

## Agent based model framework of dry bulk shipping market

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### Abstract:

This paper develops a framework for an Agent-Based Model (ABM) of a dry bulk shipping market, aiming to enhance our understanding of market dynamics. The study begins by outlining the fundamentals of the dry bulk shipping sector. It then examines the ABM methodology, emphasizing its suitability for modelling decentralized decision-making. Building on these foundations, the paper proposes a structured framework for an ABM that captures freight rate negotiations, vessel movements, in order to analyse the effects of external factors, including regulatory changes, climate policies, and economic fluctuations, on market behaviour.

**Keywords:** Agent based model; Dry bulk shipping market; freight rate

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## **1. INTRODUCTION**

Shipping is an industry which contribute to the development of civilization during the human history. There are many arguments support this point of view. Firstly, it is a real linchpin factor of globalization, and its impact returns to the end of XIX century by the soaring of the international flows of goods and people. It was a global industry before the era of globalization, since the international environment where the shipping companies operate. Secondly, no nation is self-sufficient; all countries are involved at different levels in trade to sell what they produce more efficiently than their trade partners and to purchase their needs, so they take advantage from the specialization in goods production since the transport cost of the products is moderate.

Despite the fact that shipping markets was one of the earliest fields of applied economic research, traditional economic modelling approaches often fall short in capturing its dynamic nature. Static equilibrium models, while useful for theoretical exploration, struggle to account for the decentralized decision-making processes and adaptive behaviours of market participants. In contrast, agent-based modelling (ABM) is considered as promising instrument to improve our understanding of markets characterized by heterogeneity, interactions, and emergent phenomena. By treating individual entities as autonomous decision-makers, ABM allows for the simulation of market outcomes driven by micro-level interactions, providing insights into complex phenomena such as freight rate volatility, market entry and exit dynamics, and the formation of logistical networks.

The purpose of this study is to propose a framework that analyzes the dry bulk shipping market (DBSM) through the lens of ABM. Building on established principles of ABM and insights from automated negotiation systems, this framework aims to model the interactions among shippers, shipowners, and other stakeholders in a dynamic, competitive market. In doing so, it seeks to address key research questions: How do supply and demand interact to shape freight rates throw the negotiation between shipowner and the shipper?

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In the context of the appropriate progression to answer the question of our study, we attached to it these sub-questions, which were as follows:

- What are the principal factors that affect the decisions of shipowners and shippers?
- How can the interaction between ship owners and shippers in the dry bulk freight market be modelled using agent-based modelling (ABM)?
- In order to find scientific solutions to the developed questions, this study seeks to test the following hypotheses:
- Demand for transporting of raw materials via dry bulk vessels is mainly influenced by global economic conditions such as commodities prices, economic growth rates, and oil prices.
- Market participants (e.g. ship owners and shippers) use adaptive learning to continuously adjust their strategies based on past experiences, leading to the emergence of collective behaviours that influence market trends (e.g. price fluctuations).

The proposed framework integrates key elements from existing literature on freight transport modelling, bilateral negotiation systems, and computational economics. It draws on models of free competition to capture the diversity of actors within the dry bulk market. Then, it leverages the flexibility of ABM to explore emergent market phenomena.

By presenting a comprehensive and adaptable conceptual framework, this paper contributes to both academic research and industry practice. It offers a foundation for future studies aiming to improve the efficiency and resilience of the dry bulk shipping market while addressing contemporary challenges such as environmental sustainability and geopolitical uncertainty. Furthermore, it provides a practical tool for industry leaders seeking to design effective interventions and strategies in an increasingly complex and interconnected global economy

## **2. Literature review**

A key area of research has been the application of agent-based models (ABM) and heterogeneous agent frameworks to better understand market behaviour, investment decision-making, and price formation in transport sector. (Engelen, Wout , & Bert , 2007) develop an agent-based

approach to study investment decisions in dry bulk shipping. Their work introduces multi-agent adaptive systems that dynamically integrate different trading rules and investment strategies. By embedding evolutionary models, they demonstrate how heterogeneous agents adjust their strategies over time in response to market conditions. (Engelen, Dullaert, & Vernimmen, 2009) assess market efficiency in dry bulk shipping using a multi-agent system dynamics model with a Nash equilibrium framework. Their study examines how freight rates across different vessel classes (Handymax, Panamax, and Capsize) exhibit strong interdependencies due to arbitrage processes. By modelling the substitution of vessel types based on profitability, the authors demonstrate that arbitrage opportunities contribute to an evolutionary movement toward equilibrium. Despite some scepticism regarding the Efficient Market Hypothesis (EMH) within shipping, their results suggest that efficiency is maintained through market-driven adjustments, even in short-run settings.

