An Agent-Based Model of Transitions to Sustainability in Deep Sea Shipping

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Abstract

International transport has been one of the main contributors to globalisation. Most of the literature considers international transport as contributing to economic growth through trade and therefore of major benefit to society. However, the awareness of environmental impacts has brought the overall benefits of rapidly expanding transport into question. There is an increasing requirement for innovation in shipping to reduce environmental impacts. At the same time, investment is dependent on market conditions and new technology takes time to diffuse through the industry.

This paper introduces an agent-based simulation model of innovation processes. Because the industry is concentrated, an agent based approach is used. An innovation system analysis indicates the agents and their interrelationships. The approach of transitions theory is used to identify potential niches for new technologies and markets where sustainability plays a significant role. The initial model specification concentrates on the R&D decisions of shipyards and the investment decisions of shipping companies as the fundamental determinants of technological change in shipping. Major improvements in emissions performance will require both demand-side pressure (e.g. for green logistics providers) and investment for appropriate niche markets to initiate processes of change.

Keywords: Innovation, R&D, low carbon ships, transitions

1. Introduction

The modern world and its economic development is characterised by globalisation: the accelerating interdependence of practically all people in the world with increasing economic integration, increasing political interaction, and increasing cultural contact (harmonious or conflictual) between different societies are facts of everyday life in the world we live in (Brown, 2008). International transport is one of the main contributors to this process (van Veen Groot & Nijkamp, 1999; Wackerman, 1997) and the two most important modes of long haul international transport – deep sea shipping and aviation – have seen rapid growth which is projected to continue (e.g. IMO, 2009a; Button, 2008; Hummels, 2009; OECD, 2010).

However, the ideas of sustainable development, following the Bruntland Report (Bruntland Commission, 1987) have led to a more critical examination of transportation and trade. International trade has a major impact on CO_2 emissions: Peters et al. (2009) show that allocating emissions based on responsibility by consumption can change the CO_2 emissions allocated to some countries by up to 60%. International shipping and aviation present a particularly difficult problem for climate mitigation policy, because both industries have the main part of their productive process in international waters/airspace, outside regions of national legal jurisdiction. Therefore, policy and regulation has to be agreed in the international institutions and proceeds mainly by consensus, such that countries that oppose environmental legislation can prevent the adoption of environmental policy. The environmental impacts of shipping have also been widely recognised (IMO, 2009a). OECD (2010) shows that both aviation and shipping contribute between 2 and 4% of global CO_2 emissions and are therefore significant contributors to greenhouse gas emissions. The IMO has performed an assessment of the GHG emissions of ships and mitigation technologies and is developing an international policy regime for emissions reduction (IMO, 2009a). Leduc et al. (2010) consider the innovation system in shipping and show that international regulatory systems play a critical role.

However, the only policy implemented for greenhouse gas emissions (GHGs) reductions in shipping is the Energy Efficiency Design Index (IMO, 2009b), which is an information measure and requires the adoption of binding standards to have a wide influence.

Within the shipbuilding industry, there is already an understanding that environmental impacts of shipping are becoming an important social and political issue. The projections of rapid growth in international transport (OECD, 2010) indicate that unless emissions efficiency improves rapidly, emissions from shipping will increase, leading to the risk of increasing pressures for rapid action. Increases in emissions efficiency can come through more energy efficient hull forms, through more efficient propulsion systems, through changing fuels e.g. the adoption of low sulphur diesel fuel and also through operation measures, of which slow steaming offers the largest immediate reductions (Lange et al., 2009). Engineering options for all of these possibilities have been extensively discussed and even developed, including wind based technologies (Lange et al., 2009). The adoption of slower operational speeds is planned, of which the best known current example are the Maersk containership newbuildings, planned for a potential operational speed of 18 knots (Naval architect (2011a).

However, the rate of adoption of such technologies and operational measures is slow. Lower operational speeds in comparison with the last generation of ships are not prevalent, and application of the alternative technologies remains at the demonstration stage. Given the overcapacity in many current shipping markets and the long operational lifetime of ships, there is a strong possibility that increases in activity will not be matched by efficiency improvements through investment in new, high efficiency shipping in the short to medium term out to say 2030. This will make it difficult for shipping to approach overall greenhouse gas emissions reductions targets of the order of 80% reduction, in line with UK policy for the whole economy. On the other hand, it can be argued that compared to other transport modes, shipping has relatively low cost mitigation options.

