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Investigating the determinants of ordering alternative fueled new vessels

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INVESTIGATING THE DETERMINANTS OF ORDERING ALTERNATIVE FUELED NEW VESSELS

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of the requirements for the award of the degree of Master of Science in Maritime Affairs

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views,
and are not necessarily endorsed by the University.

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Abstract

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Shipping might contribute 2-3% of global emissions at present and 17% of greenhouse gas emissions in 2050 if no further emission control actions are to be taken. The maritime transport sector is capital-intensive, risky, and highly specialized. Placing an order for a new vessel is a difficult decision for a shipowner or shipping company to make. Fuel prices constitute a large portion of daily operating costs in the shipping sector. While existing research has a lack of empirical studies of shipowners on emission abatement solutions for choosing alternative fuels, and most studies focus on emission abatement compliance of in-service vessels and fuel performance assessment.

This study utilizes the multinominal logit model to analyze the factors that impact shipowners' decisions to order alternative fueled vessels, including the size of the vessel, the type of the vessel, the contract date, the nationality of the shipowners, the ClarkSea Index, the CO_2 EU ETS price, the LNG price, the SOFR, the volume of new vessel orderbooks, and the fleet idle rate. The vessel orderbook data for this study is extracted from the Clarkson database for the period January 2020 to February 2023. The final sample contains 3928 vessels involving 1868 shipyards and 1759 shipping companies.

This paper has three main contributions. Firstly, it fills the research gap in empirical analysis of shipowners' fuel selection under regulatory changes on a global scale. Secondly, among various influencing factors studied, vessel type, shipowners' nationality, orderbook volume, fleets idle rate, carbon emissions trading system, bunker prices, and contract date can have deterministic impacts on shipowners' fuel selection, while Dwt has less significant effect and the profitability of the shipping market and SOFR are irrelevant to a shipowner’s decision. Thirdly, important implications for shipping stakeholders, including shipowners, manufacturers, and governmental bodies are drawn from this study, and the method can be extended to analyze behaviors of other stakeholders as well.

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List of Abbreviations

AIS	-- Automatic Identification System
ANOVA	-- Analysis of Variance
BDI	-- Baltic Dry Index
DWT	-- Deadweight Tonnage
ETS	-- EU Emissions Trading System
EUA	-- European Union Allowances
FQFD	-- Fuzzy Quality Function Deployment
FTOPSIS	-- Technique for Order Preference by Similarity to an Ideal
GT	-- Gross Tonnage
IMO	-- International Maritime Organization
LCS	-- Longest Common Sub-sequence
LIBOR	-- London InterBank Offered Rate
LNG	-- liquefied natural gas
LPG	-- liquefied petroleum gas
MBMs	-- Market-based Measures
MDO	-- Marine Diesel Oil
MEPC	-- Maritime Environment Protection Committee
MGO	-- Marine Gas Oil
MLP	-- Multi-Layer Perceptron
MNL	-- Multinomial Logit
NPV	-- Net Present Value
ROI	-- Return-on-investment
SCFI	-- Shanghai Containerized Freight Index

1. Introduction

1.1. Background

According to the United Nations Conference on Trade and Development, international shipping, which moves more than 90% of all traded products, is the foundation of world trade and the economy. Shipping might contribute 2-3% of global emissions at present and 17% of greenhouse gas emissions in 2050. (Zis & Psaraftis, 2018). The International Maritime Organization (IMO) has established two strategic points, 2030 and 2050, with corresponding gradient reduction targets of at least 40% reduction in carbon intensity in global shipping by 2030 and 70% by 2050 compared to 2008 and at least 50% reduction in total annual greenhouse gas emissions from shipping by 2050 compared to 2008. Low or zero carbon fuels and energy carriers are essential for meeting the targets, especially given the anticipated increase in shipping demand (Psaraftis, 2018).

The maritime transport sector is capital-intensive, risky, and highly specialized (Fan & Luo, 2013). Placing an order for a new vessel is a difficult decision for a shipowner or shipping company to make. They must consider whether and when market conditions warrant the investment, particularly during the Covid-19 epidemic, which will depend on whether existing and new shipbuilding orders can meet the demand for freight, satisfy the new convention, and improve their competitiveness in the market. MARPOL 73/78 has been ratified by 160 countries. The convention includes six technical annexes, each with extensive provisions on specific forms of pollution from vessels. Annex VI, which has been ratified by 101 countries by 2022, is updated and amended annually to limit emissions of nitrogen oxides, sulfur oxides, greenhouse gases and other pollutants.

Energy-efficiency improvements that reduce CO_2 have a good effect on the environment and the financial health of shipping firms. To comply with the new standards, the container shipping industry will have to make adjustments costing up to US$10 billion (Hoffmann et al., 2012). The expenses of the various choices vary widely for shipowners, and their choice will have a significant impact on their revenue. Depending on fuel prices and ship specifications in various countries, bunker costs make up about 47% of voyage costs across the maritime industry based on 2007 (Kim et al., 2022). In 2020, the combination of weaker demand due to the coronavirus pandemic and a mild winter has led to a price war, which has brought down oil prices (Han & Wang, 2021). Due to the magnitude of the global shipping sector and the fact that fuel expenditures make up a sizable portion of operational expenses, even modest increases in energy efficiency can have a big impact (Vilhelmsen et al., 2013). Ships will therefore need to employ comparatively low-carbon alternative fuels like liquefied natural gas (LNG), liquefied petroleum gas (LPG), biofuels and methanol or progressively transition to carbon-neutral fuels like hydrogen and ammonia in order to reach the IMO target (Xing et al., 2021).

1.2. Aims and implications

In order to fulfill the IMO's 2050 carbon intensity requirements, shipowners must decide whether and when to purchase new vessels using alternative fuels. Fuel prices constitute a large portion of daily operating costs in the shipping sector. The goal of this study is to identify the key factors influencing shipowners' investment decisions in alternative fueled vessels through an empirical analysis using the multinominal logit (MNL) model. Replacing existing vessels with new alternatively fueled vessels is one of shipowners' emission abatement solutions. The MNL offers a more thorough study of the impact of investment decisions made by shipowners in various nations under various conditions at various times as compared to the classic time series model. Whether the shipowner's investment in new fuel-powered vessels will be impacted by factors such as vessel size, type, market fluctuations, time, etc. The purpose of this study is to identify the most significant factors influencing shipowner decisions over the past three years and to provide insights and policy recommendations to inform emission abatement solutions for new shipbuilding. It also aims to improve understanding of the decisions made by shipowners ordering new vessels to comply with emission regulations.

1.3. Framework

The multinominal logit model is being used in this study to analyze the factors that impact shipowners' decisions to order alternative fueled vessels. The MNL model is a well-established model that can help determine the key influencing factors and assess the likelihood of selecting a solution. First, to collect global new vessel orderbooks data for empirical research and make a descriptive analysis. Then, to develop a multinominal logit model to represent alternative fueled vessels and explanatory variables which capture the fundamental characteristics of vessel orderbooks, market conditions, and business characteristics of shipowners to complete the empirical research. The explanatory factors of the model include the size of the vessel, the type of the vessel, the contract date, the nationality of the shipowners, the ClarkSea Index, the CO_2 EU ETS price, the LNG price, the SOFR, the volume of new vessel orderbook, and the fleet idle rate. The explained variable of the model represents the alternative fueled vessels ordering. Finally, based on the results of the empirical analysis, suggestions are put forward for shipping stakeholders.

2. Literature review

2.1. Review on new fueled vessels

There is a large body of literature that has evaluated energy efficiency improvement and emission abatement solutions for shipowners or shipping companies to address carbon emission targets. Ampah et al. (2021) searched and combined 583 eligible papers published from 2000 to 2020 from the Web of Science Core Collection and Scopus databases, and analyzed them using Biblioshiny, with LNG being the most studied fuel among alternative fuels. However, recent trends indicate that researchers are turning their attention to methanol, ammonia and hydrogen fuels. Since 2000, the research field has tripled; early development (2000-2008), slow development (2009-2013), and rapid development (2014-2020). Moshiul et al. (2022) reviewed the literature on alternative fuels for maritime transportation based on Scopus articles. The co-occurrence and co-authorship of authors' keywords were analyzed using VOS viewer analysis software and bibliomeics software. A selection of 749 articles from 1973 onwards, the current literature indicates that LNG is only a short-term consideration compared to hydrogen and ammonia, while only a few countries and institutions are currently active in this area of research. This literature can be broadly divided into three categories, the first of which is a number of articles that lean toward retrospective analysis, analyzing the unique advantages as well as the impediments to the spread of alternative fuels. Le Fevre (2018) builds on an earlier report that focused on the overall outlook for LNG as a marine fuel for marine transportation, reviewing some of the major barriers and uncertainties to LNG adoption, with projections indicating that by 2030, demand growth and the transformation of LNG carriers could lead to LNG demand of between 25 and 30 million tons per year, with vessels requiring regular and predictable sailing patterns to ensure timely fuel availability. Wan et al. (2018) reviewed the progress of the technical, operational and market routes for emission abatement and the related controversies, and concluded that the emission abatement effect brought by deceleration has been very limited, and the next approach to solve the emission abatement problem should be market-based, which also needs continuous improvement in practical application, and there is always a big gap between the commitment and action of the traditional shipping community.

The second category starts with quantitative analysis methods to calculate economic efficiency ROI, etc. There is some literature that adds non-financial elements to the analysis to resolve the uncertainty. Balland et al. (2015) proposed that economic factors were not enough to reflect the real preferences of decision-makers, and irrational behaviors of shipowners should also be considered, and multi-criteria optimization model should be used for emission control selection. Then a case application was carried out. The results showed that non-financial factors played an important role in the selection of ship emission control schemes, and relevant practitioners should provide more costs of different emission schemes. Potential and other accurate information. Hansson et al. (2020) explored the prospects of ammonia as a future fuel for the shipping sector by comparing ammonia with other alternative fuels using a multi-criteria decision analysis. The use of hydrogen is a more cost-effective fuel option for shipping than ammonia, which still has many issues to resolve before it can be rolled out on a large scale. Priyanto et al. (2020) conducted a feasibility study by developing a portfolio scenario approach based on a combination of economic benefits (NPV and payback period) and technical options, and used a portfolio scenario model to optimize the trade-off between government and shipowner interests for government subsidies. The competitiveness of methanol depends mainly on ship productivity and the price difference between methanol and MDO, and the results show that the price of methanol is optimal at a ratio of 47%

relative to MDO. Bai et al. (2021) used AIS large-scale mathematical processing methods to quantitatively measure and statistically analyze each ship type factor influencing shipowners' choices based on single-vessel dynamic data and data from automatic identification systems. This study provides important practical implications for the maritime and maritime related industries and policy makers to cope with the new emission regulations. Zou and Yang (2023) develop a mathematical model of the whole life cycle of a ship with different sizes of ships and select a variety of indicators to evaluate alternative fuels. With the current fuel prices, continuing to use scrubbers is still the most cost-effective option for all sizes of ships. Hydrogen and ammonia require higher costs in the short term, with small and medium-sized ships preferring methanol and large and oversized ships preferring MGO, which can have both economic and environmental benefits when the price of hydrogen falls below $4,000/ton. Wang and Nguyen (2017) proposed a functional combination of FQFD and FTOPSIS methods to bridge the observed gap from the industry stakeholders' perspective, achieving a quantitative assessment of LCS measures under uncertainty, although IMO's LCS technical incentives and support measures are available at different levels and in different ways, there is a clear gap between them from the industry stakeholders' perspective.