(Peng, Shan, Guan, & Yu, 2016) contribute to the discussion by introducing a reliable vessel-cargo matching model incorporating pricing game mechanism. Their work addresses the challenge of balancing supply and demand in a market where either shippers or carriers dominate at different times. Using the Gale-Shapley algorithm, they formulate a price equilibrium model to explain how disadvantaged market participants adjust their strategies to maximize surpluses. Their research highlights the importance of price competition not only between shippers and carriers but also among participants within the same group, reinforcing the role of strategic pricing in vessel-cargo allocation

Investment behaviour within the dry bulk shipping industry is heavily influenced by investor heterogeneity and market dynamics. (Alizadeh, Thanopoulou, & Leung Yip, 2017) develop a heterogeneous agent model (HAM) to examine how different investor types (speculators and operators) impact ship price volatility. They distinguish between momentum investors, who follow short-term earnings trends, and contrarian investors, who adopt countercyclical strategies. Their findings suggest that the rise of momentum investors leads to higher volatile prices, while

contrarian investors contribute to market stabilization. This work underscores the role of investor behaviour in shaping asset price cycles in the dry bulk shipping market. (Reis, 2018) advances agent-based modelling in freight transport by integrating fuzzy logic into decision-making processes. Unlike traditional models that rely on fixed pricing strategies, this study incorporates dynamic price adjustments and learning mechanisms among agents. The use of auctions to simulate transport contract negotiations introduces a realistic dimension to market behaviour. Reis emphasizes the need for disaggregated freight transport models that can capture the evolving interactions between shippers, freight forwarders, and carriers, ultimately leading to improved market predictions and policy assessments.

(O’Keeffe, 2018) develops an agent-based model pertaining to dry bulk shipping industry, simulating voyages and cargo flows through 2050. It incorporates arrangements concerning affreightment, the spot market, as well as the length charter market to reflect real-world contractual conditions. The model assesses climate change impacts, including Arctic Sea route accessibility, shifts in commodity demand, fuel price fluctuations, and mitigation policies like carbon pricing and vessel efficiency standards. A key finding is that internal system dynamics, such as shipper preferences, create more variability than external factors, affecting fleet composition, technology adoption, and shipping strategies.

In the realm of investment decision-making, (Yin, Wu, & Lu, 2019) propose a real options framework to assess ship investment strategies under uncertainty. They argue that traditional net present value (NPV) methods fail to capture the dynamic nature of investment decisions in volatile markets. Instead, their model incorporates real options thinking, considering both deferrable and abandonment options to provide more flexible investment strategies. Their findings highlight the importance of considering shipping cycles and market volatility when making capital-intensive investment decisions in DBSM.

### **3. Dry bulk shipping market fundamentals**

The market of shipping is claimed to be close to the model of a free competition market. The typical features of such a market are profit

maximization, perfect knowledge, none of shipowners or shippers is big enough to have an impact on the market and entry to the market is relatively easy.

### **3.1 The demand side:**

In general, demand for transport results from demand for goods, consequently one of the most significant characteristics is that it is a derived from demand. In addition, demand over bulk materials relies upon the consumer demand for the final products or services that go to make it. As in the case of other forms of transport, three factors must be taken into consideration:

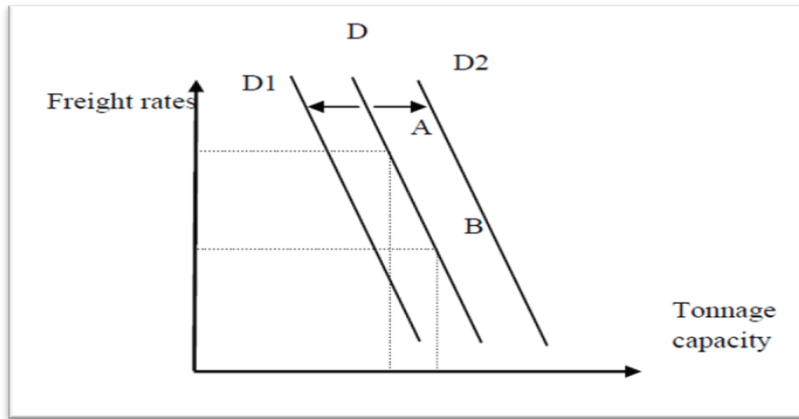
- The elasticity of the consumer demands for the final product that the bulk commodity is used for at the importing country.
- The share of the freight rate in the market price of the final product.
- The availability of substitutes, that is to say, alternative means of transport.