Therefore, there is a need to assess the processes of technological development and investment in shipbuilding, to understand the decision processes and to investigate possible measures and their effectiveness. The goal of this paper is to develop the concept for a simulation model of R&D and investment in deep sea shipping. Since, as far as we are aware, no such model exists, this paper is a first step. These processes are particularly complicated in the case of shipping, because of the complex nature of ownership and chartering arrangements, as well as the extreme level of globalisation in the industry. At the same time, decision making in shipbuilding and shipping is highly sensitive to economic considerations, such that a combined analysis of contractual relationships and markets might be able to explain innovation and investment decisions. We argue, however, that these processes of innovation cannot be addressed by conventional economic models, because of the complex institutional structure in shipping. In particular, the number of major international shipyards and shipping lines is relatively small, such that the decisions of a single actor can significantly influence the markets. Also, there are a number of different institutions that influence research and technological development. Classification societies have an important role, building in particular on considerations of safety. This is however expanding to include environmental technologies. Therefore, the paper adopts an actor or ‘agent’ based approach, which can explicitly address the detailed interactions between shipbuilders, shipping companies and customers of the shipping industry.

Firstly, the method of a sectoral system of innovation analysis (Leduc et al., 2010; Köhler. forthcoming) is used to identify the types of actors involved. Then, the ideas of transition theory are used to consider possible processes of change towards sustainability in international transport. Transition theory argues that radical changes in society will be necessary to move to a sustainable society and transitions to sustainability start from niches of economic and social activity which demonstrate a radical alternative to the current regime or mainstream (Grin et al., 2010). This is relevant for shipping because sectors such as bulk, container and Ro-Ro transport are dominated by designs based on steel hulls with low speed diesels and a fixed operational structure. However, other smaller sectors such as offshore support or icebreakers have demonstrated considerable technical change in the last 10-20 years. We propose potential niches in which deep sea shipping could become part of processes of sustainable development. Finally, a preliminary model structure is developed, to enable the interactions between actors in deep seas shipping to be investigated.

2. The maritime innovation system: sectoral system of innovation analysis

The innovation system for the maritime industry is analysed in Leduc et al. (2010). The shipbuilding industry has four main sectors: commercial (bulk cargo, container, ferry and cruise), military, offshore energy and leisure (sail and motor yachts). The leisure market is not considered here. Since knowledge of shipbuilding technology is widely diffused, EU shipyards have concentrated on either military or specialist ships. There is, however, an extensive EU supplier industry in engines, deck equipment, navigational equipment etc. The industry can be divided into shipyards, engines and systems suppliers with an extensive range of engineering consultancies for design. The industry is very mature and concentrated for large ship construction. The large shipbuilders have access to an extensive and effective innovation infrastructure, mostly within the companies themselves or through established industry consultancies.

A particular feature of shipping is the complex pattern of ownership and insurance. Ships are often not built for a shipping line, but for leasing intermediaries. All ships have to be insured for each voyage and the risk is aggregated through the Lloyds insurance market. This has had a major historical influence on innovation, because Lloyds developed the classification society system, under which classification societies in the major shipbuilding countries specify standards of construction and maintenance. Ships are required to be classified to be insured. A further important feature of standards setting is the International Maritime Organisation (IMO). Since shipping is an international activity, the IMO agrees on standards for operation and also applies international environmental policy. In the maritime sector therefore, there is a regulatory (sub) system which forms an important and distinct part of the innovation system.

The infrastructure in shipping consists of ports, waterways and coastal navigation aids. Navigation requirements and the ‘rules of the road’ for ship operations at sea are agreed through the IMO. Ports and waterways, in particular the Panama and Suez canals but also e.g. the Elbe river for access to the port of Hamburg determine overall dimensions for some ships. However, this infrastructure does not impose complex technological standards on ship construction.

The research system consists of national research institutes and universities, which undertake applied research in areas such as hull forms and propeller development. Engines and ship systems are mainly developed within the industry. Professional societies, in particular RINA (Royal Institution of Naval Architects) in the UK and SNAME (Society of Naval Architects and Marine Engineers) in the US play an important intermediary role in R&D and standards setting, providing a forum for discussion on both standards and engineering innovation.

