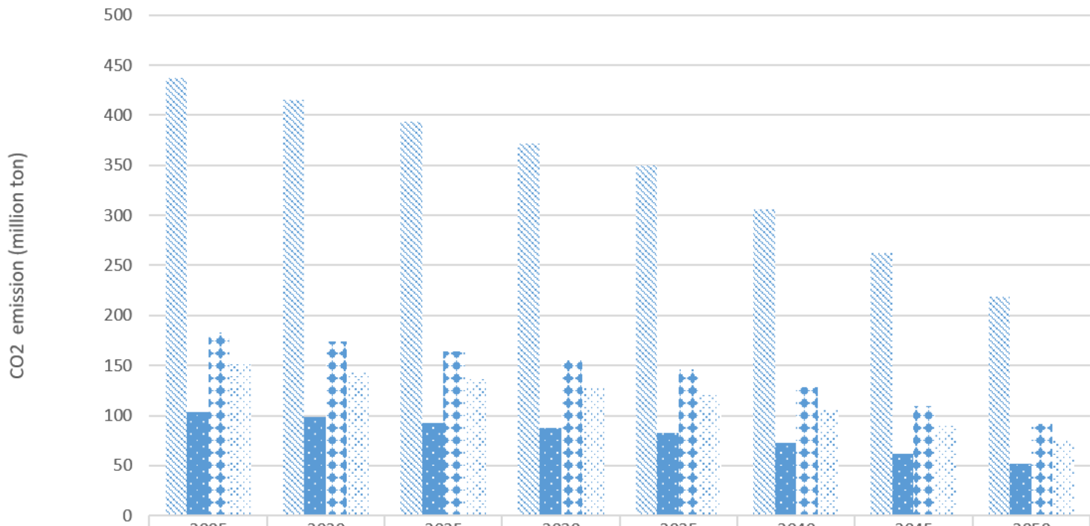
Table 4.2 summarizes the parameters of carbon allowance allocation used in this study, including the fuel consumption of the main engine (FM), auxiliary engine (FA), and consumption at port (FP) for tankers, container ships, and dry bulk carriers, along with the related parameters. According to Table 4.2, the total fuel consumption of a tanker, a container ship, or a dry bulk carrier in a single route are 1,774.02 tons, 4,931.08 tons, and 2,317.36 tons, respectively, with total CO_2 emissions of 56,236 tons, 156,315 tons, and 73,640 tons. The emission intensities are 2.39 ton/nautical mile, 6.26 ton/nautical mile and 2.70 ton/nautical mile, respectively.

Table 4.2 The energy consumption and the relative parameters used in this paper

Parameters	unit	Tanker	Container ship	Bulk carrier
VAS	knot	10	16.29	10
VMS	knot	15.9	25.0	14.7
h	nm	23,548	21,694	27,228
M	ton/day	63.93	279.26	57.15
D	day	97	55.50	112
P	kW·h	20,294.1	88,654.7	18,143.4
ML	$0 \leqq ML \leqq 1$	0.75	0.75	0.75
$SFOC$	kg/kW·h	0.175	0.175	0.175
DW	ton	260,000	186,470	207,812
FP	$/ton	450	450	450
IP	$/ton	10.28	10.28	10.28
r	$0 \leqq r \leqq 1$	10^{-8}	10^{-8}	10^{-8}

4.2.2 The Emission Cap of the Vessels

The target of the emission reduction in this study is based on EU standards, with the goal of controlling the emissions of the shipping industry so that in 2050 they will be half of that in 2005. In addition, considering the feasibility of the technical progress of vessels, in the earlier period (from 2020 to 2035), the target of emission reduction goal is that the CO_2 emission for each five-year period will be 5% better than that in previous period. For example, the reduction in emissions between 2020 and 2025 will be 5% greater than the reduction achieved between 2015 and 2020. While in the latter period (from 2035 to 2050), the emission reduction target will be 10% higher than that in the previous period, as shown as Figure 4.2. The maximum emission of tankers, container ships and dry bulk carriers can then be set according to Figure 4.2. This paper calls the maximum allowed emission the emission cap.