It has been maintained that, consumer elasticities for the final goods for which the bulk materials transported are needed tend to be inelastic. It follows that the demand for the trans-oceanic transports of the bulk materials under consideration will also tend to be inelastic (Chrzanowski, 1986, p. 53).

#### **3.1.1 The shipping demand curve:**

The freight rate and the volume of requests over shipping services over a certain time frame are fundamentally related. In accordance with the demand law, the demand curve dips downward and to the right. It is a visual depiction of the connection between a product's pricing (such as freight rate) and quantity demanded (such as long-distance sea transportation). Quantity demand changes when the freight rate shifts but other factors influencing demand stay the same. As seen in Figure 1, a shift from point A to point B throughout the demand curve can be referred in as an adjustment in quantity requested.

**Fig.1.** The demand curve



**Source:** (Lun , Lai, & Cheng, 2010)

Demand for shipping is influenced by several things. One of the most significant of these is maritime commerce. The demand for maritime shipping may fluctuate reaction to variations in the volume of seaborne trade. The demand curve for shipping will move if any of the factors influencing maritime transportation change. For instance, this curve moves slightly to left (from D to D1) as the demand for sea transportation declines. On the other side, the demand for maritime transport will rise in tandem with the volume of seaborne trade. Figure 1, it causes the curve of demand to move to right side, from D to D2.

### **3.1.2 Influential factors of the demand side:**

The principal elements that affect the demand of shipping are:

#### **a) Seaborne commodity trade**

A key driver of short-term volatility in seaborne commodity trade is the seasonality of certain markets. Agricultural assets, such as grain, sugar, and citrus fruits, exhibit pronounced seasonal fluctuations driven by harvest seasonality. (Stopford, 2009) noted that seasonality exerts a particularly strong influence upon the spot market. The unpredictable nature surrounding agricultural commodity shipments makes long-term planning difficult, leading shippers to depend primarily upon the spot charter market to secure vessel capacity. Consequently, fluctuations in grain shipments tend to have a disproportionately large impact on spot freight rates. Any estimate of the magnitude of demand for sea transport services or facilities cannot be indicative of the true position unless the distance factor is taken

into consideration (Metaxas, 1981, p. 35). Consequently, the seaborne trade is affected by two factors:

- *the world economy* which engenders the largest part of the demand, through both the import of raw materials and the manufactured goods.
- *the average haul* or sailing distance, the demand depends on the distance that exists between the point of origin and the intended destination of the cargoes.

**b) Geopolitical factor:**

The shutdown to the Suez Canal in 2024, for instance, forced ships to take the longer path via the Cape of Good Hope, adding several days to the voyage time. As a result, the supply of vessels decreased during that time. Geopolitical events like this had a significant and unexpected impact on the market. Additionally, political factors influence national decisions such as trade rules that protect local industries or prohibit the export of certain commodities in order to stabilize the local market, forcing importers to find alternative sources for their needs.

**c) Transportation cost:**

Only when the cost of the transport is low or when the quality of the imported product justifies the difference between the domestic and import prices will induce the import of goods (raw materials or final products). Because of this, transportation expenses are a crucial consideration for business. Over the past century, transportation prices have steadily decreased due to the advancement of transportation infrastructure, the introduction of larger ships, and the adoption of more efficient shipping operations management. Lower transportation costs increase demand for maritime transportation, which influences consumer choices on sourcing, price and market locations (Lun, Lai, & Cheng, 2010, p. 20).