National governments in the EU play a role in innovation in shipping through two main links. They form the membership of the IMO and therefore determine international standards and policy. Many governments in the EU also have extensive national procurement programmes for their navies and this supports a considerable part of the remaining shipbuilding industry in Germany, UK, France, Italy, Spain and the Netherlands.

The fundamental role in innovation in this industry is played by the shipbuilders (and suppliers), in response to the investment decisions from the shipping markets.

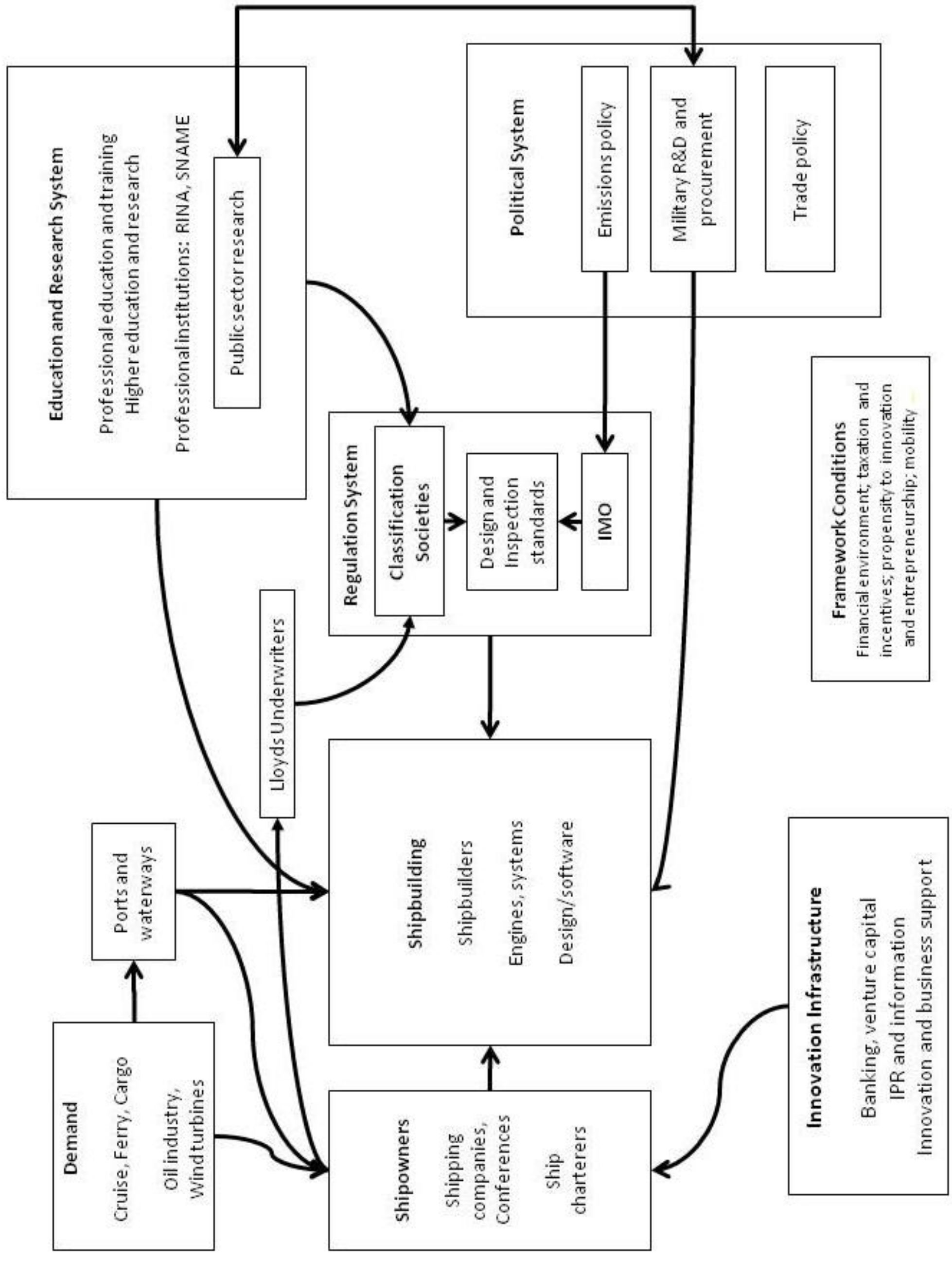

Figure 1. Innovation system Shipping

Source: own analysis

3. Transition analysis

The fundamental insight of transitions theory is that radical change takes place in niches, which if they flourish, may influence or replace the current regime. Historically, shipping since the industrial revolution has seen two large scale transitions: sail to steam in the nineteenth century (Geels, 2005, Köhler (2011) and the post war move to diesel propulsion, containerisation and Ro-Ro ferries. These latter changes are considered within the industry to have been revolutionary (Conway, 1992). Köhler (2011) is a first application of transition theory to sustainability in international transport. Köhler et al. (2009) assess a transition to sustainable mobility away from the automobile regime. Here, we undertake a preliminary qualitative analysis of current and possible niches where international transport might become part of a more sustainable production and consumption system.

3.1 The international transport regime and niches

The current international transport regime uses heavy fuel oil or diesel powered ships. Fuel costs are a significant part of operational costs, but technological innovation in energy efficiency has been incremental since the widespread adoption of containers, Ro-Ro ferries and low speed diesels. While there is some consideration of environmental impacts, this is so far of much lower priority than fuel price and reliability of service to the customer.

The other main feature of international transport is that it is based on global hub and spoke networks, with global hubs for container handling expanding to accommodate ever larger container ships. The shipbuilding and shipping industries are highly concentrated.

