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The impact of split incentives on energy efficiency technology investments in maritime transport

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ABSTRACT

This paper presents the first analysis of how the split incentive market failure affects the implementation of energy efficiency technologies in the maritime transport sector. In maritime transport, split incentives occur due to the different types of charter (resulting in the divided responsibility for fuel costs) existing between shipowners and charterers. The paper uses a robust and rigorous framework of methods to operationalise the split incentive concept in a cross-sectional survey of 275 shipowners, representing around 25% (6000 ships) of the target population, resulting in the most comprehensive data on the implementation of energy efficiency technologies in shipping. The findings show, contrary to that postulated in the literature, that firms that have majority of their ships on time charter (i.e. those that don't directly observe the energy price signal but may potentially receive an energy efficiency premium) have a higher implementation of energy efficiency technologies compared to firms that operate ships on the spot charter (i.e. directly observe the price signal). To some extent the findings could be due to the effect that other confounding variables may have on the implementation of measures and the extent to which the shipping market is correcting or overcoming the split incentive efficiency problem.

1. Introduction

Energy efficiency is a key strategy to address multiple societal challenges, including climate change, sustainable and economic development and improving energy security. Many empirical studies have identified several barriers that are hampering the uptake of the operational and technological energy efficiency solutions in various sectors, see for example Thollander & Ottosson (2008), Davis (2009), Maruejols and Young (2011), Trianni et al. (2013), Acciaro et al. (2013), Johnson et al. (2014), Jafarzadeh and Utne (2014) and Dewan et al. (2018). These barriers range from economic to behavioural barriers (Sorrell et al., 2004; Thollander et al., 2010). The most common taxonomy is given by Sorrell et al. (2004) who classify them into three main categories, economic, behavioural and organisational. This taxonomy is well grounded in the orthodox economics perspective, and each of the individual barriers are in turn grounded on specific economic theories e.g. transaction cost, agency etc. For example, Rehmatulla (2014) applies the agency theory by Eisenhardt (1989) to investigate the split incentive barrier in the context of operational energy efficiency in shipping. The split incentive or misaligned incentives barrier in the context of energy efficiency refers to the situation where the costs and benefits accrue to different entities engaged in a contract.

The focus of this study is maritime transport which contributes to around 2% (approximately 1 giga tonnes) of current global CO_2 emissions (Smith et al., 2014a; Johansson et al., 2017; Olmer et al., 2017). This share is likely to rise in the future due to rising demand (Smith et al., 2014a), and a reduction in emissions from other sectors that come under national inventories of UNFCCC member states that have ascribed to limiting global mean temperature to well below 2 °C and aiming for 1.5° under the Paris Agreement (UNFCCC, 2015). According to the Third IMO GHG Study (Smith et al., 2014a) all future scenarios for shipping under the current policies anticipate rising emissions, with at best stabilisation of emissions at 2012 by 2050. IMO, 2018, the sector agreed on it's strategy on GHG emissions which has a number of objectives, including, i. to reduce carbon intensity for new ships through further phases of the energy efficiency design index (EEDI), ii. to reduce CO2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008 and iii. to 'at least' halve total GHG emissions by 2050 compared to 2008 levels, (IMO, 2018). Given the growth rate in shipping emissions and to be consistent with the goals of the IMO's initial GHG strategy, a combination of solutions is required. In-sector reductions can be in the form of technical and operational energy efficiency solutions (Bouman et al., 2017), which will to an

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Table 1
Cost allocation between shipowner and charterer in the different types of contracts.

	Spot charter	Contract of Affreightment	Time charter	Bareboat charter
Remuneration	Per unit of cargo e.g. tonne/TEU	Per unit of cargo over a fixed duration and route	Per day	Per day
Cargo handling *(stowage and storage)*	Charterer	Charterer	Charterer	Charterer
Voyage expenses *(port and fuel costs)*	Shipowner	Shipowner	Charterer	Charterer
Operating expenses *(crew wages, maintenance, repairs, stores & supplies, insurance, overheads)*	Shipowner	Shipowner	Shipowner	Charterer
Capital expenses *(interest and capital repayment)*	Shipowner	Shipowner	Shipowner	Shipowner

extent enable shipping to course a transition towards a low carbon pathway. To achieve the third emission reduction objective, zero emission fuels and technologies are required to enter the fleet by 2030 (Balcombe et al., 2019; Hansson et al., 2019; Raucci et al., 2017).