The third category of literature puts the perspective of the shipowner and analyzes the factors that influence the shipowner's decision on emission abatement solutions in various ways. Kim and Seo (2019) used fuzzy hierarchical analysis to conduct interviews with Korean shipping companies to investigate the impact of sulfur oxide emissions regulations on shipping companies, where financial factors such as investment costs and operational costs have a significant impact on shipowners' decisions, and government and port support is also important. Kaya and Erginer (2019) used the fuzzy TOPSIS method to determine the performance values of the energy saving measures to determine the importance of the indicators affecting the decision-making process. It was found that shipowners were most concerned with the practicality of the planning, procurement and installation process of the abatement solution, or whether it would pay for itself in the short term. So the operational emission abatement solutions were therefore preferred to complete abatement technology retrofits and alternative energy vessel conversions, both of which were of concern to shipowners in terms of risk. Stalmokaitė and Yliskylä (2019) drew on the MLP's theoretical framework to understand how different shipowners respond to changes in external regimes. The study reveals the key drivers of Baltic Sea shipowners' decisions to invest in emission abatement technologies and shows that regulations also interact with each other, something that governments and organizations need to pay attention to. When fuel oil prices are relatively high, regulations can stimulate shipowners to complete the fuel transition in a more aggressive direction. Li et al. (2020) used multiple logistic regressions to analyze fleet data, identify factors that influence ship operators' decisions to comply with IMO's 2020 sulfur cap, and analyze the willingness of ship owners to make revolutionary investments in new ships, resulting in effective recommendations for ship owners, engine manufacturers, regulation makers, and others. Zhang et al. (2021) developed a Multinominal Logit Model (MNL) through ships, freight rate index, and shipowners, and concluded that ship type has a decisive influence on shipowners' emission abatement solutions and they are highly correlated with the nationality of shipowners.

If focus on the study of the factors influencing ship owners to choose new alternative fueled vessels, Mäkitie et al. (2022) used descriptive statistics and ANOVA to analyze a survey of 281 shipowners in Norway. For the relatively small number of early adopters of alternative fuels, the quest for long-term profitability, competitive advantage and improved public image were important motivations for adopting alternative fuels, and the company's business strategy, financial and intellectual resources were likely to be relevant to the shipowners' adoption of alternative fuels. Hansson et al. (2019) ranked the seven alternative fuels by evaluating their performance and incorporating the views of Swedish shipping stakeholders and proposing ten evaluation criteria. The results show that for shipowners, economic aspects, especially fuel price, play a large role in the decision, followed by fuel safety and compliance with environmental regulations, and the adequacy of fuel supply.

2.2. Review on Multinomial logit model

The Multinominal Logit Model is already a well-established model that can help estimate the probability of choosing a solution as well as identify the significant influencing factors in it. Bao et al. (2022) explored the factors influencing cruise lines' decisions to comply with the 2020 sulfur cap using multiple logit models based on data from the world's existing mail ships as well as new orders. Fluctuations in fuel prices have not had an impact on shipowners' strategies, and government financial support is hardly an incentive for owners to reduce emissions, but new vessel orders have clearly favored new alternative fuels such as LNG. Alizadeh et al. (2016) divides dry bulk vessels into tonnage segments and uses a logit model to assess the probability of a dry bulk vessel being scrapped. The influencing factors include the main characteristics of the vessel, such as age and size, as well as market-specific factors, including freight levels, fuel prices, interest rates, scrapping prices and market fluctuations, with the age of the vessel, the size of the vessel and long-term deviations from the average freight rates being important factors in increasing the probability of a vessel being scrapped. Fan and Xie (2021) investigate shipowners' vessel selection decisions and ship size preferences through a multinomial logit model. The model synthesizes the factors affecting ship size selection in terms of internal company characteristics, shipping market environment, and competitor performance. There is a tendency to order smaller ships when new ship prices are high and to prefer medium-sized ships when freight rates are high. Large shipping companies also prefer larger ships in order to remain competitive, thus confirming the nature of the oligopolistic market structure of the container market. Kanamoto et al. (2021) first estimated the port-to-port cargo flow by commodity for global dry bulk shipping using AIS data and commodity information processed by ports and berths, and then developed multiple regression and multinomial logit models to obtain the effect of trade volume on ship size, which is more important than voyage distance, and the dry bulk shipping tariff index also has an effect on the choice of ship size because of its seasonality.

2.3. Summary

From the above literature review, it is clear that after the rise of new alternative fuels such as hydrogen, ammonia, and methane, with the narrowing of fuel price differentials and the improvement of fuel refueling equipment, scrubber or low sulfur oil is likely be reduced to the transition of emission abatement solutions for existing vessels. There is a lack of empirical studies of shipowners on emission abatement solutions for choosing alternative fuels, and most studies focus on emission abatement compliance of in-service vessels and fuel performance assessment, and lack evolution in time. This study can bridge the gap between academic research on energy choices in the shipping industry and the actual response of shipowners to regulations, enrich the understanding of emission compliance decisions for shipowners ordering new vessels, and suggest next steps for improvement to accelerate the achievement of carbon reduction targets.

3. Multinomial logit model

3.1. Model building

A shipowner's choice of fuel for a new vessel can be viewed as a selection process between several mutually exclusive fuel options that are influenced by the shipowner's own situation as well as by market or other environmental factors. A discrete choice model is a convenient way to explain or predict the choice from a set of two or more discrete alternatives where the consumer is the utility maximizer and the utility of each choice is a random variable (Talluri & van Ryzin, 2004). Using this approach, in addition to obtaining the probability of shipowners choosing various options, it is also possible to identify the key influencing factors in the model. The most widely used model for discrete choice models is the logit model, and since there are multiple fuel options available to shipowners, the binomial logit model cannot be applied, but rather the multinomial logit model should be used. A MNL can be considered as a joint estimation of multiple binomial logit models with two pairs of each type of choice behavior in the explained variables. In addition to being used in marketing, the MNL is also used to analyze various choice behaviors in transportation. Based on sample data, the model's choice probability formula can be used to estimate the probability that shipowner i will choose an alternative fueled vessel j under given circumstances and to determine the influence of various factors, including the shipowner itself (Li, 2011).

The discrete choice model is based on random utility theory, which states that a respondent's preference for a given choice when faced with multiple options can be expressed in terms of a utility value that is decomposed into two components, the observable and the unobservable random variables. The observable part is composed of the characteristics of each category itself and the individual traits of the decision makers who make the selection. The unobservable part summarizes all other unobservable influences and is usually considered as the random error term. Because it is impossible to accurately predict utility due to the existence of the random error term, choice probability is used to reflect the decision maker's utility. Therefore, we establish the utility function for a shipowner ordering an alternative fueled vessel as follows:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \#(1)$$

Where U_{ij} is the utility value of alternative fueled vessel j for shipowner i; V_{ij} is the observable component of utility and ε_{ij} is the unobservable component of utility. V_{ij} is an unknown function, but in most cases it can be directly assumed to be a linear function of a set of explanatory variables, which is:

$$V_{ij} = \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots \beta_m X_{im} \#(2)$$

Where X_{i1}, X_{i2}, $\cdots X_{im}$ are the explanatory variables affecting the shipowner's decision to order an alternative fueled vessel, and β_1, β_2, $\cdots \beta_m$ are the estimated corresponding parameters for the explanatory variables.

The probability of shipowner i choosing alternative fueled vessel (P_{ij}) is given by:

$$P_{ij} = \Pr\left(U_{ij} > U_{ij} \right), for\ k \neq j, j = 1, 2, 3,4,5,6. \#(3)$$

Where U_{ij} is the maximum utility obtained by shipowner i in selecting an alternative fueled vessel j. We assume that all ε_{ij} are independently distributed, identically distributed (i.i.d.) as a Gumbel distribution with a mean value $\eta = 0$, and have a scalar value u. Thus, the probability that shipowner i chooses an alternative fueled vessel j can be further written as:

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_{k \in J} e^{V_{ik}}} = \frac{\exp\left(\beta_j X_i\right)}{\sum_{k \in J} \exp\left(\beta_k X_i\right)} \#(4)$$

$$\sum_{j=1}^{J} P_{ij} = 1\#(5)$$

Where J represents all the alternative fueled vessel options. In estimating the parameter β, the coefficients of the reference group are normalized to zero, and then the selection probabilities are calculated based on the selection data that have been collected (Louviere et al., 2000). According to equation (5), the sum of the probabilities of all alternatives must be one. Different parameter sets need to be estimated for different alternative fueled vessels. The β_j of one of the new energy vessel types is set to 0, the baseline alternative fueled vessel, and the coefficients of the non-baseline alternative fueled vessel options will be explained on the baseline alternative fueled vessel.

Then, the probability of the alternative fueled vessel scenario is represented by the following:

$$P_{ij} = \frac{\exp\left(\beta_j X_i\right)}{1 + \sum_{j=2}^{J-1} \exp\left(\beta_j X_i\right)}\#(6)$$

Additionally, for the probability of baseline alternative fueled vessel, it is represented by:

$$P_{ij} = \frac{1}{1 + \sum_{j=2}^{J-1} \exp\left(\beta_j X_i\right)}\#(7)$$

3.2. Explained and explanatory variable

3.2.1. Explained variables

The explained variables in this study are different fuels of new vessels, which are classified as follows: conventional fuel, LNG Capable, LNG Ready, Methanol (including Methanol Ready), Ammonia (Ammonia Ready, including blended fuels), and other fuels (including battery, LPG, ethane, and other blended fuels). LNG Capable means that a vessel can directly use LNG as fuel, while LNG Ready means that it can be converted into LNG powered vessels.

LNG is mainly composed of methane, and it becomes liquid after being compressed and cooled to its boiling point (-161.5℃). Usually, liquefied natural gas is stored in low-temperature storage tanks at about -161.5℃ and 0.1MPa, requiring about twice the storage space of conventional diesel fuel. During refueling operations, special double-walled pipes are required for transportation. The production and installation accuracy of these double-walled pipes are very high (Wang & Notteboom, 2014). The CO_2 emissions of LNG are about 25% lower than those of conventional fuel such as diesel (Lindstad et al., 2020). However, considering the problem of natural gas leakage during extraction, this value will be reduced to around 15% (Balcombe et al., 2019). The infrastructure for LNG refueling has flourished in recent years and has rapidly developed. As of January 2023, 185 ports worldwide provide LNG refueling services. Nevertheless, LNG should be viewed as a transitional fuel to achieve greenhouse gas emission reduction targets (Lindstad et al., 2020). If the problems of leakage, renewable supply, and engine efficiency cannot be solved, using LNG fuel alone will not meet the goal of reducing greenhouse gases by 50% (Balcombe et al., 2021).

Methanol is an alcohol-based fuel that can be blended with up to 20% conventional fuels without engine modification. However, its volumetric energy density is lower than that of LNG, which can be improved by modifying the double hull structure of existing vessels (Verhelst et al., 2019). Compared with liquefied natural gas, methanol has very low sulfur content and is also easier to maintain in a liquid state during storage (Rouwenhorst et al., 2019). At present, there is a problem of insufficient infrastructures and production capacity for methanol, but this problem can be easily solved due to the production flexibility of methanol itself. In addition, methanol is easy to ignite but does not easily cause large-scale fires and can be extinguished with water. However, considering its toxicity, a leakage problem may pose a risk to the crew's lives. Based on the carbon dioxide hydrogenation synthesis of methanol and methane, this is a promising technology that can effectively store surplus power if combined with carbon capture (Lee et al., 2020). Before the 2040s, renewable methanol will be difficult to compete with HFO in terms of cost. For ship owners of cargo ships, conventional methanol has a competitive advantage over the total cost when external costs are relatively high (Helgason et al., 2020). Methanol is a strong competitor for decarbonizing shipping (Panoutsou et al., 2021). According to DNV data, the capital expenditure of container vessels using methanol fuel is only slightly higher than that of conventional fueled vessels, while it is only one-third of the cost to build LNG-fueled container vessels (Eise Fokkema et al., 2017).