Several technologies are identified in the literature as having a potential for considerable savings. Lange et al. (2009) and Fernandez Soto et al. (2010) review the developments in ship propulsion. Biofuels for ships can be assessed as a niche at a point where a market niche could form before 2020 and niche growth could occur, especially in less price sensitive markets such as passenger shipping or in response to environmental policy. Sail/wind technologies offer zero carbon propulsion, which has been demonstrated to be effective for medium sized freighters and fishing vessels. Slower speeds allowing smaller engines and reoptimisation for minimum fuel use rather than construction cost in ships is applicable offers considerable potential savings for both container carriers and bulk/liquid bulk carriers (Lange et al., 2009). It is worth noting that if hull forms are reoptimised for slower speeds and design coefficients are chosen to minimise fuel consumption, further savings can be achieved. The first step, of installing engines for slower operational speeds, has been undertaken by Maersk in its recent container newbuildings (Naval architect (2011a). Podded propulsors with electric drives have been adopted in cruise ships and specialist vessels. They offer higher propulsion efficiencies (though currently with higher investment and maintenance costs) than conventional shaft/propellor/rudder drives and could be applied to freighters. Another area of technological innovation in shipping is in service providers such as oil rig support and supply ships, icebreakers etc. Such operators provide services where the customer may be willing to pay for a service with lower environmental impact as part of an environmental strategy (Koesler, Achtnicht and Köhler, 2012).

Niches where sustainability has a high priority can also be identified in the demand for international transport. Systems of production and consumption that are intended to contribute to sustainable development, in particular in LDCs is an area of market growth. This includes the Fairtrade system and companies such as e.g. Costa Coffee, Kenco Coffee (Kraft UK), Mars Inc. (cocoa) Greenbiz (2011) who wish to be seen as market leaders in sustainability. In the case of logistics, McKinnon (2010) shows that while logistics provision is dominated by cost, speed and reliability, there are some logistics customers that demand a 'sustainable' logistics service. Therefore, the third party logistics providers are now developing sustainable supply chain management (SSCM) systems.

Furthermore, ICT applications in logistics might change supply chain and logistics structures to much more closely coordinated and optimised production processes, with small goods consignments efficiently consolidated into container sized shipments (both aviation and maritime). Better SSCM systems could enable a reduction of risk in logistics, enabling a modal switch towards maritime transport (since a recent trend has been to use aviation for freight to cover short term variations in demand (Henstra, Ruijgrok and Tavasszy, 2007), such that seaborne freight grows faster than air freight.