	2005	2020	2025	2030	2035	2040	2045	2050
Emission Cap	437.25	415.39	393.53	371.66	349.8	306.08	262.35	218.63
Oil Tanker	103.35	98.18	93.02	87.85	82.68	72.35	62.01	51.68
Container ship	182.85	173.71	164.57	155.42	146.28	128	109.71	91.43
bulk	151.05	143.5	135.95	128.39	120.84	105.74	90.63	75.53

Figure 4.2 The emission caps of the international shipping

4.2.3 Emission of Vessels

After setting the emission caps for shipping industry, this paper, according to Figure 4.1 and emission data, calculates the average growth rate of the CO_2 emission of the shipping industry in prosperous, steady and sluggish business cycles, which are 3.00%, 0.67% and -3.22%, respectively. Then based on the average growth rate, the CO_2 emission of the shipping industry from 2020 to 2050 can be calculated, as shown in Figure 4.3. This study bases its results on an analysis of the proportion of fuel and emissions cost as a proportion of the total profit, the carbon allowance allocation, and the shipping companies' cost-benefit ratio.

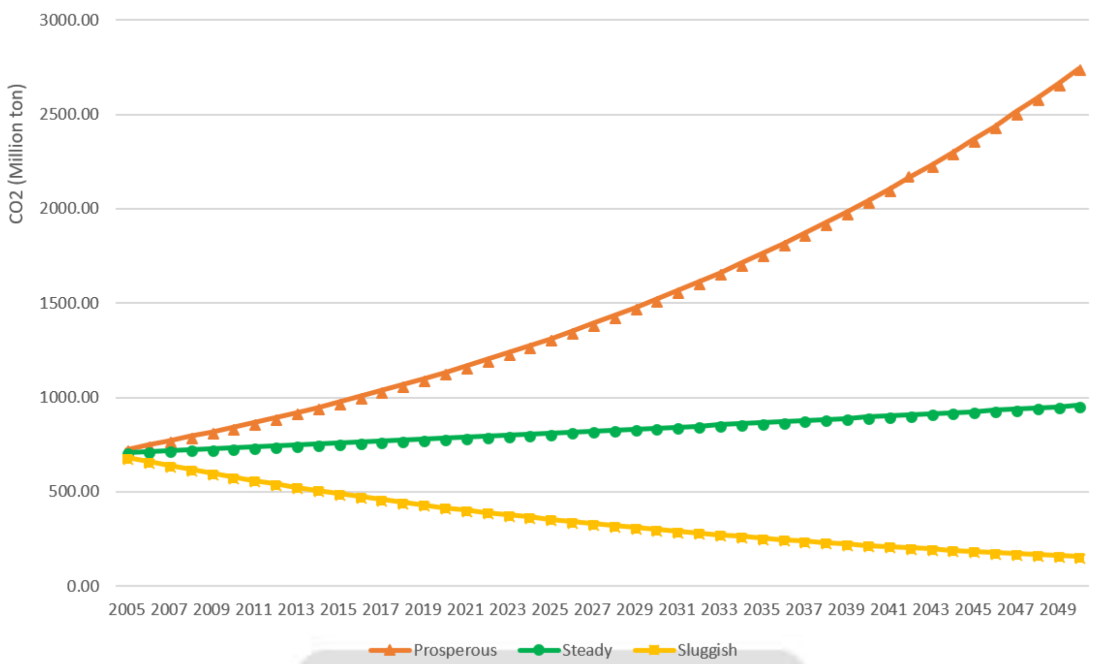


Figure 4.3 Emissions from 2005 to 2050 for the shipping industry

4.3 Proportion of Fuel Cost and Emissions Cost as Proportion of Total Profit

4.3.1 Proportion of Fuel Cost at Different Vessel Speeds as of the Total Profit

This section analyzes the fuel cost for different vessel speeds as a proportion of the total profit (not considering the emission cost). To accurately and practically measure the impact of business cycles on the shipping industry, in addition to the shipping freight rate, this study also considers the difference in shipping capacity for different business cycles. For example, the capacity of tankers in prosperous, steady, and sluggish business cycles are 100%, 75% and 50%, respectively, as listed in Table 4.3.