Ammonia, a simple compound containing one nitrogen atom and three hydrogen atoms, is an excellent hydrogen carrier due to its chemical structure (Mallouppas & Yfantis, 2021). The emissions produced by burning ammonia fuel do not contain carbon dioxide or sulfur oxide (Zincir, 2022), but nitrogen oxide emissions should not be underestimated. By installing catalytic converters, shipowners can reduce emissions (Ampah et al., 2021). Ammonia has high compatibility and can be easily compatible with engines, turbines, and combustors. Compared to conventional diesel, ammonia has a lower volume density and is five times the volume of conventional diesel (Gray et al., 2021). However, its current fuel injection and infrastructure layout cannot meet the needs of shipping use, which requires further improvement (Hansson et al., 2020). Due to its toxicity and corrosiveness, there are requirements for containers used for ammonia storage. However, its high ignition point and weak combustibility guarantee safety (Inal et al., 2022).

LPG fuels are fossil fuels like LNG, and therefore, it cannot promote complete decarbonization in the long term and generates other greenhouse gas emissions. However, some studies have shown that LPG has the best environmental performance among other fossil fuels (Foretich et al., 2021). Batteries have weaknesses such as uncertain battery life and electricity grid capacity (Steen et al., 2019). Hydrogen fuel cells have higher energy density than lithium batteries, allowing ships to run longer and travel farther. Research results have shown that the most effective way to achieve zero carbon emissions in shipping is to use dual-fuel engines (Lindstad et al., 2021). This ensures fuel flexibility during the transition stage, provides timely fuel supply, and maximizes the reduction in the risk of fuel shortage.

Between January 2020 and February 1, 2023, there was no new vessel orders for hydrogen-fueled vessels. Hydrogen fuel has the lowest carbon content of zero carbon alternative fuels and the highest energy-to-weight ratio, reaching only four times that of diesel. Nevertheless, hydrogen fuel is the least mature among several fuels, facing obstacles in production, transportation, and storage. Ammonia can enable hydrogen to have a hydrogen volume density greater than liquid hydrogen, but it will lose its advantage of greenhouse gas emissions. Hydrogen needs to be compressed (at 300 bar and 25°C) or cooled to -253°C and stored as a low-temperature liquid. To use it on vessels, special storage facilities are required, increasing capital and operating costs (Solakivi et al., 2022), making it currently only suitable for short-distance transportation.

None of these alternative green, zero-carbon or low-carbon fuels currently have a globally available or cost-effective infrastructure to support the global shipping fleet. The shipping industry has yet to determine which fuel is the best choice. We define conventional fuel as the baseline category and assign them a value of 1, while LNG Capable is set at 2, LNG Ready at 3, methanol at 4, ammonia at 5, and other fuels at 6.

3.2.2. Explanatory variables

The explanatory variables used in this study include Dwt, Nationality, Type, ClarkSea Index, BDI, SCFI, CO2 EUA Price, LNG Bunker Price, Contract Date, SOFR, Idle, and Orderbook. Vessel types are categorized into ten classes: Bulk, Container, Tanker, Gas carrier, General Cargo, Multi-Purpose, Pure car, Ro-Ro, Chem & Oil and Products. Table 1 will provide a detailed description of the explanatory variables.

Table 1 Detailed description of the explanatory variables

Explanatory variables	Description
Dwt	Deadweight tonnage of the vessel
Nationality	Shipowner’s nationality; 1 if it is China; 2, Japan; 3, Greece; 4, South Korea; 5, Singapore; 6, Taiwan, China; 7, Germany; 8, Norway; 9, Italy; 10, Netherlands; 11, Rest of world
Type	Ship type of the orderbook; 1 if ship type is dry bulker; 2, container ship; 3, crude tanker; 4, gas carrier; 5, general ship; 6, multipurpose ship; 7, pure car carrier; 8, Ro-Ro ship; 9, chem & Oil; 10, product oil vessel
ClarkSea Index	Monthly value of ClarkSea Index only for full sample model (composite index of freight market performance)
BDI	Monthly value of BDI only for dry bulker sample (Baltic Dry Index)
SCFI	Monthly value of SCFI only for container ship sample (Shanghai Containerized Freight Index)
CO2 EUA Price	CO2 European Union Allowances Price
LNG Bunker Price	Monthly value of LNG price

SOFR	Secured Overnight Financing Rate
Idle	% global idle fleet
Orderbook	% global orderbook fleet
Contract Date	Date of the orderbook contract

Research has shown that vessel size and type play a critical role in shipowners' decision-making for newbuilding orders (Vanherle & Delhaye, 2010). Gas carriers have been found to prefer LNG, while smaller vessels are more likely to use conventional fuel (Li et al., 2020). Therefore, Dwt is used as another explanatory variable to measure vessel's size.

The shipowner's nationality also affects their decision-making (Kim & Seo, 2019). Differences in development level and culture among different countries may result in varying incentives and policies. The shipowner's nationality was obtained from the Clarkson database and divided into eleven categories: China, Japan, Greece, South Korea, Singapore, Taiwan Province of China, Germany, Norway, Italy, Netherlands, and other countries. Due to sample size reasons, the categories were reduced to eight in the dry bulk model and container model: China, Japan, Greece, South Korea, Singapore, Taiwan Province of China, Germany, and other countries.

New ordered vessels tend to use alternative fuels (Li et al., 2020). As more countries suggest raising the International Maritime Organization's green targets in advance of MEPC 78 meeting, with the aim of gradually eliminating all greenhouse gas emissions from shipping by 2050. This replaces the existing target of reducing emissions by 50% from the 2008 baseline. The contract date of new vessel order was obtained from the Clarkson database and transformed into monthly data to explore whether shipowners' preference for alternative fuels would change between 2020 and early 2023.

Research has shown that the freight market and shipbuilding market are interdependent (Beenstock, 1985; Xu & Yip, 2012), but it is not yet clear how freight rates affect shipowners' decision-making for newbuilding orders. ClarkSea Index is used to represent the overall freight market performance, reflecting a composite index of the daily earnings of bulk carriers, tankers, gas carriers, and container vessels weighted by the number of vessels in each category at the beginning of the year. In early 2022, the index added LNG and chemical vessels and now covers 80% of the world's fleet capacity. Shanghai Containerized Freight Index (SCFI) and Baltic Dry Index (BDI) were used to analyze container and bulk ships separately. In addition, Orderbook, which refers to the proportion of new ship capacity to total global fleet capacity, and Idle, which represents the global idle fleet rate, were used to demonstrate how the state of the freight market influences shipowners' decision-making, including whether the level of orders and market conditions affects their decisions. These data are matched on a monthly basis with the contract date of each newbuilding contract.

Fuel costs have also been shown to impact shipowners' response to emission abatement policies (Jiang et al., 2014). LNG is currently the most mature alternative fuel option. LNG bunker price is chosen as the cost of fuel to observe whether the high or low cost of LNG fuel affects shipowners' decision-making. Estimated LNG Bunker Price is obtained from the Clarkson database and matched with the contract date on a monthly basis.

Shipping is a highly capital-intensive market. Interest rates can affect shipowners' investment risk (Kavussanos & Visvikis, 2006). In late 2021, LIBOR quotations of different terms and currencies were successively discontinued and gradually replaced by risk-free rates such as SOFR, STR, and SONIA. This study uses SOFR to represent interest rates. Secured Overnight Financing Rate is an overnight rate based on the US Treasury repurchase market. It is denominated in US dollars and has been widely used as a benchmark for loan rates. The monthly data of SOFR is matched with the contract date.

The global carbon emissions trading system has been shown to influence shipping operations, deployment, and even the construction of more energy-efficient vessels to reduce costs (Zhu et al., 2018). The EU Emissions Trading System (ETS) main futures contract for European Union Allowances (EUA) is the most important carbon financial product in the European carbon trading system. We use CO_2 EUA Price data from the most mature carbon trading market in Europe to explore whether it affects shipowners' investment in alternative fueled vessels to achieve carbon emission abatement goals. The monthly data of CO_2 EUA Price is matched with the contract date.

Three models were established in this study: the full-sample model, dry bulk model, and container vessels model. The latter two are used to focus on analyzing decision-making of dry bulk and container shipowners. The logit regression model for the full sample is represented by the following equation:

$$\ln\frac{P_{ij}}{1-P_{ij}} = \beta 0 + \beta_1 DWT_i + \beta_2 NATION_i + \beta_3 TYPE_i + \beta_4 ClarkSeaIndex_i + \beta_5 \mathrm{CO_2Price}_i + \beta_6 LNGPrice_i + \beta_7 \mathrm{SOFR}_i + \beta_8 \mathrm{Idle}_i + \beta_9 \mathrm{Orderbook}_i + \beta_{10} \mathrm{ContractDate}_i \#(8)$$

In the container vessels model, ClarkSea Index is replaced by SCFI. The data for Idle and Orderbook are specific to the container vessel fleet and no longer include the type of vessel. The logit regression model for container vessels is represented by the following equation:

$$\ln\frac{P_{ij}}{1-P_{ij}} = \beta 0 + \beta_1 DWT_i + \beta_2 NATION_i + \beta_3 \mathrm{SCFI}_i + \beta_4 \mathrm{CO_2Price}_i + \beta_5 LNGPrice_i + \beta_6 \mathrm{SOFR}_i + \beta_7 \mathrm{Idle}_i + \beta_8 \mathrm{Orderbook}_i + \beta_9 \mathrm{ContractDate}_i \quad (9)$$

In the dry bulk model, ClarkSea Index is replaced by BDI. Due to the lack of data for Idle and Orderbook across the entire dry bulk fleet, these two variables are omitted in the model, along with vessel type. The logit regression model for dry bulk is represented by the following equation:

$$\ln \frac{P_{ij}}{1-P_{ij}} = \beta 0 \; + \; \beta_1 DWT_i + \beta_2 NATION_i + \beta_3 \mathrm{BDI}_i + \beta_4 \mathrm{CO_2Price}_i + \beta_5 LNGPrice_i + \beta_6 \mathrm{SOFR}_i + \beta_7 \mathrm{ContractDate}_i \tag{10}$$

4. Data and variable analysis

4.1. Data collection

The vessel orderbook data for this study is extracted from the Clarkson database for the period January 2020 to February 2023. The Alternative Fuel Types column will show the Alternative Fuel used for the vessel, while a blank indicates that the vessel is using conventional fuel, and the order information contains information such as order status, builder, contract date, gross tonnage (GT), deadweight tonnage (DWT), vessel type, expected date of construction, and owner, etc. In addition, the monthly data of ClarkSea Index, BDI, SCFI, CO2 EUA Price, LNG Bunker Price, SOFR, Idle, and Orderbook are found in the database and matched with the contract date. In the process of cleaning the data, individual orders with no dwt data were removed. The final sample contains 3928 vessels involving 1868 shipyards and 1759 shipping companies. Table 2 summarizes the number of merchant vessels categorized according to the vessel type in the sample.

Table 2 The number of merchant vessels categorized according to the vessel type

Vessel type	Number of Orders	Proportion
Bulk	1226	31.21%
Container	1050	26.73%
Tanker	137	3.49%
Gas carrier	470	11.97%
General Cargo	239	6.08%
Multi-Purpose	100	2.55%
Pure car	128	3.26%
Ro-Ro	39	0.99%

Vessel type	Number of Orders	Proportion
Chem & Oil	361	9.19%
Products	178	4.53%
Total	3928	100.00%

Data source: Clarkson

4.2. Descriptive statistics

4.2.1. Alternative fuels

We divided alternative fuels into six categories, Table 3 shows that among 3928 vessels, 69.09% used Conventional fuel, 15.33% used LNG Capable, 3.41% used LNG Ready, 2.77% used Methanol, and 3.87% use Ammonia, 5.52% use Other fuel, It can be seen that most shipowners still prefer LSF and scrubbers, with nearly 20% of shipowners choosing to install scrubbers in Conventional fueled vessels, which is consistent with the results of other studies on in-service fleets (Li et al., 2020). With the gradual development and completion of fuel supply and fueling facilities, LNG is still the main choice of alternative fuel, followed by methanol and ammonia fuel, which have appeared to have a significant increase in proportion compared to previous studies (Zhang et al., 2021). These fuels have made some progress in development. In terms of tonnage ratio, ammonia fuel can account for 8.23%, and its development speed is faster than that of methanol. Hydrogen fuel cells have not appeared in Alternative Fuel as it still is in the development stage.