Table 1 shows the different types of contracts used in the shipping industry and how the contracts vary the responsibility for fuel and capital costs as well as other costs, from shipowners to charterers, which give rise to split incentives (Acciaro et al., 2013). Given this connection with split incentives barrier, this section delves further in defining these charters and their prevalence in different shipping sectors. In a spot charter, a charterer contracts a shipowner to transport a specified amount of cargo, which is similar to hiring a taxi. The amount paid by the charterer is for a unit of cargo transported, which includes an apportionment of all the costs incurred by the shipowner including fuel costs for that voyage. A contract of affreightment is essentially the same as a spot charter, but is constrained to a fixed route over a specified duration, which gives the freedom to a shipowner to choose any vessel to meet the cargo transport requirement. In a time charter, a charterer hires a vessel along with the crew for a certain period of time or a single trip (trip time charter), giving the charterer the operational control of the vessel, similar to hire of a vehicle with a driver. The amount paid by the charterer is for daily hire cost of the ship and crew and the charterer also bears the fuel costs related to the voyages undertaken during that period. In a bareboat charter the charterer has full control of the vessel along with the commercial and legal responsibility for it, similar to a long lease. From the perspective of carriage of goods, the contracts can be distilled into spot charter and time charter (Wilson, 2010). In terms of chartering strategies[1] of firms, all of the aforementioned contracts are used in the shipping sectors, however there is prevalence of some types of charters in some sectors. Rehmatulla and Smith (2015a) show that majority (90%) of ships in the tanker sector are chartered-out on spot charter, whereas 60% of ships in drybulk are chartered-out on time charter and with regards to containerships, all ships are assumed to be equivalent to spot chartered-out, since the shipper pays per unit of cargo transported (per container referred to as Twenty-foot Equivalent Unit, TEU) and the container line company pays for the fuel and all other costs. In all these sectors there is varying distribution of chartered-in strategies relative to ownership of vessels. For example, in the case of container ships, the top ten container lines, representing 80% of the market share in terms of capacity, on average own 45% of their ships (Alphaliner, 2020) with the remainder ships chartered-in on bareboat charter and time charters, whereas the top ten drybulk and tanker shipping companies own approximately 80% and 85% of the vessels, respectively (Robertshaw, Forthcoming). The charter-in and charter-out strategies of firms depends on the freight market conditions, the balance between a shipowner and charterers assessment of risk (Stopford, 2009) and concentration of buying power (Poulsen and Johnson, 2016). When charterers perceive risks in increasing freight rates due to lack of supply, their strategy would be lock-in the transport service through time charters. Therefore prevalence of the type charters in sectors could change over time as a result of these dynamics. An example of this is the reversal of chartered-out fleet of tankers, which during 70's were mainly on time charter to oil majors but currently only around 10% of the tanker fleet is time chartered-out.

Whilst there are various occurrences of the split incentives (Rehmatulla et al., 2017b), the split incentives arising in the time charter is the most common, where fuel costs are borne by the charterer, (in addition to the daily charter rate) and capital and operating costs are borne by the shipowner. Since fuel costs are borne by charterers, the shipowner must warrant to the charterer minimum service quality through a speed and fuel consumption guarantee under good weather conditions. When a ship fails to meet the guarantee, a performance claim can be made by charterers to compensate for the loss of productivity due to lower speed or higher fuel costs due to increased fuel consumption. This under performance of a ship can arise due to a number of factors, including due to lack of maintenance of the ship e.g. due to lack of hull cleaning which would increase the ships resistance through the water. In some cases it has been shown that shipowners engage in strategic behaviour, quoting lower warranted speed and higher fuel consumption (i.e. better than actual performance) in time charters (Veenstra and Dalen, 2011). Refer to Rehmatulla (2014) for a

[1] 'Chartered-in' refers to a company's ability to increase it's capacity through bareboat and time charter in addition to owned vessels. 'Chartered-out' refers to a company's ability to earn a revenue through provision of transport services through spot charter, time charter, contract of affreightment and bareboat charter.

detailed analysis of specific clauses in spot and time charter parties that lead to split incentives, adverse selection and moral hazards. The split incentive and adverse selection problems in the time charter are further exacerbated due to the short duration of time charters (Poulsen and Johnson, 2016) and the ability of shipowners to recoup investment in energy efficiency through higher charter rates (Adland et al., 2017; Prakash et al., 2016; Agnolucci et al., 2014). Thus, the degree of the split incentive varies according to exposure of the market, the duration of contracts and whether shipowners are being rewarded for energy efficiency.

Having understood the chartering practices of the shipping sector, the key research question that this paper aims to answer is; to what extent does the implementation of energy efficiency technologies vary according to the different types of charter. The focus is on energy efficiency technologies instead of operational measures, as there is a marked difference in the capital outlay of the measures and thus would reveal the pervasiveness of the split incentive barrier. The paper is structured as follows; section 2 provides a review of studies that have examined the split incentives, which is followed by section 3, which provides further details on the methods used to gather data. Section 4 shows the results of the first/zero-order relationships and section 5 presents the second-order/controlled relationships and provides further discussion on the findings. The key conclusions, policy implications and further work are presented in section 6.

2. Literature review

This section provides a review of the studies that have investigated the split incentive barrier in context of energy efficiency, studies that have suggested existence of split incentives in shipping and a review of the studies that have attempted to assess the implementation energy efficiency technologies in shipping and their results regarding the split incentive.