Table 4.3 The capacity ratio of the shipping sector in different business cycles

	Tanker	Container ship	Bulk Carrier
Prosperous	100%	95%	100%
Steady	75%	85%	75%
Sluggish	50%	75%	50%

The settings of the vessel speed of tanker/container ship/bulk carrier at high, normal and low speeds are 14/22/14 knots, 12/20/12 knots and 10/18/10 knots, respectively. Table 4.4 shows different vessel speeds, and the differences in fuel costs as a proportion of the total profit. The results are consistent with those of Zhu et al. (2018), who found that when vessels speeds are kept at 20 knots, the ratio of the fuel cost in general is between 15% to 30%, depending on the bunker price. For instance, in a prosperous business cycle the proportion of the fuel cost at high, normal and low speeds is 28.11%, 25.47% and 19.50%, respectively, which means when vessels travel at higher speeds, the shipping companies also suffer higher cost. Furthermore, when the vessel's speed is kept constant during prosperous, steady, and sluggish business cycles , the proportion of the fuel cost is 28.11%, 36.09%, and 45.70%, which indicates that during sluggish business cycles, shipping companies should reduce vessels' speed to decrease their fuel costs.

Table 4.4 The proportion of the fuel cost for different vessel speeds

	high speed	normal speed	low speed
Prosperous	28.11%	25.47%	19.50%
Steady	36.09%	32.70%	25.03%
Sluggish	45.70%	41.42%	31.70%

4.3.2 Proportion of Emission Cost at Different Tading Price of the Total Profit

The carbon trading price for the shipping industry is based on the average price of 10-year trading data from the EU ETS. This study defines the high, middle, and low trading prices as 40 USD/ton, 25 USD/ton, and 10 USD/ton. According to the results listed in Table 4.5, the proportion of the emission cost at different trading prices in different business cycles has different impacts. In general, the proportion of CO_2 allowance cost is much lower than that of fuel cost under each scenario, which is consistent with the findings of Koesler et al. (2015) and Zhu et al. (2018). For example, in a prosperous business cycle in 2020, the profit proportion of emission costs at high, middle and low trading prices would be 4.00%, 2.57% and 1.15%, respectively. Interestingly, the proportion of the emission cost for shipping companies in the sluggish business cycle is negative, which denotes that shipping companies can get a surplus carbon allowance, in other words, they can sell their surplus carbon allowance for a profit.

Table 4.5 The proportion of the emissions cost at different trading prices

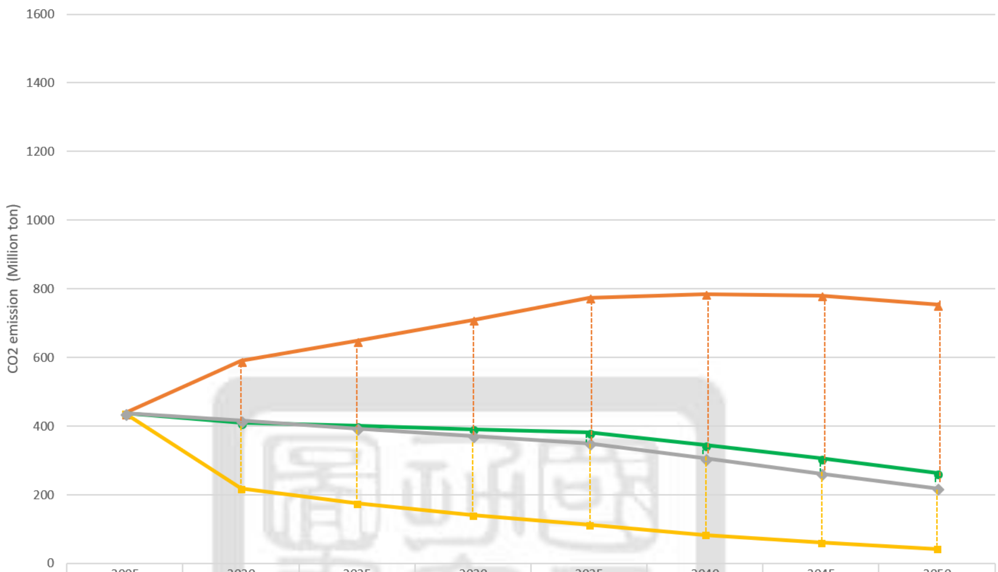
Business cycle	Trading cost	2020	2025	2030	2035	2040	2045	2050
Prosperous	High	4.00%	6.53%	9.54%	13.18%	18.14%	24.13%	31.48%
	Mid	2.57%	4.27%	6.34%	8.90%	12.49%	16.94%	22.55%
	Low	1.15%	2.00%	3.13%	4.62%	6.84%	9.76%	13.63%
Steady	High	0.36%	1.25%	2.15%	3.09%	4.62%	6.22%	7.86%
	Mid	0.23%	0.79%	1.36%	1.97%	2.96%	4.02%	5.12%
	Low	0.09%	0.32%	0.57%	0.84%	1.31%	1.83%	2.39%
Sluggish	High	-5.33%	-5.67%	-5.87%	-5.96%	-5.34%	-4.64%	-3.86%
	Mid	-3.23%	-3.43%	-3.55%	-3.60%	-3.24%	-2.83%	-2.36%
	Low	-1.14%	-1.20%	-1.23%	-1.24%	-1.14%	-1.01%	-0.86%