Table 3 Fuel selection distribution statistics

Alternative fuel	Number of Orders	Proportion	Tonnage (Million)	Proportion
Conventional fuel	2714	69.09%	152.6463	60.24%

Alternative fuel	Number of Orders	Proportion	Tonnage (Million)	Proportion
LNG Capable	602	15.33%	60.1423	23.73%
LNG Ready	134	3.41%	1.3165	0.52%
Methanol	109	2.77%	10.7172	4.23%
Ammonia	152	3.87%	20.8534	8.23%
Other fuel	217	5.52%	7.7204	3.05%
Total	3928	100%	253.3961	100%

Data source: Clarkson

According to Table 4, which summarizes the new building prices of 13,000-15,000 TEU container vessels, the average TEU of conventional fuels is at a high level, but their newbuilding price is the lowest among all alternative fueled vessels. This indicates that the newbuilding price of unconventional alternative fueled vessels is much higher than that of conventional fueled vessels. Methanol fueled vessels are nearly 40% more expensive than conventional fueled vessels.

Table 4 Fuel selection distribution statistics according to TEU and newbuilding price

	Conventional	LNG Capable	LNG Ready	Methanol	Ammonia
Average TEU	14818.2	14939.8	13078.0	13000.0	15000.0
Average NB Price($m)	122.4	153.2	124.2	171.4	140.4

Data source: Clarkson

4.2.2. Vessel type analysis

Table 5 shows different alternative fueled vessels chosen for different vessel types. It can be seen that different vessel types have preferences for different alternative fuels.

The proportion of conventional fueled vessels is over 70% for Bulk, General Cargo, Multi-Purpose, Ro-Ro, Chem & Oil, and Products. Bulk even reaches 93.3%. Shipowners are not willing to invest in alternative fuels for bulk carriers. Compared with container vessels with a sample size of more than 1000, they have stable returns, high costs, and fixed routes, while the routes of bulk carriers are not fixed and the distance of a single voyage is longer. The use of conventional fuel can provide sufficient power and sailing time without frequent refueling and supply, which improves sailing efficiency and economy to a certain extent. The bulk shipping market has been in a downturn for many years (Yang et al., 2021), with poor market returns, and shipping companies are unwilling to try expensive alternative fuels. This may be why most bulk shipowners choose conventional fuels. In a survey conducted in November 2022 (S&P Global Commodity Insights, 2022), 112 respondents including shipowners, ship operators, charterers, brokers, and analysts, most participants expect that the returns of different dry bulk carrier types such as Capesize, Panamax, and Supramax in 2023 will be almost the same, with the market overall downturn, only one-third of dry bulk shipping practitioners expect that new orders in the next five years will use alternative fuels. In addition, the demand of dry bulk cargo owners for emissions reduction is also low (Poulsen et al., 2020). In contrast, more than 35% of container shipowners in the orderbook data chose alternative fuels. 55% of Gas carriers and 60% of Pure car use LNG fuel, because gas carriers themselves have the storage space needed for LNG. Multi-Purpose vessels will choose methanol more than other vessel types, and Tankers and Pure car vessels will have a higher proportion of ammonia. It is worth mentioning that Pure cars all use alternative fuels instead of conventional fuels. The proportions of Gas carriers, Pure cars, and Ro-Ro choosing other fuels are also high, including battery, LPG, ethane, and other blended fuels.

Table 5 The number of merchant vessels categorized according to the vessel type

Vessel type	Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels	Total
Bulk	93.3%	3.7%	0.4%	0.2%	2.4%	0.0%	1226
Container	64.6%	14.8%	7.3%	7.5%	5.2%	0.6%	1050
Tanker	48.9%	13.1%	18.2%	0.0%	18.2%	1.5%	137
Gas carrier	15.3%	55.7%	0.0%	0.0%	3.0%	26.0%	470
General Cargo	90.8%	1.3%	0.0%	0.0%	0.0%	7.9%	239
Multi-Purpose	82.0%	0.0%	0.0%	10.0%	0.0%	8.0%	100
Pure car	0.0%	60.9%	0.0%	5.5%	14.8%	18.8%	128
Ro-Ro	71.8%	7.7%	0.0%	0.0%	0.0%	20.5%	39
Chem & Oil	82.5%	3.0%	5.5%	1.1%	1.9%	5.8%	361
Products	71.9%	15.2%	3.9%	3.9%	1.1%	3.9%	178

Data source: Clarkson

4.2.3. Dwt analysis

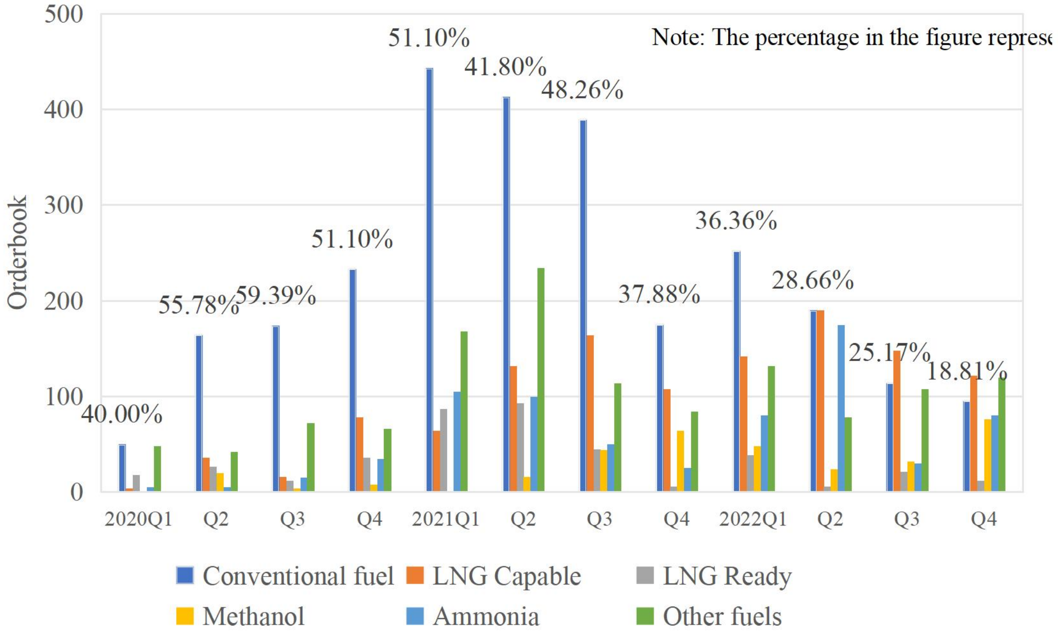
From Table 6, we can see that the average and minimum Dwt of new ships using LNG, Methanol and Ammonia fuel are much higher than Conventional fuels, and the larger the ships, the more willing the shipowners are to use these alternative fuels, where the average and minimum Dwt of new ships using Ammonia fuel are the largest. Due to the large number of Battery ships and their technical bottleneck of battery energy density, at this stage electric ships are mainly used in small and medium-sized vessels with very small Dwt.

Table 6 Statistical description of newbuilding vessels' DWT according to alternative fuels

Alternative fuel	DWT				
	Mean	Std. Dev.	Max.	Min.	Median
Conventional fuel	56244.03	53214.68	319202	72	42000
LNG Capable	99904.07	63507.25	309000	2500	96000
LNG Ready	98246.87	88293.42	300927	110	50000
Methanol	98322.62	71696.05	225000	4000	81000
Ammonia	137193.59	86235.12	321020	18000	145000
Other fuels	35578.10	25643.35	157000	38	30000
Total	67526.65	62069.33	321020	38	55000

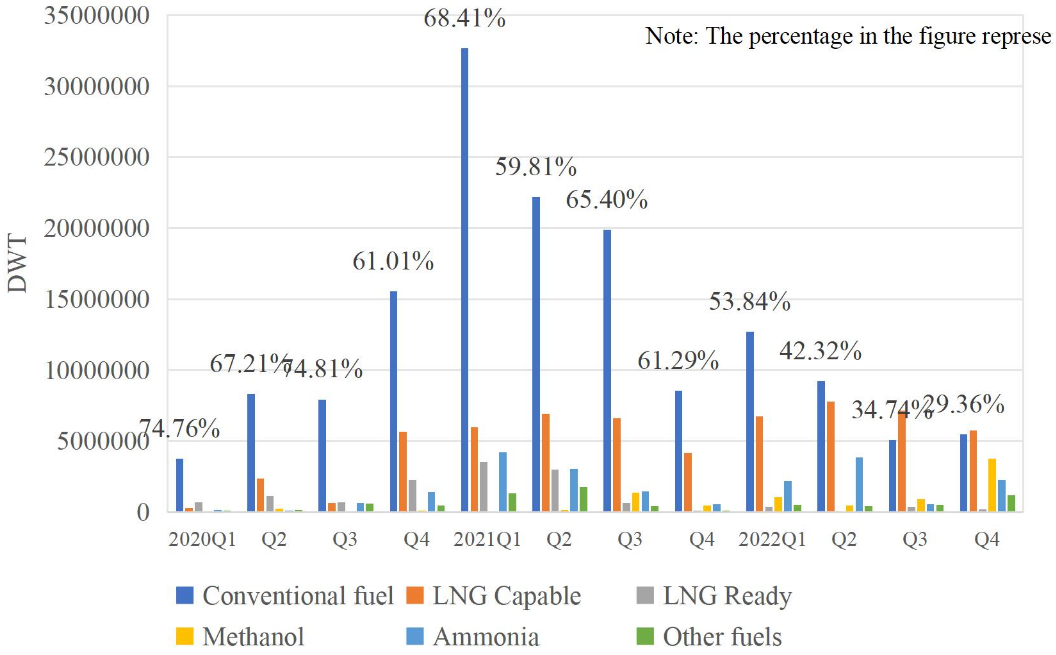
Data source: Clarkson

4.2.4. Contract date analysis



Data source: Clarkson

Figure 1 The contract date of the orderbooks according to alternative fuels



Data source: Clarkson

Figure 2 The contract date of the orderbooks' Dwt according to alternative fuels

According to Figure 1, orderbooks from 2020 to 2022 were classified by different fuels. In 2020, due to the impact of COVID-19, there were very few orderbooks, and most shipowners chose conventional fuel. The percentage in the figure shows the proportion of new vessels using conventional fuel. It can be seen that since the third quarter of 2020, the proportion of conventional fuel has continued to decline, dropping to 18.81% by the end of 2022. At the same time, the number of shipowners choosing LNG Ready has been decreasing, while the number of those choosing LNG Capable has been increasing. For achieving the mid-term emissions reduction target in 2030, LNG is the preferred choice of shipowners. In addition, ammonia and methanol have shown an upward trend after Q3 2021. Various technologies related to the production, storage, and use of new alternative fuels are becoming increasingly mature, and more and more shipowners are trying alternative fuels other than LNG. According to Figure 2, the decline trend of conventional fuels is basically consistent with Figure 1, but it is worth mentioning that by Q4 in 2022, compared with 18% of the order volume, conventional fuels still account for nearly 30% from the perspective of Dwt, and the mainstream alternative fuels are LNG and methanol

4.2.5. Shipowners analysis

According to Table 7, we can see the top ten shipowners in terms of orderbook volume. None of them use more than four types of fuel among the six categories listed. Companies such as CDB Leasing, Wan Hai, SITC, Evergreen and Nisshin use conventional fuel for their ships. Eastern Pacific Shpg, CMA CGM and MSC have a large number of LNG fueled orders. In addition, CMA CGM has many methanol fuel orders, MSC has many ammonia fuel orders, and Eastern Pacific Shpg has many other fuel orders, including six ethane fueled orders. In March 2023, Maersk Broker reported that all sizes of available ships for rental are very scarce, therefore these shipowners would tend to adopt diversified emission abatement solutions rather than relying on a single choice.