2.1. Review of studies that suggest split incentives in transport and non-transport sectors

The split incentive barrier stems from the principal agent problem or the agency relationship (Jensen and Meckling, 1976), which suggests the desires or the goals of the principal and agent conflict (split incentives problem) and that it is difficult or expensive to verify the agent's actions (informational problem) (Eisenhardt, 1989). Thus, the split incentive problem and informational problems (imperfect information and asymmetric information) are inextricably linked and generally categorised as market failures in context of energy efficiency (Brown, 2001).

Split incentives have been mostly discussed in the building sector, mainly for private rental in the residential sector. Whilst there are many studies that have found the split incentives to exist in this sector, the studies have investigated their existence with other barriers and not in isolation. Blumstein et al. (1980) is the first study that alludes to the split incentive problem in the residential sector, suggesting a "landlord-tenant" issue (Rehmatulla, 2014). Berchling and Smith (1994) is the first study that examines the effect split incentives in residential homes using secondary data (English House Condition Survey). The study shows that the implementation of energy efficiency measures in privately rented properties was lower compared to owner-occupied households. Scott (1997) supports the findings of Berchling and Smith (1994) in that ownership of energy efficiency measures differed amongst households, with higher ownership of energy efficiency measures in the owner-occupied households that were able to 'appropriate the benefits of the investment' (Scott, 1997, p. 203).

Murtishaw and Sathaye (2006) is the first study that solely focused on split incentives. They propose that different types of split incentives occur in different cases. The most common occurrence is where the cost of energy is borne by the tenant whereas the energy investment capital is borne by the landlord, classed as the 'efficiency problem'. Other situations, such as the 'usage' problem occur when the landlord is responsible for investment in energy efficiency and energy costs. A key finding of their study is that the principal agent cases are not static but vary according to the technology or end use (e.g. space heating) being studied. For example, in the case of lighting only 5% of households are affected by the principal agent efficiency problem, for refrigerators over 30% of households are affected by principal agent efficiency problem and for water heaters 78% of households are affected by principal agent efficiency problem. This finding suggests that the energy efficiency technology itself and the mobility of energy efficiency technology is an important factor affecting the principal agent problem.

Davis (2009) compares energy efficiency of appliances between owner-occupiers and tenants. Ceteris Peribus, the study shows that tenants were "significantly less likely to have energy efficient refrigerators, clothes washers and dishwashers" (Davis, 2009, p. 1), confirming findings of Murtishaw and Sathaye (2006) and the 'efficiency' principal agent problem. Levinson and Niemann (2003) and Maruejols and Young (2011) explore cases where energy costs are included in the tenants' monthly bill, that is supposed to result in a 'usage problem' according to Murtishaw and Sathaye (2006). Both studies found evidence that the tenants behaved differently leading to suboptimal energy consumption. Melvin (2018) finds that the split incentive efficiency problem causes landlords to forgo energy efficiency investments and consequently the tenants' energy bill is higher by 2% compared to owner-occupied dwellings. The findings from the buildings sector not only confirm the existence of the split incentive, but also suggest that it is important examine energy end use and type of energy efficiency measure to determine the extent of split incentives.

To date only three studies have specifically focused on investigating the principal agent problem in the transport sector. Graus and Worrel (2008) and Vernon and Meier (2012), both show that the 'efficiency' and 'usage' split incentives problems exist in the transport sectors analysed (company car leases and road freight sector). Split incentives in maritime transport have been alluded to by various studies see for example, Acciaro et al. (2013), Johnson et al. (2014), Jafarzadeh and Utne (2014), Agnolucci et al. (2014), Riise and Rødde (2014), Parker and Prakash (2015) and Adland et al. (2017). Rehmatulla and Smith (2015b) investigates the existence of split incentives in the implementation of operational measures in maritime transport in greater detail using a triangulated approach. Their findings suggest that split incentives exist in the implementation of some of the operational energy efficiency measures, such as speed reduction, which is exposed to the 'usage' problem and trim draft optimisation, which is exposed to the 'efficiency' problem.

2.2. Review of studies on implementation of energy efficiency in shipping

Relatively few attempts have been made to assess the uptake of energy efficiency technologies in shipping. To date four studies have attempted to gauge the implementation energy efficiency technologies, these are: DNV GL (2014), IMarEST & Colfax (2015), Rojon and Smith (2014), HSH Nordbank (2013). Here we review two of these studies that can help to develop the method and understand the state of the art on the literature. For a detailed analysis of the aforementioned studies refer to Rehmatulla et al. (2015) and Rehmatulla et al. (2017c).