4.4 Carbon Allowance Allocation and Cost-benefit Analysis

4.4.1 Carbon Allowance Allocation

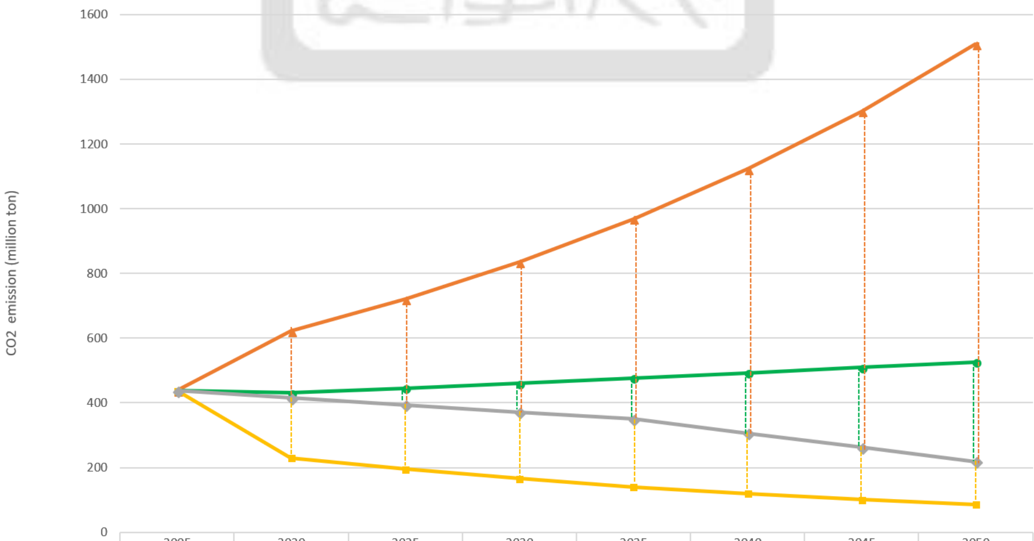
To decide carbon allowance allocations, this study considers two scenarios based on the guidelines of the EEDI: shipping companies deploying vessels in keeping with the guidelines of the EEDI (scenario A); and directions of the EEDI are disregarded (scenario B). If the vessels follow EEDI guidelines, emissions will decline due to improvements in vessels' technology, as shown in Figure 4.4; and if not, the emissions will continue to grow, as in Figure 4.5. In scenario A, the settings of the carbon reduction of the vessels and the emission cap are the same, which in the earlier period (from 2020 to 2035), the carbon emission reduction for each five year-period will be 5% more than that in the previous period. For example, the emission reduction of vessels in 2020 and 2025 are 5% and 10% greater than they were in 2015, respectively. While in the latter period (from 2035 to 2050), the carbon reduction will be 10% more than that in the previous period.

Figure 4.4 and Figure 4.5 also show the gap between the emission cap and the emission of vessels in both scenarios for different business cycles. For both scenarios, the grey line represents the emission cap of the shipping industry, while the orange, green and yellow lines denote the emissions in prosperous, steady and sluggish business cycles, respectively. To calculate the gap, for instance, in 2035 of scenario A, the emission cap is set at 349.80 million tons, and the emissions of vessels in prosperous business cycles is 774.40 million tons, therefore, the gap (424.60 million ton) is represented by the orange dotted line. While the most important of all, for both scenarios, the emissions of vessels are below the emission cap only during the sluggish business cycle.