Table 7 Top ten shipowners in terms of orderbook volume

Rank of the number of orders		Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels
1	Eastern Pacific Shpg	33	32	2	0	0	26
2	CDB Leasing	81	0	0	0	0	0
3	CMA CGM	16	45	0	18	0	0
4	MSC	12	34	3	0	26	0
5	Seaspan Corporation	40	20	0	0	5	0
6	BoCom Leasing	36	18	0	0	0	0

Rank of the number of orders		Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels
7	Wan Hai	48	0	0	0	0	0
8	SITC	47	0	0	0	0	0
9	Evergreen	47	0	0	0	0	0
10	Nisshin	45	0	0	0	0	0

Data source: Clarkson

Furthermore, we conducted a survey of the top ten shipping companies in the world according to market share to investigate their use of alternative fuels, as shown in Table 8. Evergreen and Wan Hai have not chosen any alternative fuels besides conventional fuels. Hapag-Lloyd and HMM mostly use LNG, while Maersk has not ordered any conventional fuel or LNG ships. Maersk does not have an excessive plan to use LNG as a temporary fuel, and has been experimenting with other alternative fuels such as methanol and ammonia (Maersk, 2020). Currently, Maersk's new vessel orders are focused on methanol. All new orderbooks from ONE have selected ammonia. This result differs from previous research where ONE ordered LNG-fueled vessels (Zhang et al., 2021). MSC, CMA CGM, COSCO, on the other hand, are relatively diverse, covering three or more types of fuels.

Table 8 Top ten shipping companies in terms of orderbook volume

Top 10 shipowners		Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels
1	Maersk	0	0	0	19	0	0
2	MSC	12	34	3	0	26	0
3	CMA CGM	16	45	0	18	0	0
4	COSCO	48	8	0	12	0	2

	Top 10 shipowners	Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels
5	Hapag-Lloyd	0	12	0	0	0	0
6	ONE	0	0	0	0	10	0
7	Evergreen	47	0	0	0	0	0
8	HMM	3	0	12	0	0	0
9	Yang ming	0	0	0	0	0	0
10	Wan Hai	48	0	0	0	0	0

Data source: Clarkson

Regarding the nationality of shipowners, our sample covered shipowners from 83 different countries. We selected the top 7 countries, which accounted for over 75% of all orders. From Table 9, it can be seen that the majority of the top-ranking countries' new vessel orders are dominated by conventional fuels. However, Greece, South Korea, and Singapore have relatively higher proportions of orders using alternative fuels. Korean shipowners have shifted from their original tendency to install scrubbers on conventional fueled vessels to using alternative fuels for emission reduction (Kim & Seo, 2019). Shipowners from China and Japan, the two major shipbuilding countries, still use alternative fuels to a lesser extent.

Table 9 Top 7 countries in terms of orderbook volume

	Top 7 countries	Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels	Total
1	China	909	83	31	19	0	20	1062
2	Japan	674	83	0	7	17	26	807
3	Greece	232	54	36	6	15	18	361
4	South Korea	87	67	31	1	0	18	204

Top 7 countries		Conventional fuel	LNG Capable	LNG Ready	Methanol	Ammonia	Other fuels	Total
5	Singapore	100	43	6	9	8	27	193
6	Taiwan, China	170	4	0	0	0	0	174
7	Germany	103	19	10	18	6	11	167

Data source: Clarkson

5. Empirical analysis

5.1. Model fitting

This study used Stata17 software for multinomial logit model, and the results of the likelihood ratio test for the model are shown in Table 10, which is a commonly used model fitting evaluation method for MNL (Mazzanti, 2003). The LR chi-squared test statistic is an indicator of the overall goodness of fit of the model, testing the joint significance of all variables except the constant. The p-values are all 0, which means that compared with the model containing only the constant term, the model from overall better fit, so this set of explanatory variables has a significant effect on the explained variables. Log likelihood is calculated for the null model containing only one constant variable and the full model containing all explanatory variables, which can be used for comparison of nested models.

Pseudo R2, also known as McFadden's R2, is a likelihood ratio index used to compare the relative size of log-likelihood values between models that include only the constant term and those that include all explanatory variables. The higher the value, the better the fit of the model. An R2 value between 0.2 and 0.4 is considered "very satisfactory" (Law, 2010). The full sample model has an R2 value of 0.5007, the container vessels model has an R2 value of 0.4998, and the dry bulk model has an R2 value of 0.5909. These results indicate that all three models have a very good fit.

Table 10 Likelihood ratio test for the MNL model

Regression Model	LR chi2	Prob > chi2	Log likelihood	Pseudo R2
Full sample model	4103.96	0.0000	-2046.64	0.5007
Container model	1191.45	0.0000	-596.122	0.4998

Dry bulk model	448.56	0.0000	-155.288	0.5909

Finally, we compared the percent correct results of the three regression models, as shown in Table 11. Since the other fuels did not appear in the dry bulk model, there were no other fuel data. Full sample model, container model, and dry bulk model, the overall percent correct was 80.60%, 76.00% and 96.41%. Among them, the full sample model and container model had a higher percent correct for LNG Capable options, reaching more than 60%. The model helps explain the fuel choices for new shipbuilding orders.

Table 11 The percent correct results of the MNL model

Alternative fuel	Full	Container	Dry bulk
	Percent correct	Percent correct	Percent correct
Conventional fuel	96.17%	92.33%	99.48%
LNG Capable	64.29%	60.65%	35.56%
LNG Ready	4.48%	15.58%	0.00%
Methanol	39.45%	37.97%	100.00%
Ammonia	42.76%	54.55%	86.67%
Other fuels	25.35%	100.00%	(-)
Total	80.60%	76.00%	96.41%

5.2. Parameter estimates

First, we used the likelihood ratio test of explanatory variables to evaluate whether each explanatory variable alone is significant for the dependent variable of the entire model, as shown in Table 12. We found that in the full sample model, Dwt, Nationality, TYPE, LNG Bunker Price, Idle, Orderbook, ClarkSea Index, and CO2 EUA Price were significant ($p < 0.01$), and Contract Date was significant ($p < 0.05$). For the container model, Dwt, Nationality, LNG Bunker Price, SOFR, Idle, Orderbook, and CO2 EUA Price were significant ($p < 0.01$), and Contract Date was significant ($p < 0.05$). For the dry bulk model, only Dwt was significant ($p < 0.01$), and there were fewer significant explanatory variables, possibly because the proportion of dry bulk shipowners choosing conventional fuel is as high as 93.3%, and there are very few who choose alternative fuels, resulting in a small sample size.

Table 12 Likelihood ratio test of explanatory variables

Explanatory variable	Full		Container		Dry bulk	
	Chi-Square	Sig	Chi-Square	Sig	Chi-Square	Sig
Dwt	438.42	0.000	123.28	0.000	86.69	0.000
Nation	461.31	0.000	138.94	0.000	31.09	0.313
Type	732.8	0.000	(-)	(-)	(-)	(-)
ClarkSea Index	17.6	0.004	(-)	(-)	(-)	(-)
BDI	(-)	(-)	(-)	(-)	1.38	0.848
SCFI	(-)	(-)	7.46	0.189	(-)	(-)
CO2 EUA price	18.96	0.002	16.8	0.005	4.11	0.391
LNG Bunker price	37.52	0.000	23.03	0.000	3.01	0.556
SOFR	3.79	0.579	35.39	0.000	4.95	0.293
Idle	25.26	0.000	36.94	0.000	(-)	(-)
Orderbook	55.37	0.000	30.11	0.000	(-)	(-)
Contract Date	12.4	0.030	12.66	0.027	1.94	0.747

Next, to investigate whether the explanatory variables have differential effects on the different groups, we performed a Wald test on the model. One of the main advantages of MNL is to determine the specific impact of particular explanatory variables on each group. The Wald test measures the significance of the specific explanatory variables by rejecting the null hypothesis that the estimates equal to zero. Conventional fuel was set as the baseline group and was used to compare with other alternative fuels. Table 13-17 shows the parameter estimates and Wald test results. Since the Other fuels did not appear in the dry bulk model, there were no other fuel data. The coefficient represents the estimated coefficient of MNL, and the RRR represents relative risk, indicating the change of odds ratio for each explanatory variable with respect to the reference group. It is obtained by raising the estimated coefficient to a power. The economic interpretation of the relative risk coefficient is the change in log odds of selecting a certain category relative to the reference group caused by a one-unit change in the explanatory variable. An RRR greater than 1 indicates that when the explanatory variable increases, the log odds of choosing that option group increases; an RRR less than 1 indicates that when the explanatory variable increases, the log odds of choosing that option group decreases; and when the RRR is equal to 1, it means that the change in the explanatory variable does not affect the log odds of that group.

Table 13 The parameter estimates and Wald test results of LNG Capable

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
Constant	-7.44169 (0.810)	(–)	54.75876 (0.446)	(–)	-44.70662 (0.994)	(–)
DWT	0.00003***(0.000)	1.00003	0.00004***(0.000)	1.00004	0.00002***(0.000)	1.00003
NATION(China)	-2.62575***(0.000)	0.07239	-34.60588 (1.000)	9.35E-16	18.68775 (0.998)	1.31E+08
NATION(Japan)	-2.33336***(0.000)	0.09697	-3.43150***(0.000)	0.03234	19.10008 (0.998)	1.97E+08
NATION(Greece)	-2 167969***(0.000)	0.11441	-2.13920***(0.006)	0.11775	19.88398 (0.998)	4.32E+08
NATION(South Korea)	-1.30550***(0.000)	0.27104	-2.03450***(0.004)	0.13074	43.84424 (0.999)	1.10E+19
NATION(Singapore)	-0.36928 (0.154)	0.69123	0.60790 (0.111)	1.83660	21.67491 (0.997)	2.59E+09
NATION(Taiwan, China)	-3.52629***(0.000)	0.02941	-34.85840 (1.000)	7.26E-16	19.74575 (0.998)	3.76E+08
NATION(Germany)	0.00267 (0.994)	1.00267	0.86793*(0.099)	2.39198	0.38945 (1.000)	1.47617
NATION(Norway)	0.38400 (0.342)	1.46815	(–)	(–)	(–)	(–)
NATION(Italy)	0.13630 (0.716)	1.14603	(–)	(–)	(–)	(–)
NATION(Netherlands)	-2.13826***(0.009)	0.11786	(–)	(–)	(–)	(–)
NATION(Others)+	(–)	(–)	(–)	(–)	(–)	(–)
TYPE(Bulk)	-3.171348***(0.000)	0.01517	(–)	(–)	(–)	(–)
TYPE(Container)	-1.40137***(0.000)	0.08005	(–)	(–)	(–)	(–)
TYPE(Tanker)	-4.00831***(0.000)	0.00927	(–)	(–)	(–)	(–)
TYPE(Gas carrier)	3 147586***(0.000)	7.86988	(–)	(–)	(–)	(–)
TYPE(General Cargo)	-2.02515***(0.003)	0.09109	(–)	(–)	(–)	(–)
TYPE(Multi-Purpose)	-21.09775 (0.998)	0.00001	(–)	(–)	(–)	(–)
TYPE(Pure car)	25.11180 (0.997)	5.83E+14	(–)	(–)	(–)	(–)
TYPE(Ro-Ro)	-0.35942 (0.634)	0.52678	(–)	(–)	(–)	(–)
TYPE(Chem & Oil)	-1.41362***(0.001)	0.10693	(–)	(–)	(–)	(–)
TYPE(Products)+	(–)	(–)	(–)	(–)	(–)	(–)
ClarkSea Index	-3.01E-06 (0.915)	0.00003	(–)	(–)	(–)	(–)

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
BDI	(–)	(–)	(–)	(–)	-0.00029 (0.303)	0.99971
SCFI	(–)	(–)	0.00074 (0.105)	1.00074	(–)	(–)
CO2 EUA Price	-0.03923***(0.002)	0.96153	-0.08900***(0.000)	0.91477	0.02196 (0.459)	1.02221
LNG Bunker Price	0.00069***(0.000)	1.00069	0.00047 (0.309)	1.00047	0.00011 (0.826)	1.00011
SOFR	-0.11567 (0.470)	0.89077	0.79769 (0.121)	2.22041	-0.32961 (0.507)	0.71921
IDLE	-1.37934***(0.000)	0.25174	-1.17620***(0.000)	0.30842	(–)	(–)
ORDERBOOK	1 540146***(0.000)	4.66527	0.49488***(0.000)	1.64030	(–)	(–)
CONTRACT	-0.00239 (0.954)	0.99761	-0.08590 (0.388)	0.91769	0.02530 (0.834)	1.02562

* : significant at the 0.1 level.