HSH Nordbank's (2013) survey of sixty shipping companies within its portfolio, was one of the first studies that attempted to gauge the nature of implementation of energy efficiency technologies and the impact of policies (at the global level) on the attitude towards implementation. The results show that almost half of the respondents were engaged in either acquiring energy efficient newbuilds or were retrofitting their vessels. The sample is not representative, but nevertheless suggests a high degree of technical interventions were taking place. A third of the respondents had retrofitted more than 50% of their fleet and almost 40% had done this for less than 10% of their fleet. Another important finding relevant to this research is that they find shipowner operators are most progressive in their implementation compared to other shipping companies e.g. management companies, and suggest that the split incentive could possibly explain the difference in implementation. The same is also suggested by Poulsen and

Sornn-Firese (2015). However, the data on implementation of specific energy efficiency technologies is not disaggregated to show the difference by types of companies. This is in contrast to HSH Nordbank (2013) findings which suggests that for almost 80% of the respondents that it will take over 3 years to recoup the costs in energy efficiency investments and that almost 50% of the respondents believed that higher charter rates can be achieved as a result of better energy efficiency, a sentiment that is corroborated with Agnolucci et al. (2014), which shows that on average only 40% of the financial savings delivered by energy efficiency accrue to the shipowner for the period 2008–2012 in the dry bulk Panamax sector.

Rojon and Smith (2014) survey 130 shipowners & operators to assess the implementation of energy efficiency technologies and how they have verified the savings from these interventions. The survey showed almost 80% of the respondents had adopted fuel saving technologies in the past five years, almost half of which include more than one technology at a time. Similar to HSH Nordbank (2013), Rojon and Smith (2014) show that propeller modifications had been implemented by over half of the respondents in the sample. Whilst the data can be broken down by ship type and type of company (i.e. what technologies have been implemented in which ship types & by which type of operator), the data is not captured for the size of the ships on which the technologies are implemented, whether the technologies were retrofitted or for newbuilds and implementation by type of charter.

2.3. Summary

The aforementioned studies which focused on the agency problem in the building industry and other sectors find the existence of both cases split incentives, where tenants pay for energy bill and where they don't pay for the energy bill. On the other hand within the maritime transport sector the cross-sectional surveys have mainly focused on the general level of implementation and have not considered how the implementation can be different under the split incentive proposition elucidated in the former and within the energy economics literature. Therefore, the key research question that this paper aims to answer is, to what extent does the implementation of energy efficiency technologies vary according to the different types of charter.

3. Method

In order to represent a wide cross-section of the implementation of energy efficiency technologies an online survey using the Tailored Design Method (TDM) (Dillman, 2009) was used for the questionnaire design, sampling strategy, mode of distribution and follow ups. Following Rehmatulla et al. (2015), this is the only other paper which attempts to measure specifically the split incentives using data gathered from a bespoke survey. A full list of energy efficiency technologies was derived from the Low Carbon Shipping project (Smith et al., 2014b) and Calleya et al. (2012) as well as various other industry sources Lockley et al. (2011), OCIMF (2011) and IMarEST & Colfax (2015). In total 44 technologies were included in the survey, grouped into five categories. The full list of technologies can be found in Rehmatulla, 2014.

3.1. Questionnaire design

For the flow chart of the survey questions, question formats and survey tools see Fig. 1 and for more details on the wording of the survey questions refer to appendix. In order to avoid respondent burden and increase response rates the majority of the survey consisted of categorical variable questions. The design considerations mainly follow those detailed in Rehmatulla (2014) which describes in detail the choice of question types, number of questions, length of the survey, pretesting/piloting, which closely follow the Tailored Design Method (Dillman, 2009).

3.2. Operationalization and indicators of hypothesis

In line with previous research and literature aforementioned, at the company level, it is postulated that firms with a higher proportion of ships on time charter will have lower implementation of energy efficiency technologies, due to the efficiency problem (i.e. not paying for fuel directly and lack of energy efficiency premiums), similar to case two described in Vernon and Meier (2012). The opposite is postulated for firms that have a higher proportion of ships on spot charter, analogous to case 1 described in Vernon and Meier (2012). The survey uses a numerical (ratio variable) approach to assess the level of split incentives (the independent or causal variable). The numerical approach follows the method described in Rehmatulla et al. (2015). This method takes the firms overall chartering strategy to assess the split incentive and categorises the firms into two groups, firms with a majority of their fleet chartered-out on spot charter and firms with a majority of their fleet chartered-out on time charter.[2] In some cases it is possible that ships that may have been chartered-out on time charter by the respondent companies could be further sublet to another firm and that firm could further sublet the vessel on time or spot charter, since most contracts (charter party) allow for this. The level of subletting depends on ship type, ship size and duration of charters (Rehmatulla, 2014). Rehmatulla (2014) shows the level of subletting, from time charter to voyage charter, is higher in tankers compared to dry bulk. Due to the nature of the cross-sectional survey it is not possible to detect sub-chartering beyond the respondent company. Table 2 shows the total number of firms that fall under these two categories and Fig. 2 shows the distribution of the chartering level for each of the groups as given by the respondents. The distributions show that for group 1, the chartering ratios are better representative of firms with majority of their fleet on spot charter, compared to group 2.