	2005	2020	2025	2030	2035	2040	2045	2050
Prosperous	437.25	590.43	648.45	709.67	774.40	785.40	780.45	754.05
Steady	437.25	409.12	400.95	391.30	381.04	344.58	305.58	263.18
Sluggish	437.25	217.88	175.23	140.72	112.20	83.55	60.72	42.90
Emission cap	437.25	415.39	393.53	371.66	349.80	306.08	262.35	218.63

Figure 4.4 Gap between actual emissions and the emission cap for scenario A



	2005	2020	2025	2030	2035	2040	2045	2050
Prosperous	437.25	621.50	720.50	834.90	968.00	1122.00	1300.75	1508.10
Steady	437.25	430.65	445.50	460.35	476.30	492.25	509.30	526.35
Sluggish	437.25	229.35	194.70	165.55	140.25	119.35	101.20	85.80
Emission cap	437.25	415.39	393.53	371.66	349.80	306.08	262.35	218.63

Figure 4.5 Gap between actual emissions and the emission cap for scenario B

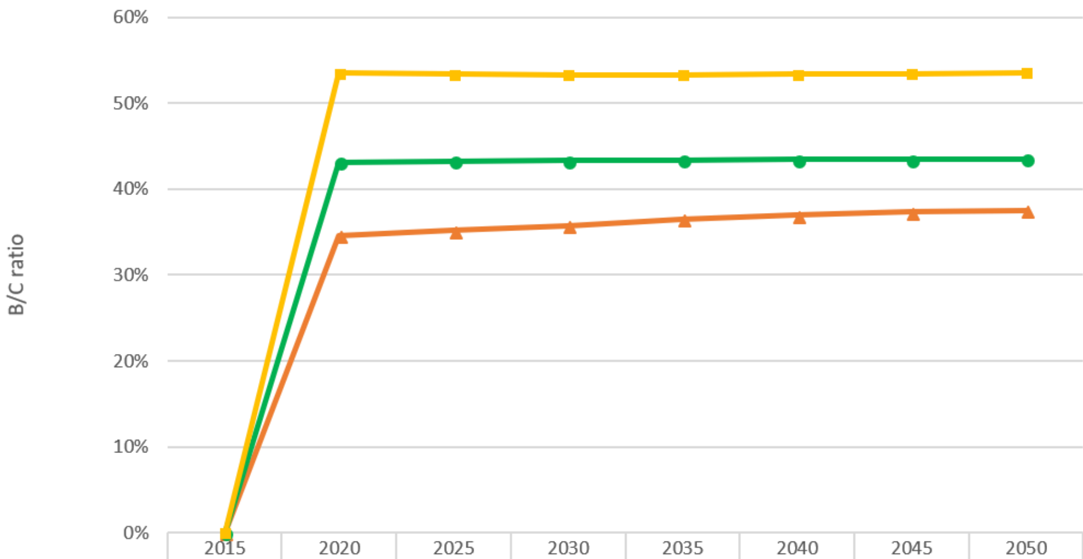
Next, based on the results of Figure 4.4 and Table 4.5, this paper calculates the minimum free allowance allocation of the shipping industries for both scenario, as shown in Table 4.6. For example, in 2020 for scenario A, the free allowance allocation for the decision maker is set at 70% in the prosperous business cycle, namely, shipping companies need to buy an extra 30% of carbon allowance in the trading market to meet their operation needs. Based on the data shown in Table 4.6, compared with scenario B, shipping companies can almost double their free allowance in scenario A. Therefore, the results show that if shipping companies use vessels in keeping with the EEDI, they can not only reduce their emissions, but obtain more carbon allowance.

Table 4.6 Minimal free allowance allocation for shipping

Business Cycle Scenarios		2020	2025	2030	2035	2040	2045	2050
Scenario A	prosperous	70%	61%	52%	45%	39%	34%	29%
	steady	102%	98%	95%	92%	89%	86%	83%
	sluggish	191%	225%	264%	312%	366%	432%	510%
Scenario B	prosperous	67%	55%	45%	36%	27%	20%	14%
	steady	96%	88%	81%	73%	62%	52%	42%
	sluggish	181%	202%	225%	249%	256%	259%	255%