A further possibility is that the continuing economic growth in newly industrialised countries (NICs) leads to the development of new major trade flows, in particular 'South-South' flows, between NICs and between NICs and LDCs. If NICs place more emphasis on environmental innovation and the development of eco-technologies, this may lead to the diffusion of low carbon technologies for shipping and aviation in international transport, led not only by the current 'green' market leaders, but also by new firms based in NICs and also LDCs that grow with the growth in the NICs' and LDCs' economies. In particular in shipbuilding, shipyards in NICs could develop and sell designs that include the niche low carbon technologies identified above. Biofuels production and supply systems could be adopted on a large scale, as the NICs have a high potential for biofuels production. These considerations could also lead to a move to transporting higher value goods by ship, so that the NICs growth and the expansion of trade with NICs and South-South trade happens in the maritime sector rather than aviation. Geographically diverse consumer demand from LDCs and NICs as well as the developed world and diffusion of production into NICs could make continued global concentration in logistics difficult, leading to an increase in smaller capacity point to point services with a much more extensive network of international services. Since many of these routes require smaller capacity and operate in smaller ports with limited infrastructure for container handling, general purpose combined container/Ro-Ro ships could more common, as in the EU-Africa trades (Naval Architect, 2011b).

4. Concept for an agent based model: constructing markets from the 'bottom up'

Following the analysis of agents in section 2 above, this initial model specification concentrates on the shipbuilders and investment decisions of shipping companies. These decisions are determined by economic considerations, although a decision to invest in new ships or R&D always has an element of judgment, because of the long time frame over which investment decisions will play out. Because the industry is highly concentrated such that individual agents may have an impact on the operation of the markets, we have chosen to start by considering (notional) individual shipyards and shipping companies i.e. agents, with transport demand exogenous. We model the interactions of the agents to develop demand and supply curves and rather than assuming a market clearing price, incorporate a simple iterative mechanism for determination of the prices achieved by each shipyard and shipping company. The agents and their interactions are outlined in figure 2. Note that there are multiple shipyard and shipping company agents.

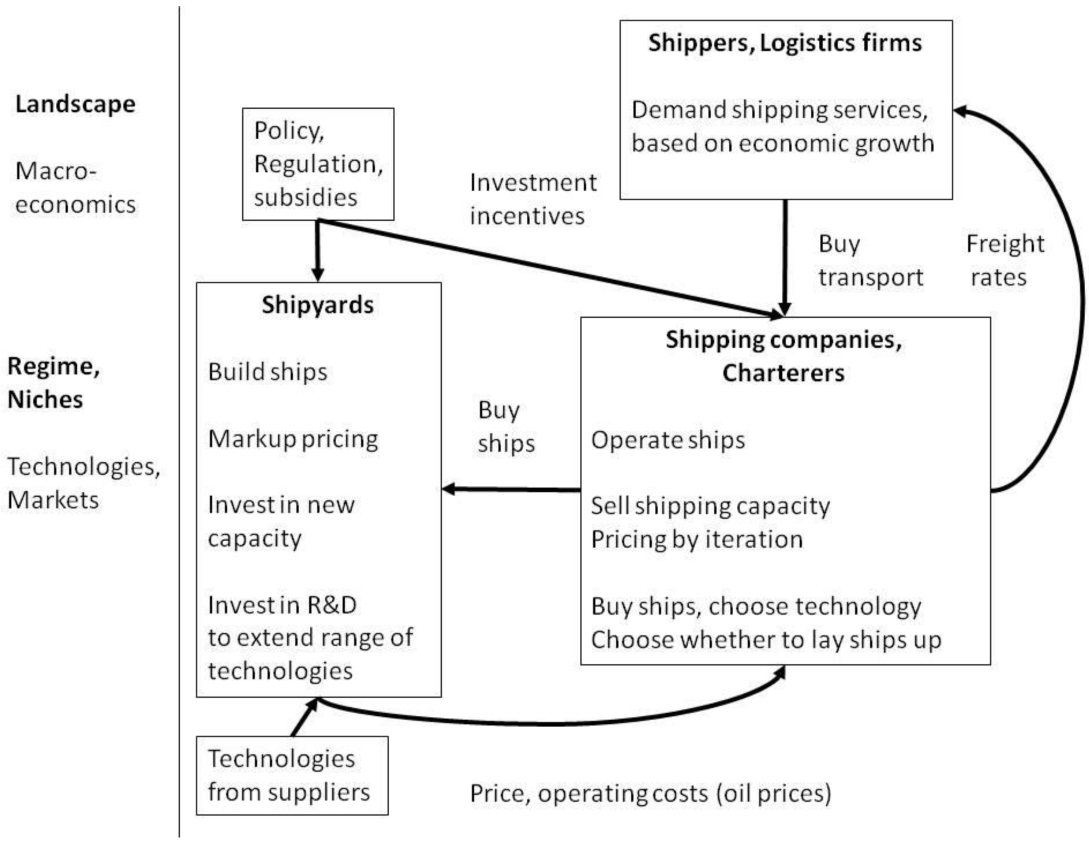

Figure 2. Model structure: interaction between shipyards, shipping companies and customers

Source: own analysis

The model is intended to develop scenarios of investment and new technology uptake. The main inputs are demand for transport for a set of ship types and the parameters of the decision functions of the agents. There are two types of agents: shipyards and shipping companies involved in markets for the following ship types: Cruise, Ro-Ro, container, bulker, tanker, specialist.