### **3.2 The supply side**

Supply of maritime transportation is typically assessed in terms of available vessel capacity, that presents the tonnage capable of carrying cargo between ports. The segment of the fleet actively engaged in the freight market is referred to as "active shipping supply," whereas vessels

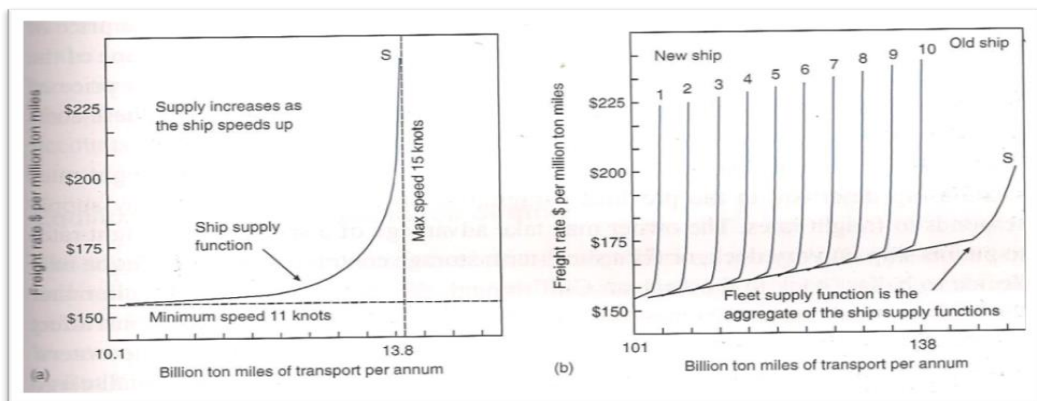
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that are temporarily out of service, such as laid-up tonnage, constitute "available supply." Together, these two categories form the total shipping supply (Lun , Lai, & Cheng, 2010, p. 22). Furthermore, the responsiveness of shipping supply to fluctuations in demand is inherently slow due to structural constraints. Shipbuilding is a time-intensive process, often requiring several years from order to delivery. Additionally, vessels have a long operational lifespan, typically ranging from 25 to 30 years, making it challenging to promptly adjust capacity in response to declining demand, particularly when excess tonnage must be eliminated.

#### **3.2.1 The shipping supply curve:**

The freight rate and the sea transport tonnage capacity have a functional connection known as supply. The marginal cost of the marginal vessel needed to meet the transportation demand determines the market freight rate. Economist distinguished between two situations, the first refers to full employment of the fleet. In this case, to increase the supply in short term the vessels must increase their speed and postpone unnecessary maintenance. As a consequence, the supply function becomes inelastic and freight rates explode. The second case refers to unemployment of the full capacity, the supply is over the demand, as a result the rates plunge, and the least cost-efficient vessels will leave the market, and the supply becomes elastic in the short-term.

**Fig.2.** Shipping supply



**Source:** Martin Stopford 2009

#### **3.2.2. Influential factors of the supply side:**

The supply of shipping service is affected by the following:

**a) Merchant fleet:**

The fleet constitutes the cornerstone for all discussions of the accessibility of shipping. Tinbergen (1959) identified the supply elasticity in relation to the fleet (0.9). This indicates that when the fleet rises 10%, the supply will rise by 09%. Consequently, the global dry bulk merchant fleet greatly impacts the dry bulk freight market. At the end of 2022, the bulk carrier fleet reached, in regard to tonnage, 998.5 million deadweight tons (million dwt) compared with 970.6 million dwt at the end of 2022 (shipping insight, 2023).

**b) Fleet productivity:**

The operational efficiency of a ship fleet is calculated by dividing the total cargo ton-miles transported during a one year by the active deadweight fleet. Additionally, this efficiency is influenced by four key factors: speed, time spent in port, deadweight utilization, as well the number of days the ships are loaded at sea.

*Speed* governs the duration a vessel takes on a trip, when the vessel sails faster; it takes shorter time than usual on a trip. This means that, the ship's capacity for carrying improves. In the short-term navigating speed is considered as a mechanism via which the supply may be regulated. Nevertheless, when the speed of the vessel increases, its fuel consumption substantially increases. Secondly, *port time* is one of the important factors which affect the productivity. Congestion produces temporary decreases of fleet's performance. Thirdly, the *deadweight utilization (DWU)* relates to the cargo strength lost due to stores, bunkers, etc. that prohibit a complete load from being transported (Stopford, 2009, p. 155). Finally, a vessel's period is split into *laden days at sea* and 'unproductive' days (in port, ballast, or off hire). A decrease in unproductive time permits an increase in loaded days at sea (Stopford, 2009, p. 156). The fleet's productivity fluctuates in reaction to market circumstances; the initial response of the commercial fleet is normally to decrease its speed to save bunker expenses.

**c) Shipbuilding:**

The shipbuilding industry is the source of the supply of new tonnage capacity, since it determines the supply of tonnage to the market. In

principle, the orderbook should adjust to higher demand by the construction of new ships, although if the demand falls, the activity of the newbuilding market should drop off. Nevertheless, this has impact just in the long term.