** : significant at the 0.05 level.

*** : significant at the 0.01 level.

Table 14 The parameter estimates and Wald test results of LNG Ready

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
Constant	-44.08021 (0.345)	(–)	-43.21814 (0.547	(–)	16.69389 (0.909)	(–)
DWT	0.00001***(0.000)	1.00001	0.00001***(0.000)	1.00001	-2.17E-06 (0.869)	1.00E+00
NATION(China)	0.12237 (0.720)	1.13017	1.38177**(0.032)	3.98192	-0.25653 (0.833)	0.77373
NATION(Japan)	-19.21765 (0.997)	4.51E-09	-31.56311 (1.000)	1.96E-14	-19.95647 (0.999)	2.15E-09
NATION(Greece)	1.29652***(0.000)	3.65652	3.41716***(0.000)	30.48257	-19.44004 (0.999)	3.61E-09
NATION(South Korea)	1.86690***(0.000)	6.46822	3.63792***(0.000)	38.01274	0.80533 (1.000)	2.23743
NATION(Singapore)	0.19352 (0.708)	1.21351	1.20781 (0.201)	3.34614	-21.06477 (1.000)	7.11E-10
NATION(Taiwan, China)	-20.95086 (0.998)	7.96E-10	-31.22629 (1.000)	2.75E-14	-20.09883 (1.000)	1.87E-09
NATION(Germany)	1.47886***(0.001)	4.38792	3.44465***(0.000)	31.33238	2.72102*(0.092)	15.19586
NATION(Norway)	2.05580***(0.005)	7.81306	(–)	(–)	(–)	(–)
NATION(Italy)	0.85026 (0.220)	2.34025	(–)	(–)	(–)	(–)
NATION(Netherlands)	-19.55563 (0.999)	3.21E-09	(–)	(–)	(–)	(–)
NATION(Others)+	(–)	(–)	(–)	(–)	(–)	(–)
TYPE(Bulk)	-2.31355***(0.000)	0.09891	(–)	(–)	(–)	(–)
TYPE(Container)	0.82867*(0.063)	2.29026	(–)	(–)	(–)	(–)
TYPE(Tanker)	0.32131 (0.549)	1.37894	(–)	(–)	(–)	(–)
TYPE(Gas carrier)	-19.03630 (0.998)	5.40E-09	(–)	(–)	(–)	(–)
TYPE(General Cargo)	-19.74675 (0.998)	2.66E-09	(–)	(–)	(–)	(–)
TYPE(Multi-Purpose)	-21.43609 (0.999)	4.90E-10	(–)	(–)	(–)	(–)
TYPE(Pure car)	2.04284 (1.000)	7.71249	(–)	(–)	(–)	(–)
TYPE(Ro-Ro)	-19.59276 (0.999)	3.10E-09	(–)	(–)	(–)	(–)
TYPE(Chem & Oil)	0.39370 (0.422)	1.48246	(–)	(–)	(–)	(–)
TYPE(Products)+	(–)	(–)	(–)	(–)	(–)	(–)
ClarkSea Index	0.00001 (0.784)	1.00001	(–)	(–)	(–)	(–)

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
BDI	(–)	(–)	(–)	(–)	-0.00086 (0.511)	0.99914
SCFI	(–)	(–)	0.00010 (0.828)	1.00010	(–)	(–)
CO2 EUA Price	-0.04002*(0.055)	0.96077	-0.04662 (0.122)	0.95445	-0.04888 (0.508)	0.95230
LNG Bunker Price	-0.00049 (0.148)	0.99951	-0.00108*(0.066)	0.99892	0.00180 (0.149)	1.00181
SOFR	0.00641 (0.978)	1.00643	-0.15351 (0.759)	0.85769	0.12419 (0.903)	1.13223
IDLE	0.41295 (0.378)	1.51127	0.99809***(0.001)	2.71309	(–)	(–)
ORDERBOOK	0.54287 (0.177)	1.72094	0.16102*(0.087)	1.17471	(–)	(–)
CONTRACT	0.04892 (0.431)	1.05014	0.04899 (0.621)	1.05021	-0.02630 (0.898)	0.97405

* : significant at the 0.1 level.

** : significant at the 0.05 level.

*** : significant at the 0.01 level.

Table 15 The parameter estimates and Wald test results of Methanol

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
Constant	-128.46750**(0.011)	(–)	-34.13589 (0.845)	(–)	6861.56100 (0.998)	(–)
DWT	0.00002***(0.000)	1.00002	0.00004***(0.000)	1.00004	0.00154 (0.982)	1.00154
NATION(China)	-2.17885***(0.000)	0.11317	-5.07549***(0.000)	0.00625	-51.52334 (0.998)	4.20E-23
NATION(Japan)	-1.31995**(0.013)	0.26715	-32.61336 (1.000)	6.86E-15	95.72668 (0.995)	3.88E+41
NATION(Greece)	-1.64974**(0.010)	0.19210	0.20420 (0.737)	1.22654	91.97311 (0.997)	8.78E+39
NATION(South Korea)	-2.37400**(0.022)	0.09311	-33.13606 (1.000)	4.07E-15	103.77730 (1.000)	1.17E+45
NATION(Singapore)	-0.27263 (0.535)	0.76137	1.40457**(0.011)	4.07379	59.62739 (0.999)	7.87E+25
NATION(Taiwan, China)	-18.94310 (0.994)	5.93E-09	-32.87795 (1.000)	5.26E-15	58.62238 (0.999)	2.88E+25
NATION(Germany)	1.24129***(0.002)	3.46006	2.80113***(0.000)	16.46331	129.24350 (0.997)	1.35E+56
NATION(Norway)	-18.02162 (0.999)	1.49E-08	(–)	(–)	(–)	(–)
NATION(Italy)	-17.83824 (0.991)	1.79E-08	(–)	(–)	(–)	(–)
NATION(Netherlands)	-0.36558 (0.629)	0.69379	(–)	(–)	(–)	(–)
NATION(Others)+	(–)	(–)	(–)	(–)	(–)	(–)
TYPE(Bulk)	-4.61395***(0.000)	0.00991	(–)	(–)	(–)	(–)
TYPE(Container)	0.01263 (0.983)	1.01271	(–)	(–)	(–)	(–)
TYPE(Tanker)	-18.38427 (0.990)	1.04E-08	(–)	(–)	(–)	(–)
TYPE(Gas carrier)	-15.88385 (0.991)	1.26E-07	(–)	(–)	(–)	(–)
TYPE(General Cargo)	-17.21881 (0.991)	3.33E-08	(–)	(–)	(–)	(–)
TYPE(Multi-Purpose)	-0.46252 (0.521)	0.62970	(–)	(–)	(–)	(–)
TYPE(Pure car)	22.52423 (0.998)	6.06E+09	(–)	(–)	(–)	(–)
TYPE(Ro-Ro)	-16.00095 (0.995)	1.12E-07	(–)	(–)	(–)	(–)
TYPE(Chem & Oil)	-1.66680**(0.035)	0.18885	(–)	(–)	(–)	(–)
TYPE(Products)+	(–)	(–)	(–)	(–)	(–)	(–)
ClarkSea Index	-0.00018***(0.000)	0.99982	(–)	(–)	(–)	(–)

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
BDI	(–)	(–)	(–)	(–)	-0.01040 (1.000)	0.98965
SCFI	(–)	(–)	0.00069 (0.340)	1.00069	(–)	(–)
CO2 EUA Price	-0.06363***(0.002)	0.93835	-0.09027***(0.007)	0.91369	5.37469 (0.991)	215.87380
LNG Bunker Price	0.00009 (0.728)	1.00009	-0.00182***(0.004)	0.99819	-0.10108 (0.998)	0.90392
SOFR	0.06366 (0.819)	1.06573	0.31303 (0.678)	1.36756	67.05461 (0.997)	1.32E+29
IDLE	0.56415 (0.234)	1.75796	0.76426 (0.188)	2.14740	(–)	(–)
ORDERBOOK	3.99885***(0.000)	54.53527	0.89120 ***(0.005)	2.43805	(–)	(–)
CONTRACT	0.12622*(0.061)	1.13453	0.01697 (0.945)	1.01712	-10.21571 (0.998)	0.00004

* : significant at the 0.1 level.

** : significant at the 0.05 level.

*** : significant at the 0.01 level.

Table 16 The parameter estimates and Wald test results of Ammonia

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
Constant	-178.59400***(0.007)	(–)	0.90454***(0.001)	(–)	211.21240 (0.190)	(–)
DWT	0.00003***(0.000)	1.00003	0.00005***(0.000)	1.00005	0.00005***(0.000)	1.00005
NATION(China)	-20.78155 (0.995)	9.43E-10	-35.92073 (1.000)	2.51E-16	-22.07413 (0.995)	2.59E-10
NATION(Japan)	-1.31741***(0.000)	0.26783	-2.22595***(0.009)	0.10796	-4.07630***(0.001)	0.01697
NATION(Greece)	-1.04635***(0.009)	0.35122	-33.26895 (1.000)	3.56E-15	-21.18284 (0.998)	6.32E-10
NATION(South Korea)	-22.60451 (0.999)	1.52E-10	-35.98033 (1.000)	2.37E-16	-3.95550 (1.000)	0.01915
NATION(Singapore)	0.02643 (0.954)	1.02678	1.39439**(0.024)	4.03252	-22.33015 (0.999)	2.01E-10
NATION(Taiwan, China)	-21.20268 (0.998)	6.19E-10	-38.31593 (1.000)	2.29E-17	-22.50216 (0.999)	1.69E-10
NATION(Germany)	0.76862 (0.134)	2.15678	2.43402***(0.001)	11.40468	-19.89098 (0.999)	2.30E-09
NATION(Norway)	2.51354***(0.000)	12.34852	(–)	(–)	(–)	(–)
NATION(Italy)	2.20550***(0.000)	9.07480	(–)	(–)	(–)	(–)
NATION(Netherlands)	2.20811***(0.002)	9.09849	(–)	(–)	(–)	(–)
NATION(Others)+	(–)	(–)	(–)	(–)	(–)	(–)
TYPE(Bulk)	0.01828 (0.983)	1.01845	(–)	(–)	(–)	(–)
TYPE(Container)	0.92248 (0.278)	2.51552	(–)	(–)	(–)	(–)
TYPE(Tanker)	0.42674 (0.645)	1.53226	(–)	(–)	(–)	(–)
TYPE(Gas carrier)	3.68185***(0.000)	39.71967	(–)	(–)	(–)	(–)
TYPE(General Cargo)	-17.10371 (0.998)	3.73E-08	(–)	(–)	(–)	(–)
TYPE(Multi-Purpose)	-20.43797 (0.999)	1.33E-09	(–)	(–)	(–)	(–)
TYPE(Pure car)	26.26722 (0.997)	2.56E+11	(–)	(–)	(–)	(–)
TYPE(Ro-Ro)	-16.10865 (0.998)	1.01E-07	(–)	(–)	(–)	(–)
TYPE(Chem & Oil)	1.94339**(0.041)	6.98237	(–)	(–)	(–)	(–)
TYPE(Products)+	(–)	(–)	(–)	(–)	(–)	(–)
ClarkSea Index	0.00001 (0.776)	1.00001	(–)	(–)	(–)	(–)

	Full		Container		Dry bulk	
	Coe (Sig)	RRR	Coe (Sig)	RRR	Coe (Sig)	RRR
BDI	(–)	(–)	(–)	(–)	-0.00012 (0.800)	0.99988
SCFI	(–)	(–)	-0.00124 (0.152)	0.99876	(–)	(–)
CO2 EUA Price	-0.02651 (0.180)	0.97384	-0.11289**(0.023)	0.89325	0.13184*(0.073)	1.14093
LNG Bunker Price	-0.00090***(0.005)	0.99910	-0.00143 (0.114)	0.99857	-0.00107 (0.267)	0.99893
SOFR	-0.60540*(0.061)	0.54585	-4.27476***(0.000)	0.01392	1.60966 **(0.035)	5.00112
IDLE	-0.37785 (0.481)	0.68533	1.22425 (0.121)	3.40160	(–)	(–)
ORDERBOOK	0.59793 (0.214)	1.81834	0.36263 (0.123)	1.43710	(–)	(–)
CONTRACT	0.23102**(0.010)	1.25988	0.90454***(0.001)	2.47081	-0.30773 (0.172)	0.73511

* : significant at the 0.1 level.