Shipyards receive orders from shipping companies and build ships. They can also choose to invest to increase capacity or invest in R&D. The emissions and energy efficiency impacts of R&D will be calibrated on the potential niche technologies identified in section 3 above. The costs of ships (capital and operational) are dependent on the technology level. The initial price offer for a ship is a markup on costs of the individual shipyard. If they receive more orders than they can fulfill, a queue of orders arises. If they do not receive enough orders to fill their capacity, then they reduce their price, to a minimum of their costs minus subsidies. If they receive no orders, the shipyard closes.

Shipping companies sell transport and invest in ships. Demand is exogenous to the agents' decisions, being based on economic growth scenarios (i.e. in microeconomic terms, there is a vertical demand curve for each period of the model). The initial price of transport that a shipping company offers is also a markup on their current costs of operation (including costs of fuel and emissions).

The shipbuilding and shipping markets operate iteratively. Demand for shipping is matched to shipping companies' prices, starting from the lowest. If there is insufficient transport capacity to meet demand, then the individual companies increase their price by a small proportion. This gives the shipping companies extra profits and this is then invested in more ships. If there is more transport capacity than demand, the most expensive shipping companies do not receive contracts and reduce their price to a minimum of coverage of operational costs. If shipping companies then still receive insufficient contracts, they lay up some of their ships. The investment decisions then form the demand curve for new ships and the market for newbuildings operates in a similar way.

Initially the period for each time step in the simulation model will be set at 2 years, long enough for most newbuildings to be completed, with investments in shipyard capacity coming on stream in the next period. The model will be calibrated on historical build data (the IHS Fairplay dataset for newbuildings since 1945 has been purchased) and will run over a time frame of 2030+.

5. Conclusions

Within the shipbuilding industry, there is already an understanding that environmental impacts of shipping are becoming an important social and political issue. However, the rate of adoption of such technologies and operational measures is slow. The goal of this paper is to develop the concept for a simulation model of R&D and investment in deep sea shipping. The paper adopts an actor or 'agent' based approach, which can explicitly address the detailed interactions between shipbuilders, shipping companies and customers of the shipping industry.

The method of a sectoral system of innovation analysis (Leduc et al., 2010; Köhler. forthcoming) is used to identify the types of actors involved. The fundamental role in innovation in this industry is played by the shipbuilders (and suppliers), in response to the investment decisions from the shipping markets. The industry is very mature and concentrated for large ship construction. Professional societies, in particular RINA (Royal Institution of Naval Architects) in the UK and SNAME (Society of Naval Architects and Marine Engineers) in the US play an important intermediary role in R&D and standards setting and engineering innovation. All ships have to be insured for each voyage and the risk is aggregated through the Lloyds insurance market. This has had a major historical influence on innovation, because Lloyds developed the classification society system, under which classification societies in the major shipbuilding countries specify standards of construction and maintenance.

Several technologies are identified in the literature as having a potential for considerable savings, including biofuels, wind energy, and slower speeds as well as new propulsion systems and afterbody forms. Market niches where sustainability has a high priority can also be identified: in the current

Fairtrade products and potentially through future growth of low carbon technology policies in the NICs, which offer growth markets in international transport.

This initial model specification concentrates on the shipbuilders and investment decisions of shipping companies. We model the interactions of the agents to develop demand and supply curves and rather than assuming a market clearing price, incorporate a simple iterative mechanism for determination of the prices achieved by each shipyard and shipping company. The model will be calibrated on historical build data (the IHS Fairplay dataset for newbuildings since 1945 has been purchased) and will run over a time frame of 2030+.

Changes in the structure of demand for logistics and passenger shipping will be considered in future work. A further area of research will be institutional and market barriers to the uptake of new technology, and the examination of the differing possibilities for innovation both in the shipping industry socio-technical regime and the niches that have been identified.

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