The survey also included measures of test variables, i.e. those that clarify the link between independent and dependent variable, in this case sector of operation, company type, company location and company size. Overall, the number of respondents were evenly split between case 1 and case 2, as shown in Table 2. Disaggregating the chartering group by size shows inherent or underlying relationships between chartering group and firm size, which is statistically significant (Phi 0.315, at the 0.05 significance level)[3] (Table 3). Disaggregating the chartering group by sector, shows a lower but statistically significant correlation than the aforementioned relationship (Phi 0.264, at the 0.05 significance level) (Table 4). Furthermore, there is also a statistically significant relationship between size of the firm and the sector in which it operates (Cramers V .257, at the 0.05 significance level). These relationships could be market related, for example Parker and Prakash (2015) found that volatility in the rates around the time of the fixture affected the contract choice. This means that in order to reliably explain the causal relationship between chartering group and implementation of energy efficiency technologies, the size and sector need to be controlled for. There could also be potential bias in the location of the company, size and age of ships, with the implementation of energy efficiency technologies. In the following sections, both zero-order relationships and controlled relationships (controlling for size and sector) for a limited number of measures are presented.

3.3. Sampling frame and strategy

The survey mainly uses a stratified sampling approach (75% of

[2] The survey captured chartering 'in' and chartering 'out' strategies of firms. Under chartered-in options included % owned, % time chartered-in, % bareboat chartered-in and for chartered-out we include % spot chartered-out, % time chartered-out, % on Contract of Affreightment, % bareboat chartered-out. For the analysis on implementation, we do not control for the chartering in strategies but only for the chartering out strategies as presented in Table 2 and Fig. 2.

[3] Firm size was categorised as follows: small (1–10 ships), medium (11–49 ships) and large (50 and above).