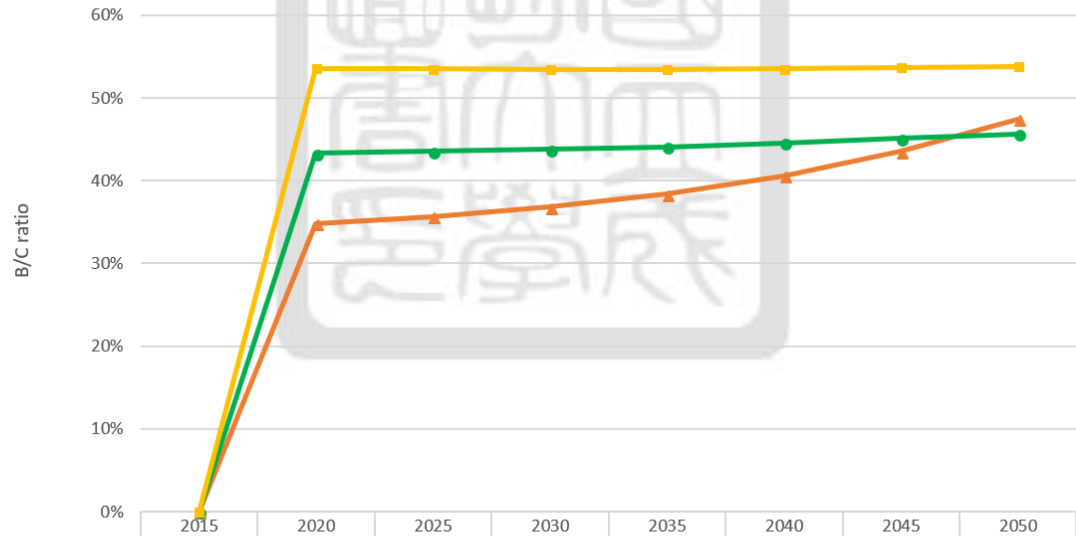
4.4.2 Cost-benefit Analysis

Finally, based on Table 4.6, this study further analyzes the cost-benefit ratio (CBR) for both scenarios when shipping companies follow the emission cap guidelines. The results are shown in Figure 4.6 and Figure 4.7. According to Figure 4.6, for example in 2020 of scenario A, the shipping companies' CBR in prosperous, steady and sluggish business cycles will be 34.62%, 43.17%, and 53.49%, respectively. In the sluggish business cycle, although the shipping companies can sell their surplus carbon allowance, their CBR is still higher due to reduced profits.



	2015	2020	2025	2030	2035	2040	2045	2050
prosperous	0%	34.62%	35.16%	35.78%	36.50%	36.99%	37.34%	37.52%
steady	0%	43.17%	43.26%	43.33%	43.41%	43.45%	43.49%	43.49%
sluggish	0%	53.49%	53.39%	53.34%	53.31%	53.37%	53.47%	53.60%

Figure 4.6 Shipping companies' CBR in scenario A



	2015	2020	2025	2030	2035	2040	2045	2050
prosperous	0%	34.83%	35.70%	36.84%	38.35%	40.60%	43.55%	47.45%
steady	0%	43.30%	43.54%	43.80%	44.08%	44.55%	45.08%	45.65%
sluggish	0%	53.54%	53.48%	53.45%	53.43%	53.54%	53.67%	53.83%

Figure 4.7 Shipping companies' CBR in scenario B

4.5 Summary

This study first utilizes the Monetary Policy with the Federal Fund Rate to identify the shipping freight rate for three different business cycles, designated as prosperous, steady and sluggish. Secondly, using the data and the models presented in chapter three to analyze the fuel consumption and energy emission of vessels, the settings of the emission cap for the shipping industry were then decided. Finally, this paper analyzes the proportion of the fuels cost at different vessel speeds and the emissions costs at different carbon trading prices as a proportion of the total profit, the carbon allowance allocation, and cost-benefit analysis. The results show that shipping freight rates are higher in the prosperous business cycles. The total fuel consumption of tankers, container ships, and bulk carriers in a single route are 1,774.02 ton, 4,931.08 ton, and 2,317.36 tons; total CO_2 emission are 56,236 tons, 156,315 tons, and 73,640 tons; while the emission intensity is 2.39 tons/nautical mile, 6.26 tons/nautical mile and 2.70 tons/nautical, respectively. In addition, when vessels travel at higher speeds, the proportion of fuel cost to total profit is higher. When comparing for different business cycles, it can be seen that the proportion in the sluggish business cycles is higher. When comparing different carbon trading price, it can be seen that when carbon trading price is higher the proportion of the emission costs of the total profit is higher. And when comparing different business cycles, the proportion in the sluggish business cycles is also higher. Regarding the carbon allowance allocation vessels both following and not following the EEDI scenarios, because vessels emit more CO_2, shipping companies need to buy more carbon allowance in the prosperous business cycle, whereas during the sluggish business cycle shipping companies can sell their allowances to make profit. Finally, for the cost-benefit analysis, in the prosperous business cycle scenario shipping companies' cost-benefit ratio (CBR) is lower, indicating that their total profits are higher; while in the sluggish business cycle, their CBR is higher. When comparing vessels following the EEDI guidelines or disregarding them, shipping companies can save more costs in the former scenario. Therefore, this study suggests that in the sluggish business cycles, the shipping companies can reduce vessel speed to save cost. In addition, if the shipping companies follow the EEDI recommendations, they can not only reduce vessels emission but reduce cost.