** : significant at the 0.05 level.

*** : significant at the 0.01 level.

Table 17 The parameter estimates and Wald test results of Other fuels

	Full		Container	
	Coe (Sig)	RRR	Coe (Sig)	RRR
Constant	-50.68646 (0.173)	(–)	-3.13E+05 (0.987)	(–)
DWT	-0.00001***(0.008)	0.99999	-0.09465 (0.987)	0.90969
NATION(China)	-3.23106***(0.000)	0.03952	-505.44350 (0.988)	3.10E-220
NATION(Japan)	-3.09387***(0.000)	0.04533	-523.24500 (0.998)	5.70E-228
NATION(Greece)	-2.10179***(0.000)	0.12224	136.49010 (0.998)	1.89E+59
NATION(South Korea)	-1.57107***(0.000)	0.20782	-26.04314 (0.998)	4.89E-12
NATION(Singapore)	0.19471 (0.565)	1.21495	100.62760 (1.000)	5.03E+43
NATION(Taiwan, China)	-20.51457 (0.998)	1.23E-09	252.47260 (0.999)	4.40E+109
NATION(Germany)	-0.93367**(0.031)	0.39311	509.51730 (0.999)	1.90E+221
NATION(Norway)	1.25358***(0.002)	3.50285	(–)	(–)
NATION(Italy)	-25.23486 (1.000)	1.10E-11	(–)	(–)
NATION(Netherlands)	-2.19618***(0.001)	0.11123	(–)	(–)
NATION(Others)+	(–)	(–)	(–)	(–)
TYPE(Bulk)	-19.68896 (0.995)	2.81E-09	(–)	(–)
TYPE(Container)	-1.65336***(0.006)	0.19141	(–)	(–)
TYPE(Tanker)	0.28463 (0.760)	1.32927	(–)	(–)
TYPE(Gas carrier)	4.56649***(0.000)	96.20563	(–)	(–)
TYPE(General Cargo)	0.22280 (0.673)	1.24958	(–)	(–)
TYPE(Multi-Purpose)	0.03523 (0.954)	1.03586	(–)	(–)
TYPE(Pure car)	24.63360 (0.997)	4.99E+10	(–)	(–)
TYPE(Ro-Ro)	1.24791*(0.068)	3.48304	(–)	(–)
TYPE(Chem & Oil)	0.04276 (0.931)	1.04369	(–)	(–)
TYPE(Products)+	(–)	(–)	(–)	(–)
ClarkSea Index	-0.00005 (0.101)	0.99995	(–)	(–)

	Full		Container	
	Coe (Sig)	RRR	Coe (Sig)	RRR
BDI	(–)	(–)	(–)	(–)
SCFI	(–)	(–)	-0.06381 (0.993)	0.93818
CO2 EUA Price	-0.03889**(0.014)	0.96186	-103.80610 (0.987)	8.27E-46
LNG Bunker Price	0.00027 (0.243)	1.00027	-0.37440 (0.990)	0.68771
SOFR	-0.03527 (0.853)	0.96535	-1465.02400 (0.987)	0.00001
IDLE	-0.30111 (0.401)	0.74000	445.50450 (0.988)	3.00E+193
ORDERBOOK	1.37820***(0.000)	3.96775	-109.89460 (0.988)	1.88E-48
CONTRACT	0.05545(0.265)	1.05702	436.80920 (0.987)	5.10E+189

* : significant at the 0.1 level.

** : significant at the 0.05 level.

*** : significant at the 0.01 level.

5.3. Discussion and implication

5.3.1. The impact of the DWT on decisions of ordering alternative fueled new vessels

Among the many factors, the explanatory variable Dwt has a significant impact on the explained variable of all three models. Vessels with smaller Dwt tend to use conventional or other fuels, including many small vessels that use battery power. However, in terms of RRR, they are all close to 1, and the distinguishing effect of Dwt on different alternative fuels is not very clear. In the full sample model, shipowners tend to choose LNG and ammonia for vessels with larger Dwt, followed by methanol. In the container model and the dry bulk model, vessels with larger Dwt tend to prefer LNG. In the container model, for each unit increase in Dwt, the increase in the probability of choosing LNG is 2.8 times that of methanol and 2.6 times that of ammonia, with a significance level of $p < 0.01$. In the dry bulk model, it is more biased towards methanol, but the influence of Dwt on the choice of these different alternative fuels is very small. Overall, in the full sample model, Dwt has a positive correlation with these alternative fuels but the RRRs are also relatively close, that is, the distinguishing effect is not significant. This conclusion is consistent with Li's research (Li et al., 2020). He found that although the average Dwt of LNG-fueled vessels is much higher from the statistics perspective, the influence of Dwt on shipowner's emission abatement solution is small based on MNL regression results. Due to economies of scale, the size of the vessel only determines whether shipowners invest in alternative fuels, and it does not play a critical role in investing in a particular fuel. For container vessels, LNG is currently the shipowners' trusted mainstream clean fuel as Dwt increases. For dry bulk shipowners, it is methanol.

5.3.2. The impact of the nationality of the shipowners on decisions of ordering alternative fueled new vessels

The different nationalities of shipowners also affect their preferences for decision-making. Surprisingly, the top four countries in terms of orderbook volume: China, Japan, Greece, and South Korea have a smaller likelihood of choosing alternative fuels compared to conventional fuels, except for Greece and South Korea, which show a preference for LNG Capable-fueled vessels. The same results apply to the dry bulk model. In the container model, German shipowners tend to prefer LNG. Overall, the odds ratio of alternative fuels over conventional fuels are less than 1 for most of these top-ranking countries, except for those that have some preference for

LNG. This may be due to larger shipping power reacting more slowly to the transition to zero-carbon fuels or waiting for the optimal fuel to achieve zero-carbon goals. It is worth noting that hydrogen fuel has not yet appeared in the data on alternative fuels. Hydrogen and hydrogen-based fuels are a good solution for carbon reduction and decarbonization in the maritime industry. According to China's commitment vision, by 2060, hydrogen-based fuel cell applications will meet about 10% of the energy demand in the field of waterborne transportation. However, currently, small hydrogen-powered vessels are the mainstream, mainly comprising sightseeing and experimental vessels. Only Germany shows a preference for LNG-fueled vessels in the container model, reflecting the fact that LNG fuel is mature and widely used in various countries. However, despite being a fossil fuel that can eliminate sulfur and nitrogen and reduce CO_2 emissions compared to conventional fuels, LNG also carries the risk of unburned methane escaping into the atmosphere. As methane, the primary fuel in LNG, has a greenhouse gas effect 28 times greater than that of CO_2 over a period of 100 years, the greenhouse gas effect caused by methane emissions completely offsets the decarbonization potential of LNG. Therefore, LNG is considered a transitional fuel for emissions reduction. Compared to other countries, Greece, South Korea, Germany, and China are more inclined to LNG Ready rather than LNG Capable, especially in the container model, with the former three showing probabilities of 30 times, 38 times, and 31 times that of conventional fuels, respectively, while China reaches 3.9 times, with the significance level of $p < 0.01$.

From the perspective of other fuels, Germany is more likely to choose methanol, which is three times that of conventional fuels, with a significance level of $p < 0.01$. The German engine manufacturer MAN has made significant investments in methanol technology. In November 2021, the company revealed its plans to upgrade its new four-stroke engines to be able to use future green fuels, including methanol and ammonia. The engines designed for methanol power were launched in 2022. From 2024, solutions for the use of methanol in four-stroke engines will be provided. Norway, Italy, and the Netherlands are more likely to adopt ammonia, which are 12 times, 9 times, and 9 times that of conventional fuels, with a significance level of $p < 0.01$. And the possibility of Norway choosing other fuels is also high. At the COP27 conference, the Norwegian delegation announced a major commitment to reduce maritime emissions at the same rate as the country's reduction by 50% by 2030. To achieve this, Norway will need 700 low-emission and 400 zero-emission vessels. Harald Solberg, CEO of the Norwegian Shipowners' Association, mentioned that 90% of Norwegian shipowners have already expressed their willingness to equip their vessels with new technologies. They are considering a wide range of solutions, such as green ammonia, hydrogen, wind-assisted propulsion, batteries, and using artificial intelligence to reduce fuel consumption. At the end of 2023, the 1MW ammonia fuel cell system designed and developed by Norway's Alma Clean Power will be installed on the “Viking Energy”. The ammonia-powered fuel cell system will be installed on a commercial vessel for the first time. In the container model, Singapore and Germany prefer methanol and ammonia, with a possibility four times that of conventional fuels ($p < 0.05$) for Singapore and ten times that for Germany ($p < 0.01$). In the dry bulk model, no specific preferences have been observed. Overall, in addition to ordering a large number of LNG-fueled vessels, Germany tends to favor methanol, while Norway, Italy, and the Netherlands favor ammonia. Singapore places extra emphasis on methanol and ammonia in container vessels, while Norwegian shipowners exhibit a preference for other fuels.

5.3.3. The impact of the vessel type on decisions of ordering alternative fueled new vessels

The vessel type also affects the preferences of shipowners. For dry bulk carriers, shipowners are more likely to prefer conventional fuel vessels over LNG-fueled vessels. In addition, Container, Tankers, General cargo and Chem & Oil vessels are also less likely to choose LNG. It is possible that Bulk and Tankers are reluctant to use LNG due to their unpredictable port stopovers that may temporarily disrupt the preparation of LNG refueling stations in ports. Additionally, for Tankers, operators own a lower proportion of the industry compared to other sectors, making it easier for them to adapt to using low sulfur fuel. The probability of Tankers choosing conventional fuel is even 50 times higher than that of LNG with a significance level of $p < 0.01$. The only vessel type with a relatively strong preference for LNG is the Gas carrier. Here, the probability of adopting LNG is 23 times higher than conventional fuel with a significance level of $p < 0.01$. It is more likely for Gas carrier to use LNG as fuel, as there are more and more vessels transporting LNG, which simultaneously use it as fuel because they follow routes that are easy to approach the LNG fuel facilities for refueling. Container vessels show a preference for LNG Ready, which is 2.2 times higher than conventional fuel($p < 0.1$). With regard to methanol, Bulk and Chem & Oil vessels rarely use it. The probability of Bulk using conventional fuel is more than 100 times higher than that of methanol with a significance level of $p < 0.01$. No type of vessel shows a special preference for methanol. For ammonia, the probability of choosing it among Gas carriers and Chem & Oil vessels is 39 times and 6 times that of conventional fuel, with a significance level of $p < 0.01$ and $p < 0.05$. Regarding other fuels, container vessels choose this type of fuel less frequently, while the probability of Gas carriers choosing other fuels is 96 times that of conventional fuels with a significance level of $p < 0.01$, and Ro-Ro ships have a probability of 3.4 times with a significance level of $p < 0.1$. In general, for vessels with unpredictable port stopovers and routes, the use of LNG as fuel is relatively low due to incomplete refueling facilities. Methanol is rarely used in Bulk and Chem & Oil, while Chem & Oil vessels prefer ammonia. Many Ro-Ro shipowners use other fuels. Gas carriers are more willing to invest in alternative fueled vessels that use ammonia fuel and other fuels.