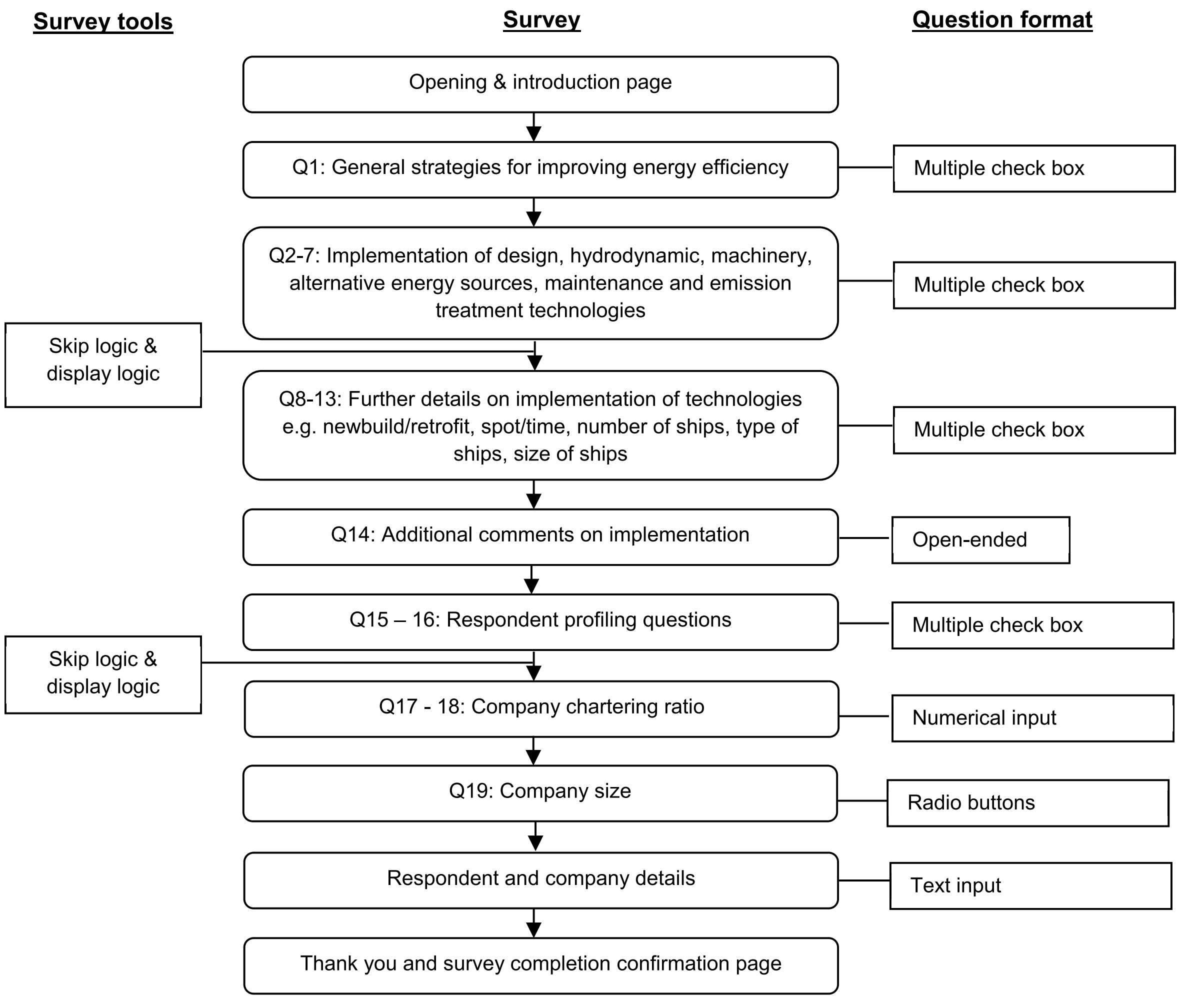

Fig. 1. Survey question flow chart.

Table 2
Frequency of case 1 and case 2 (Chartering ratio variable - numerical).

Group	Description	Grouping rule	N
1 – Case 1	Majority of the fleet is chartered-out on spot charter.	>50% chartered-out on voyage	75
2 – Case 2	Majority of the fleet is chartered-out on time charter.	>50% chartered-out on time	81

respondents), which is complemented by a non-random sampling approach (e.g. memberships of associations). For the stratified approach firms were selected from the Clarksons Shipping Information Network (SIN) database. Rehmatulla et al. (2017c) shows the stratified population according to the company's size, its sector of operation and geographical location of the firms headquarters for the tanker[4] (wetbulk), drybulk and container sector, as together they represent nearly 70% of total CO_2 emissions from shipping (Smith et al., 2014a). Further details on the sampling strategy can be found in Rehmatulla et al. (2017c).

3.4. Response rates

The stratified sampling approach using the TDM method (calling shipping company technical departments) led to 199 responses out of 270 calls made (thus 70% response rate). 76 responses were received from member associations' database or mailing lists. In total 275 responses were received, representing over 6000 ships (25% of the population of interest), making this study the first to receive a high response rate on this subject. Out of the 191 respondents who indicated their company size, the majority (56%) were medium sized firms, and the remainder equally split as small and large firms.

Over half of the respondents were from senior level management consisting of technical directors, technical managers and fleet managers. These were followed by technical superintendents (including senior superintendents), sustainability or energy efficiency managers and project managers. The majority of the responses were from companies headquartered in the EU (75%), mainly in Greece (20%) and Germany (18%), and this is not surprising given that a 55% of large and medium sized shipowners are headquartered in these countries and both continue to be in the top five ship owning nations (UNCTAD, 2018).

Several factors may have introduced bias in the cross-sectional survey that was administered. These can be mainly related to the timing of the survey rather than respondent bias, which was to a large extent effectively controlled through the stratified sampling approach. At the time of survey, a number of regulatory changes were being implemented, including the IMO regulations on sulphur emissions which required a reduction on marine fuel Sulphur content in the Emission Control Areas (ECAs). At the same time the IMO EEDI Phase 1 was also implemented, which could increase the take up technologies on the newbuild fleet. In addition to the regulatory context, the shipping market (in all ship types) also faced depressed freight rates due to oversupply, whilst at the same time fuel prices were at their

[4] Refers to oil, product and chemical tankers only and does not include LNG or LPG carriers.