**d) Ship scrapping:**

The ratio among new ship arrivals to fleet deletions, which include ships scrapped as well as lost at sea, affects the pace of fleet growth in the maritime industry. By removing ships from the market when the supply of shipping ability exceeds the demand, scrapping provides a critical function as a buffer balancing demand as well as supply in the freight market. Additionally, there is a negative correlation between the scrap market along with freight market due to an overcapacity in the latter, which leads to higher scrapping and an equalizing out of the supply and demand in both. The opposite happens when the freight market is expanding.

**e) Freight rates:**

Freight rates have a significant impact in influencing the supply of marine transport. As a fundamental market mechanism, they influence decision-makers by encouraging short-term capacity adjustments and driving long-term cost-reduction strategies. The bulk shipping sector operates on a wholesale basis, providing services in large volumes through contracts with an extremely limited number of industrial clients, often at independently arranged rates. Pricing dynamics are central for supply of transportation. In the short term, shipping supply reacts to fluctuations in freight rates by adjusting vessel speeds and shifting between active service and lay-up status. Over the long run, freight rates significantly impact investment decisions, influencing both the scrapping of older vessels and the ordering of new tonnage to align with market conditions.

**4. Agent based model**

Agent-based modelling (ABM) refers to a simulation technique for analysing complex systems. It is particularly useful in understanding emergent behaviours in social, economic, and transport systems. ABM is grounded in the principle of modelling a system as a collection of autonomous, interacting agents that follow predefined rules, often exhibiting complex adaptive behaviour as a result (Tessfatsion, 2022). The fundamental principles of ABM are centred around autonomy,

heterogeneity, interactivity, and emergence. According to (Tsfatsion, 2022), a well-defined agent in ABM is a computational entity capable of independent action. These agents interact with other agents and with their surroundings, resulting to system-wide patterns that cannot be easily predicted from individual behaviours. This bottom-up approach contrasts sharply with traditional equation-based models, which often rely on aggregate assumptions (Elsenbroich & Polhill, 2023).

#### **4.1 Elements of an ABM:**

A well-structured ABM consists of several key elements that define its dynamics and effectiveness:

##### **4.1.1. Agents :**

- Agents represent individual entities with autonomous behaviour.
- They possess characteristics such as goals, memory, adaptation, and decision-making abilities.
- Agents can be individuals, households, firms, or vehicles, depending on the application domain (Tsfatsion, 2022).

##### **4.1.2. Agent Interactions :**

- Agents interact with one another and their environment through predefined rules.
- These interactions drive system-wide emergent behaviours, such as traffic congestion or market dynamics (Huang, Cui, & Zhang, 2022).
- Communication mechanisms among agents include direct messaging, indirect influence through environmental changes, or probabilistic interactions.

##### **4.1.3. Environment:**

- The environment represents the spatial and contextual setting where agents operate.
- It can be static (e.g., a fixed road network) or dynamic (e.g., fluctuating economic conditions).
- Environmental changes influence agent behaviours, creating feedback loops essential for realistic simulations (Siegfried, 2014).

#### **4.1.4. Rules and Decision-Making Mechanisms:**

- Rules define how agents behave and make decisions in response to environmental changes and interactions.
- Decision-making can be based on deterministic rules, probabilistic models, or machine learning algorithms for adaptive learning (Tefatsion, 2022)

#### **4.1.5. Temporal Dynamics :**

- ABMs evolve over discrete or continuous time steps, simulating real-world progression.
- Time progression is managed through event scheduling, synchronous or asynchronous updates, or Monte Carlo simulations (Elsenbroich & Polhill , 2023).

#### **4.1.6. Emergent Behaviour :**

- One of the most critical features of ABM is emergent behaviour, where system-wide patterns arise from individual agent interactions.
- Examples include self-organizing traffic flow, financial market bubbles, and social segregation (Huang, Cui, & Zhang, 2022).

#### **4.1.7. Validation and Calibration :**

- Ensuring model accuracy involves calibration against empirical data and sensitivity analyses.
- Techniques include statistical comparisons, historical validation, and expert input (Siegfried, 2014).