Chapter 5 Conclusion and Suggestions

This chapter is divided into three sections: conclusions and suggestions, limitations, and, finally, recommendations for future research.

5.1 Conclusion and Suggestions

This study first utilizes Monetary Policy with the Federal Fund Rate to identify the shipping freight rate of three business cycles as prosperous, steady and sluggish. Secondly, based on the data and the model conducted in chapter three, fuel consumption, energy emission of vessels, and settings of emission caps for the shipping industry are analyzed. The emission cap settings are based on EU standards, which strive to control the emissions of the shipping industry such that in 2050 they will be half of the 2005 levels. In addition, considering the feasibility of the technological progress of vessels, in the earlier period (from 2020 to 2035), the target of the emission reduction is the CO_2 emission for each five year will be 5% more than that in previous period; while in the latter period (from 2035 to 2050), the target of the emission reduction will be 10% more than that in previous period. Finally, this study analyzes the proportion of the fuels cost at different vessel speeds and the emissions cost at different carbon trading prices as proportions of the total profit, the carbon allowance allocation of the shipping industry, and the cost-benefit analysis for the shipping companies.

The results can be summarized as follows:

(1) The shipping freight rates of tankers, container ships, and bulk carriers in the prosperous business cycles, are 27.63 ton/USD, 1,115 TEU/USD, 16.83 ton/USD; in the steady business cycle 25.38 ton/USD, 1,051 TEU/USD and 12,43 ton/USD; while in the sluggish business cycle 21.41 ton/USD, 1,038 TEU/USD and 13.53 ton/USD, respectively. According to these results, the shipping freight rate in the prosperous business cycle is 129%, 107% and 124% higher than that in the sluggish business cycle.

(2) In this study, the chosen shipping route and distance traveled by tankers, container ships and bulk carriers are set as the distances from Ningbo to Bonny (23,548 knots), Far East to North Europe (21,694 knots), and Qingdao to Tubarao (27,228 knots). Furthermore, the fuel consumption of tankers, container ships, and bulk carriers in a single route is 1,774.02 tons, 4,931.08 tons, and 2,317.36 tons; the total CO_2

emissions are 56,236 tons, 156,315 tons, and 73,640 tons; while the emission intensity is 2.39 ton/nautical mile, 6.26 ton/nautical mile, and 2.70 ton/nautical, respectively.

(3) The fuel costs of the vessels at high, normal and low speeds, as a proportion of the total profit, in the different business cycles are different: in the prosperous business cycle they are 28.11%, 25.47%, and 19.50%; in the steady business cycle 36.09%, 32.70%, and 25.03%; and in the sluggish business cycle 45.70%, 41.42%, and 31.70%. Thus, the results show that when the vessels travel at high speed, the proportion of the fuel cost to the total profit is higher; while when the vessels sail at low speed, the proportion is lower. If comparing for different business cycles, in the sluggish business cycle the fuel cost as a proportion of the total profit for the shipping companies is higher due to making less profit in this business cycle; while the proportion is lower in the prosperous business cycle because of higher profits from the cargo. Therefore, it is suggested that in the sluggish business cycles shipping companies should adopt a strategy of vessel speed reduction (VSR) to reduce their fuel cost.