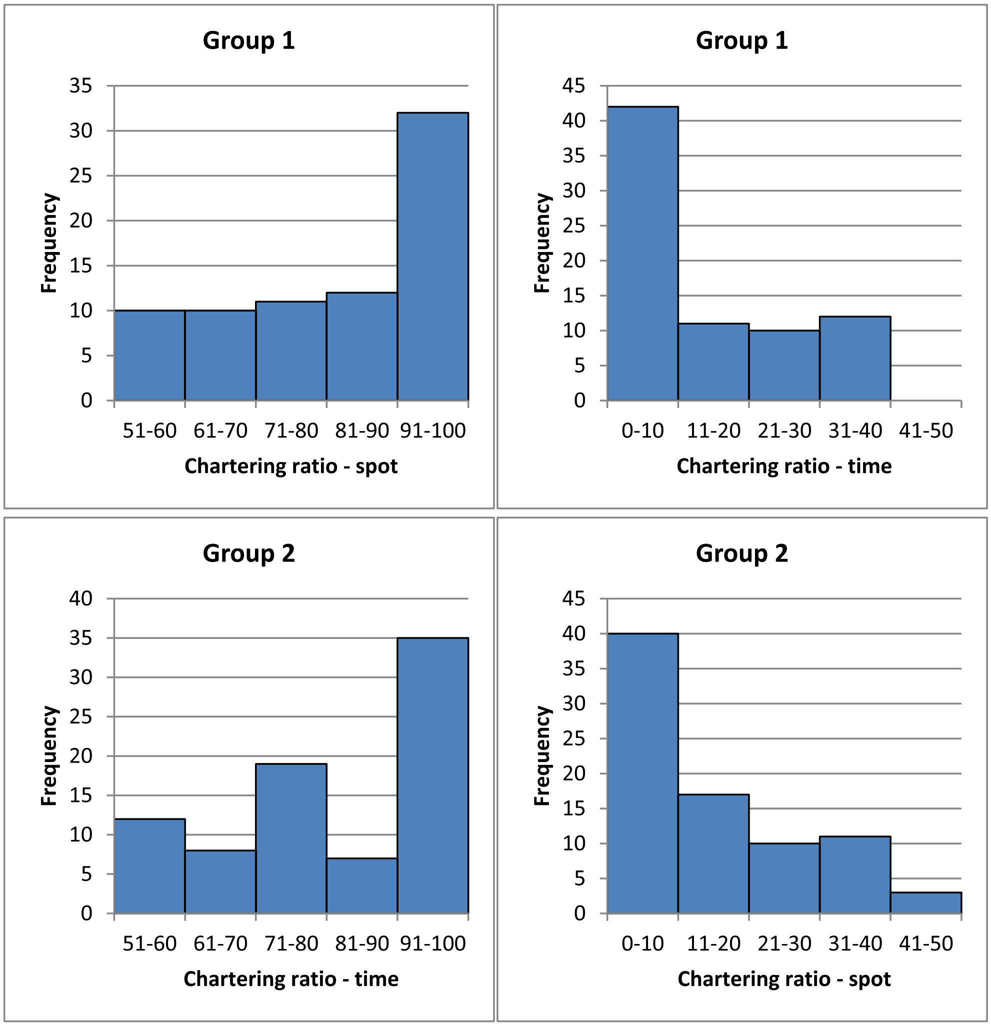

Fig. 2. Distribution of chartering ratios by each group.

Table 3
Chartering group and size.

Size	Group 1	Group 2
Small	13	22
Medium	37	51
Large	24	6
Total	74	79

Table 4
Chartering group and sector.

Sector	Group 1	Group 2
Wetbulk	32	20
Drybulk	11	23
Container	8	8
Total	51	51

lowest levels, half of the long-term average, at $300 per tonne of heavy fuel oil. Both of these market factors could have an adverse effect on implementation of technologies as the payback period of various energy efficiency measures is further extended.

4. Results

This section presents an overview of the results for the non-controlled zero-order relationships i.e. between chartering groups and their implementation of energy efficiency technologies and controlled relationships for hydrodynamic measures. Table 5 shows the total number of technologies implemented by each chartering group for the different types of technologies. This is derived by adding the number of technologies each company reported to have implemented in its fleet (this does not take into account the number of ships). The average value describes the number of technologies implemented by each firm. This analysis shows whether there are a diverse set of technologies that are being implemented by the chartering groups. There isn't a clear trend of group one having higher implementation than group two. As an example, Fig. 3 shows the implementation frequency distribution of design technologies by each chartering group.

Table 5
Total and average number of technologies implemented by chartering group.

Technology group	Group 1	Group 2
Design technologies	117 mean 1.6	129 mean 1.61
Hydrodynamic technologies	85 mean 1.15	71 mean 0.9
Machinery technologies	200 mean 2.8	185 mean 2.4
Alternative fuel technologies	13 mean 0.17	16 mean 0.19
Emission treatment technologies	17 mean 0.26	12 mean 0.16

Figs. 4 and 5 and Fig. 6 show the implementation of the energy efficiency technologies by the chartering groups. The Y axes of Figs. 4–6 shows the percentage range of ships in which these technologies have been implemented by the respondents. This is given as a range (maximum and

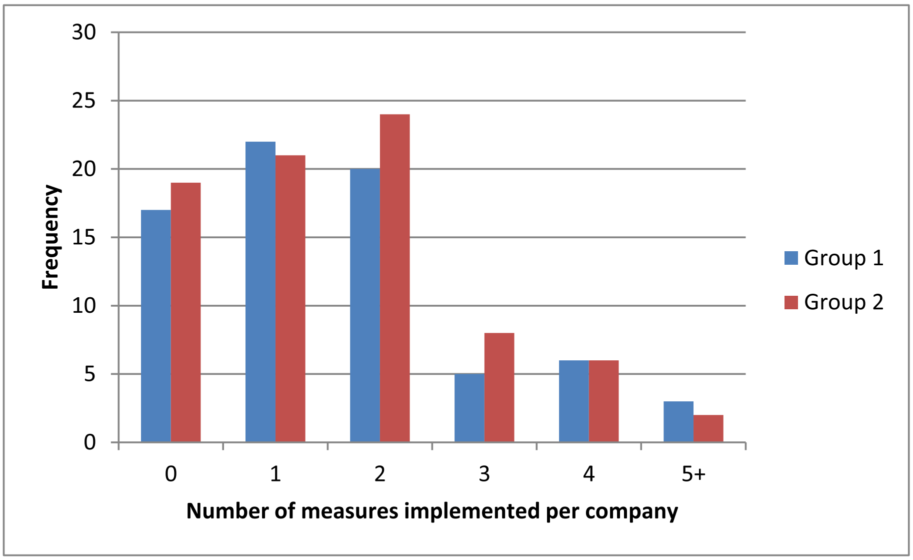

Fig. 3. Implementation of design technologies by survey respondents.