5.3.4. The impact of the freight index on decisions of ordering alternative fueled new vessels

Regarding the ClarkSea Index variable, when the ClarkSea Index rises, the probability of shipowners ordering methanol-fueled vessels decreases, but its RRR is close to 1, which has limited impact on shipowners' decisions. The effects for other fuels are not significant, and the effects of SCFI in the Container model and BDI in the Bulk model are also insignificant. Therefore, it can be said that market conditions can cause some effects, but they are very limited. The rise and fall of the shipping market cannot impact shipowners' decisions to purchase alternative fuel vessels. Studies have shown similar results in the empirical analysis of shipowners' emission reduction preferences, indicating that economic incentives or fluctuations have limited influence on shipowners' decisions (Zhang et al., 2021). In addition to financial factors, shipowners may pay more attention to fuel maturity, ease of refueling, and compliance with IMO policies.

5.3.5. The impact of the CO2 EUA Price on decisions of ordering alternative fueled new vessels

The CO_2 EUA price variable has a significant impact on both LNG and methanol fuel ($p < 0.01$). When the CO_2 EUA price rises, the probability of shipowners ordering LNG Capable, LNG Ready and methanol decreases slightly. Both LNG and methanol fuel emit some greenhouse gases and may not fully comply with the IMO's current carbon-neutral policy, yet synthetic methanol still has a high potential for CO_2 reduction. The increase in the EU carbon futures price from 20 euros/ton in early 2020 to a price range of 80 to 100 euros/ton demonstrates the EU's determination to support Europe's achievement of the Green Deal through the EU carbon market. The European Parliament passed a bill in 2023 that extended the carbon market reserve mechanism until 2030. By 2030, the total carbon quota will need to be reduced by 43% compared to the total quota in 2005, so the EU carbon price is expected to remain high. Additionally, market-based measures (MBMs) for reducing emissions in shipping, including emission quotas, trading systems and carbon taxes, were discussed and approved during the MEPC 79 meeting. The MEPC 80 meeting in July 2023 will prioritize medium-term measures such as technological and economic measures, which could be a fusion of multiple measures. These measures, like the EU carbon futures, will encourage shipowners to invest in alternative fueled vessels. The CO_2 EUA price variable in the container model yielded the same results, while in the dry bulk model, an increase in CO_2 EUA price will cause more shipowners to order ammonia-fueled vessels, and they will be more likely to choose completely zero-carbon fuels.

5.3.6. The impact of the LNG Bunker Price on decisions of ordering alternative fueled new vessels

Besides, the LNG Bunker price has a significant impact on shipowners' orders for LNG-fueled vessels. As the LNG fuel price rises, the probability of ordering LNG-fueled vessels also increases ($p < 0.01$). This may be due to the large increase in LNG-fueled vessels orders, which in turn stimulates the LNG fuel market. It also indicates that the LNG fuel price is no longer able to hinder the order of LNG-fueled vessels, as the shift from conventional fuel has become the trend with the formulation of carbon reduction targets. LNG, as a relatively mature clean fuel, has been proven to be cost-effective at different prices, even when the conventional fuel price is much lower than the LNG fuel price, and the cost under different routes is more stable (Eise Fokkema et al., 2017). From the shipowners' perspective, stability is essential for minimizing financial risks and operational interruptions. However, the LNG price variable did not have the same impact on the LNG-fueled vessel orders in the container and dry bulk models.

5.3.7. The impact of the SOFR on decisions of ordering alternative fueled new vessels

Regarding the SOFR variable, it had no significant impact in the full sample model, nor did the volatility of the US dollar interest rate affect the shipowners' decisions in the container model. However, in the dry bulk model, the increase in the US dollar interest rate would increase the probability of shipowners choosing ammonia fuel by five times that of conventional fuel ($p < 0.05$). Therefore, SOFR had some impact on the bulk newbuilding market.

5.3.8. The impact of the fleet idle rate on decisions of ordering alternative fueled new vessels

For the Idle variable, in the full sample model, the idle rate of the fleet only had a significant impact on LNG-fueled vessels. The increase in the idle rate would reduce the inclination of shipowners towards LNG-fueled vessels to a quarter of that of conventional fuel, with a significance level of $p < 0.01$. In the container model, shipowners' inclination towards LNG Capable would also be reduced to one-third of that of conventional fuel, while they would invest more in LNG Ready vessels, about 2.7 times that of conventional fuel, with a significance level of $p < 0.01$. The order volume of LNG-fueled vessels continued to rise between 2020 and 2022, but when the idle rate of the fleet increased, leading to oversupply, shipowners would reduce their orders of LNG-fueled vessels.

5.3.9. The impact of the orderbook volume on decisions of ordering alternative fueled new vessels

For the Orderbook variable, as the percentage of world new orderbook capacity to existing capacity increases, indicating a higher number of orderbooks, the proportion of LNG, methanol, and other fuels will also increase. The probability of LNG will be four times that of conventional fuel, other fuels will be three times that of conventional fuel, and methanol will even be 54 times that of conventional fuel, with a significance level of $p < 0.01$. In the container model, the increase in orderbooks will lead to an increase in the probability of LNG Capable, LNG Ready, and methanol-fueled vessels by 1.6 times, 1.1 times, and 2.4 times, respectively, with a significance level of $p < 0.01$. This indicates that when shipowners need to place more new vessel orders to increase capacity, they will consider more alternative fueled vessels, thereby increasing the proportion of clean energy, especially methanol.

5.3.10. The impact of the contract date on decisions of ordering alternative fueled new vessels

As time progresses, in the full sample model, the probability of shipowners choosing methanol and ammonia fueled vessels will increase to 1.13 times and 1.25 times that of conventional fuel ($p < 0.1$), respectively. In the container model, newer orderbooks will have a higher probability of ammonia-fueled vessels, which will be 2.5 times that of conventional fuel ($p < 0.01$). However, the time variable did not have a significant impact in the dry bulk model. Currently, ships are undergoing a wave of reform, gradually abandoning conventional fuels. In 2022, global shipowners ordered and operated about 80 methanol-fueled vessels, mainly purchased by large shipping companies such as Maersk, CMA CGM, and COSCO. However, many shipowners are still in a wait-and-see state. Ammonia fuel has now been produced through diversified electricity conversion, and its emission reduction potential exceeds the storage and flexibility challenges of this fuel.

5.3.11. Summary of discussion and implication

The empirical results of this study indicate that the size of the vessel only determines whether shipowners invest in alternative fueled vessels, rather than a specific type of alternative fuel.

Different shipowner nationalities lead to different policy research directions, which influence their decision-making. LNG production and supply have matured and are widely used by various countries, while Germany is currently researching engines that use methanol and ammonia fuels, with a preference for methanol. Italy and the Netherlands lean toward ammonia fuels, while Norway is considering various ways to reduce fuel consumption, including ammonia fuels and battery fuels. Singapore focuses on methanol and ammonia for container vessels.

Vessel type also influences shipowner preferences. Container vessels, tankers, general cargo vessels, and chem & oil vessels use LNG less frequently than other vessel types. Dry bulk and Chem & Oil vessels use methanol less frequently, but Chem & Oil vessels favor ammonia fuel. Gas carriers' shipowners are more willing to use ammonia fuel and other blended fuels.

Furthermore, carbon emissions trading systems such as the EU carbon futures will decrease shipowners’ desire to choose alternative fuels that still emit carbon. The rise in LNG fuel prices no longer inhibits shipowners from choosing LNG fuel. The ups and downs of the shipping market are unlikely to affect shipowners’ decisions to invest in alternative fueled vessels, but when fleet idle rates are high, shipowners will reduce orders for LNG-fueled vessels. The more vessel shipowners order, the more willing they are to try alternative fuels. Over time, shipping companies are more likely to choose methanol and ammonia-fueled vessels. Some big players are still in a wait-and-see state, waiting for the best fuel to emerge.

6. Recommendations for shipping industry to meet emission reduction targets

Shipowners' knowledge, funds, and vessels may all influence their fuel adoption preferences (Mäkitie et al., 2022). Currently, shipowners are investing in early-stage alternative fueled vessels that are more convenient for retrofitting and refueling, such as Gas carriers which are suitable for LNG as fuel due to their storage equipment and reliable refueling devices. Similarly, Chem & Oil vessels are also suitable for alternative fuels such as ammonia and methanol. Moreover, since the cost of alternative fueled vessels is higher than conventional fuels, investing in larger vessels is a more cost-effective option for faster cost recovery. Four Chinese companies rank in the top ten global shipping companies, but except for COSCO's investments in LNG and methanol-fueled vessels, Evergreen and Wan Hai have no investments in alternative fuel vessels, and Yang Ming has not yet decided on its current fuel usage and has not made any vessel investments during this period. China's large shipping companies need to accelerate the pace of fuel transformation. Currently, Greece, South Korea, and Singapore lead in the use of alternative fuels.

For shipyards and engine manufacturers, more non-financial factors need to be considered in research and development. Currently, there is no large-scale hydrogen production, storage, and use program available, despite its potential as a fuel. Moreover, most biofuels cannot be used with traditional engines even with minor modifications, requiring a completely new research and development process. In addition, shipyards need to break down barriers to the use of alternative fuels in some ship types, such as dry bulk carriers or general cargo vessels. To attract more orders for alternative fueled vessels, more marketing efforts should be directed toward countries in Southern Europe and South Asia, where shipowners have a stronger awareness and interest in using alternative fuels.

High investment costs and difficulties in financing are the main barriers to adopting alternative fuels (Mäkitie et al., 2022). The maritime sector can increase its focus on alternative fuels by conducting research and experiments, which can reduce shipowners' investment costs, improve infrastructure, reduce technological uncertainty, and establish knowledge, thereby addressing the obstacles faced by wide use and long-distance voyages (Bach et al., 2020). Therefore, it is necessary to establish reasonable market governance and incentives through national policymakers, such as public procurement of shipping routes or carbon emission trading systems. These may be key policy mechanisms to stimulate the early niche market for maritime alternative fuels. There are also many specific issues to be addressed, such as the high turnover rate of personnel on board and the difficulty of providing energy efficiency training for crew members. The IMO can encourage more of this kind of training, which benefits the proper and reasonable use of clean fuels.

Stakeholders in the shipping industry should work together to adopt comprehensive and systematic measures to address these challenges. HMM are collaborating with KMI and shipbuilding industries to comply with environmental regulations and installation of facilities (Korean Marine Equipment, 2018). Efforts from all aspects are essential to attain long-term sustainable solutions, as it is not enough to rely only on one party's efforts.

7. Conclusions and limitations

7.1. Conclusions

The research findings of this paper show that:

First and foremost, vessel types affect shipowners' alternative fueled vessel orders, and vessel types with non-fixed docking times and routes use fewer alternative fuels. Gas carriers tend to use LNG and ammonia, while Chem & Oil vessels tend to use ammonia

Secondly, for vessels with large Dwt, shipowners are more willing to use alternative fuels, but Dwt does not determine which alternative fuel shipowners choose

Thirdly, shipowners' nationality also influences their decisions, with Germany tending to use methanol, Italy, Netherlands, and Norway tending to use ammonia, and Singapore focusing on methanol and ammonia for c[i]ontainer vessels

Fourthly, the profitability of the shipping market cannot influence shipowners' fuel choices, but when the volume of orderbooks increases, shipowners are more willing to try alternative fueled vessels

Fifthly, the carbon emission trading system can enhance shipowners' tendency to choose completely zero-carbon fuels

Last but not the least, as technology advances, more and more shipowners are choosing ammonia and methanol fuels, but some big players remain in a wait-and-see state. Among the major vessel types, hydrogen fueled vessels has not yet emerged.

7.2. Limitations

However, some limitations still exist in this study. Firstly, it focuses only on fuels and can be expanded to cover other emission abatement behaviors. Secondly, the newbuilding vessels data from only the last three years were analyzed, which may have limited implications, so further studies with longer-term data are needed.

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