### **4.2. Framework and Implementation:**

Several frameworks have been developed to standardize ABM development. One notable framework is the **General Reference Model for Agent-Based Modeling and Simulation (GRAMS)**, which provides a structured methodology for designing and executing ABM simulations (Siegfried, 2014). GRAMS facilitates modular development and enhances model comparability, addressing key issues in ABM scalability and computational efficiency

## **5. Agent Based Modelling Framework**

The ABM framework of the DBSM is described in this section. An object-oriented method is used to simulate the physical system, and agent

interactions carry out decision-making. The framework is covered in full in the following.

### **5.1. Agents:**

Shippers, shipbrokers, and shipowners are the three categories of agents. Companies on the supply and demand sides of shipping are represented by shipowners and shippers, respectively. The agents in charge of market relations are the shipbrokers.

#### **5.1.1. Shipper:**

The shipper can be an end-user, a trading house, or a supplier who sells goods under the Cost and Freight (CFR) Incoterm. Their primary objective is to meet contractual obligations by ensuring the commodity is transported within the agreed time window

#### **5.1.2. Shipowner:**

The shipowner wants to maximise his profit; to do so he usually uses different strategies. He manages his own fleet, moreover, he has full information about his fleet, and forms his own opinion about the market outlook. In bad times the shipowner can accept to hire his vessels below their running cost or lay-up them, if this situation continues for long time he may be forced to scrap his old vessel, or sell relatively new one to get some cash flow to survive the downturn.

#### **5.1.3. Broker:**

The shipbrokers manage all market interactions on the shipping market. they serve as middlemen, bringing transactions together by connecting demand (cargo) and supply (ships).

### **5.2. Agent Interactions:**

Actions are initiated either autonomously or in response to preceding events (such as the introduction of a new cargo into the spot market) thereby driving subsequent decision-making processes among agents. Each agent has its own strategies and tactics to negotiate with the opponent, each agent has also his own view of the market conditions.

#### **5.2.1. Spot Market Dynamics:**

Freight rate negotiation is the process to match unallocated cargoes with vessels, the freight rate determination relies on a bargaining

mechanism among shipowners and shippers, both of which are presented by brokers during the negotiation process. Shippers and shipowners negotiate upon a tariff for transporting cargo via a loading port toward their final port over a specified timeframe. Market clearing in this context results in a temporary equilibrium, where prices adjust to immediate supply and demand conditions. However, this equilibrium varies across regions due to spatial inconsistencies in supply-demand relationships, further influenced by vessel size categories. Vessels that secure contracts adjust their schedules accordingly to load the assigned cargo, while shippers update their inventory levels, reducing stock in anticipation of the subsequent time step. the model does not impose an equilibrium condition; rather, market dynamics unfold through continuous agent interactions, with participants responding to one another's decisions and price signals in a decentralized and adaptive manner.

### **5.2.2. Negotiation protocol:**

In order to fix freight agreements efficiently, shipowners and shippers negotiate using a defined procedure. Usually, the procedure starts when the shipper requests a goods quote, and then both sides exchange offers and counteroffers. Shipbrokers, who help with communication and fill in information gaps, are frequently used in these negotiations. Before an agreement is reached, important contractual terms such freight rates, laytime, demurrage, and vessel availability are thoroughly negotiated. The negotiation process differs based on whether it takes place in the time-charter market, which entails longer-term contractual commitments, or the spot market, where transactions are completed quickly. Formal negotiations conclude with the issuance of a recap message that outlines the agreed terms, followed by the fixture confirmation.

Negotiations in the DBSM are shaped by the strategic interaction between shipowners and shippers, where bargaining power, tactics, and prevailing market conditions play a crucial role. Bargaining power is determined by factors such as fleet availability, cargo volume, and competition. In tight markets with high vessel demand, shipowners have the upper hand, whereas in weak markets, shippers can dictate terms. Various tactics, including anchoring (setting an initial extreme offer), bluffing, and

strategic concessions, are employed to gain leverage. Time pressure also influences negotiations, as shipowners seek to minimize idle time while shippers aim to secure favourable rates. Information asymmetry further complicates the process, as parties may withhold or selectively disclose market intelligence to strengthen their position. Additionally, factors such as bunker fuel prices, geopolitical risks, and macroeconomic trends impact negotiations by altering the expectations of future freight rates.

### **5.3 Object definition:**

The cargoes and vessels are considered as non-autonomous agents.

#### **5.3.1. Vessel:**

The vessel has the following attributes: age, speed, fuel consumption rate, location, DWT, minimum draft, operating cost. The status of vessels is: Available, booked, Reposition, Layup, Scrap, sink. The vessels do not interact with each other; their location and status are observed by their owners. Vessels are permitted only to berth at ports which are secure the minimum acceptable vessel draft.