(4) The emission cost at high, middle and low trading prices, in relation to the total profit, in the different business cycles in 2050 will also be different: in the prosperous business cycle it will be 31.48%, 22.55%, and 13.63%; in the steady business cycle 7.86%, 5.12%, and 2.39%; and in the sluggish business cycle -3.86%, -2.36%, and -0.86%, respectively. Based on these results, the proportion of the emission cost at high trading price of the total profit is higher. And if comparing the different business cycles, in the sluggish business cycle the proportion of the emission cost as a proportion of the total profit is lower.

(5) Regarding carbon allowance allocation, this study considers two scenarios of the shipping companies deploying and not deploying the vessels in keeping with the regulation of the EEDI. According to the results of the former scenario, in 2050 the allocated free allowance for shipping industry in prosperous, steady and sluggish business cycles are set to be 29%, 83%, and 510%. This suggests that shipping companies should sell their surplus carbon allowance (5.1 times actual emission) in the sluggish business cycle; while in the prosperous and the steady business cycles, the shipping companies still need to buy 71% and 17% carbon allowance,

respectively. In the latter scenario, the free allowance allocated by the decision maker in 2050 are 14%, 42%, and 225%. By the same logic, the results denote that in the sluggish business cycles, the shipping companies get enough and can sell to the trading market (2.25 times of the actual emission). Therefore, it can be seen that the shipping companies need to buy more carbon allowance in the prosperous business cycle because the actual emissions are far higher than the emission cap; while the shipping companies can sell their surplus carbon allowance only in the sluggish business cycle.

(6) Finally for the cost-benefit analysis, in the scenario of the vessel in keeping with the EEDI, the cost-benefit ratio (CBR) in prosperous, steady and sluggish business cycles in 2050 are projected to be 37.52%, 43.49%, and 53.60%, respectively. While in the scenario of not keeping with the EEDI in 2050, the CBR will be 47.45%, 45.65%, and 53.83%. Thus, according to the results, in the prosperous business cycle the CBR for shipping companies is lower, denoting that the total cost of the total profit is lower; if in the sluggish business cycle, the shipping companies get higher CBR, representing that the total cost of total profit is higher. If we compare the two scenarios, the shipping companies can lower their operation cost more efficiently when keeping with the EEDI. Especially in the prosperous business cycle of 2050, the shipping companies can reduce cost by about 9.33% more than without the EEDI scenario. The results provide a guideline that if shipping companies deploy the vessels in keeping with the EEDI, they can reduce cost efficiently.

5.2 Limitations

In this study, because of the difficulty in obtaining some of the data, the scope of the study and the design of the scenarios cannot be comprehensively covered. This study summarizes the following limitations:

(1) The characteristics of the multiple waypoints of the shipping routes:

In this study, shipping route of container ships with a single origin and single destination are considered. However, in practice, shipping usually involves multiple waypoints in shipping routes, so this assumption may underestimate vessels emissions and operating costs.

(2) The settings of the shipping sector:

The scope of this study only includes three vessels types, including tankers, container ships and bulk carriers. And the average annual emissions of the above vessels from 2013 to 2015 accounted for only 55% of the shipping sector. However, other vessels such as cruise ships, yachts, and Ro-Ro ships, etc, are not included in this paper because the data is hard to obtain. Therefore, this study only evaluates the three vessels types to represents the whole shipping sector.

5.3 Future Research

According to the limitations of this study, some parts should be further studied in future research for extension and improvement. This study lists the following points as follow-up directions:

(1) For the future works, the characteristics of the multiple waypoints of the shipping industry can be included with more detailed calculation to evaluate the emission of vessels.

(2) The settings of the shipping freight rates in this study, is firstly bases on the business cycles defined by the Federal Fund Rate, and then analyzes the relationship between the business cycles and the freight rate data. However, the business cycles and the shipping freight rates defined by the different indexes and methods have different the outcomes. Therefore, future studies can utilize different indexes and methods to identify the average of shipping freight rates, and further explore the carbon allowance allocation for the shipping industry.

(3) The settings of the scenarios in this study consider only vessels in keeping with the EEDI and without the EEDI. However, in practice, IMO has other emission reduction strategies such as carbon taxes, and SEEMP, ect. Therefore, the scenario settings for the future research can utilize other strategies of emission reduction to analyze the impact on the carbon allowance allocation for the shipping industry.

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