#### **5.3.2. Cargo:**

Only when a vessel is dedicated to transporting it does a cargo get created. At the loading port, the cargo is created and is waiting for the ship. After that, it is loaded onto the ship at the port's loading rate for that kind of commodity.

#### **5.3.3. Port:**

A port has a fixed geographical location, along with a specified number of berths and a defined draft. Additionally, it handles a set range of imported and exported commodities. The loading and discharging rates, as well as the associated costs, are also predetermined.

### **5.4. Environment:**

Within an ABM, relationships among agents occur through either networks or spaces, which are primarily physical places with agents responding through co-location or even proximity. Networks are created for the market. Agents can enter the spot freight market in order to participate in the negotiations.

#### **5.4.1. The global maritime shipping network:**

The worldwide marine shipping networks, which consists of ports as the links among them, is known as the geographic network. Multiple edges between nodes can indicate the presence of various pathways. Nevertheless, the ships are plotted geographically in the model. Moreover, a ship takes the shortest route.

#### **5.4.2. Agent communication networks:**

A dynamic and decentralized network linking shipowners, shippers (owners of cargo), and brokers powers the shipping industry. In order to carry commodities, shipowners establish connections with shippers, negotiating freight prices and vessel availability. These networks are extremely flexible, impacted by previous encounters, strategy choices, and market conditions. Spot market transactions produce temporary, short-lived interconnections, but long-term contracts produce steady, repeating connections. The network facilitates more effective negotiating. Network strength is shaped by market intelligence, trust, and reputation, which affects freight prices and decision-making.

#### **5.4.3. Regulatory bodies:**

government bodies and international organizations that establish pollution control laws, or ban export of a commodity for local reasons, or those that affect shipments (e.g., environmental laws, tariffs, or economic incentives). Are considered in this framework as a part of the environment.

#### **5.4.4. Market conditions:**

Global industrial activity, geopolitical events, fuel price volatility, and weather conditions introduce additional uncertainties. All these previously cited elements need to be added in our framework to enables a deeper understanding of market mechanisms, allowing for scenario analysis and strategic decision-making in response to evolving economic conditions.

#### **5.5. Representation of time:**

The model operates in a sequential manner, advancing in discrete daily time steps. The shipbroker actively engages in the spot market on a daily basis, provided that cargoes are available for transport. Concurrently, both shippers and shipowners undertake strategic planning processes.

Shippers conduct operational planning at every time step to assess potential cargo opportunities, whereas shipowners initiate their operational planning only when viable cargoes emerge in the spot market. Tactical planning for both parties ensue as a natural extension of their strategic considerations.

### **5.6. Parameter setting:**

The parameters need to be determined to run the model

- fleet structure, number of vessels in each class with age distribution.
- The quantity of shipowners and their holdings.
- The quantity of shippers and their demand pattern.
- Market conditions; fuel prices, weather conditions.
- The number of time steps.

## **6. Conclusion**

This paper presents an Agent-Based Model (ABM) framework for analysing the dynamics of DBSM, emphasizing the complex interactions between shipowners, shippers, and market conditions. By modelling the processes of decision-making of heterogeneous agents within a dynamic environment, the proposed framework captures the emergent behaviours that shape freight rate fluctuations, vessel allocation, and trade flows. Unlike traditional equilibrium-based models, the ABM approach allows for a more granular examination of negotiation strategies, and adaptive behaviours in response to evolving market conditions.

The findings highlight the significance of market structure, and external shocks in influencing shipping cycles. By allowing the emergence of elements such as port congestion, seasonal demand variations, and regulatory constraints, the model developed using this framework will enhance our understanding of how micro-level interactions contribute to macroeconomic market trends. Additionally, the framework provides a foundation for scenario analysis, enabling stakeholders to assess policy interventions, risk management strategies, and the impact of structural changes in global trade.

Future research should focus on refining behavioural rules, integrating more detailed empirical data, and expanding the model to include additional factors such as financial constraints and ship financing

mechanisms. Advancements in computational power and data availability further enhance the potential for ABM applications in maritime economics, offering valuable insights for policymakers, industry practitioners, and researchers. Ultimately, this study emphasizes the usefulness of ABM as a potent tool to analyze the complexities of the DBSM and its evolving dynamics.

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