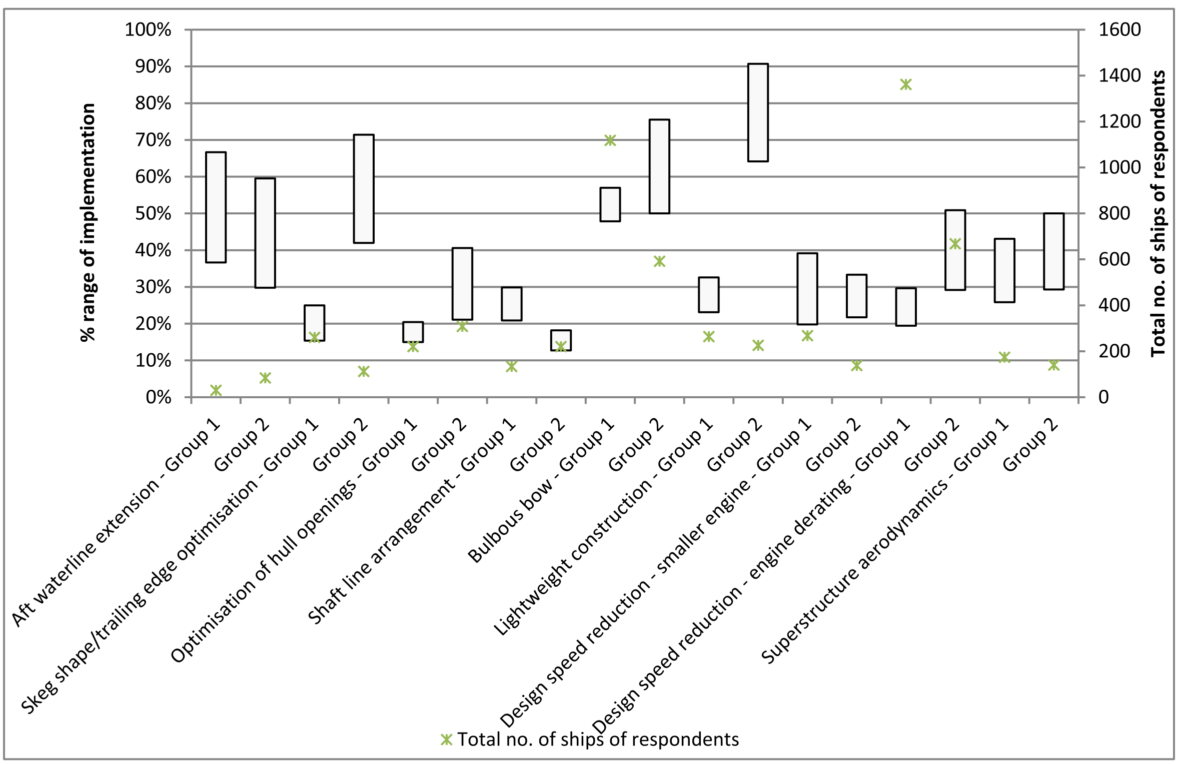

Fig. 4. Implementation of design based technologies.

minimum) because the survey question contained categorical variables such as 1–5 ships, 6–10 ships, etc. to minimise respondent burden. The minimum and maximum (range) is calculated by taking the size of the firm reported multiplied by the average number of ships contained in that size category. The average number of ships is obtained from the Clarksons World Fleet Register database i.e. the sampling frame, and the average number of ships was four, twenty and ninety for small, medium and large firms, respectively.

Fig. 4 shows the implementation of design technologies split into the two chartering groups. It can be observed that group two i.e. companies for which the majority of vessel operate on time charters, has higher implementation for most technologies except for three technologies. Across all the technologies chartering group one had an average implementation range of 25%–38%, whereas chartering group two had an average implementation range between 33% and 54%.

Fig. 5 shows the implementation of hydrodynamic technologies by the chartering groups. The trend follows that which is observed in Fig. 4, where chartering group two has higher implementation in all technologies except for two technologies. However, unlike the design technologies the average implementation range doesn't vary by quite as much, with chartering group two having slightly higher implementation range, between 21% and 46% compared to 20%–44% for chartering group one.

Fig. 6 shows the implementation of machinery technologies by the two chartering groups. Once again across all the technologies, ten out of twelve machinery technologies had a higher range of implementation amongst firms that mainly had ships on time charter. Across all the technologies chartering group one had an average implementation range of 30%–40%,

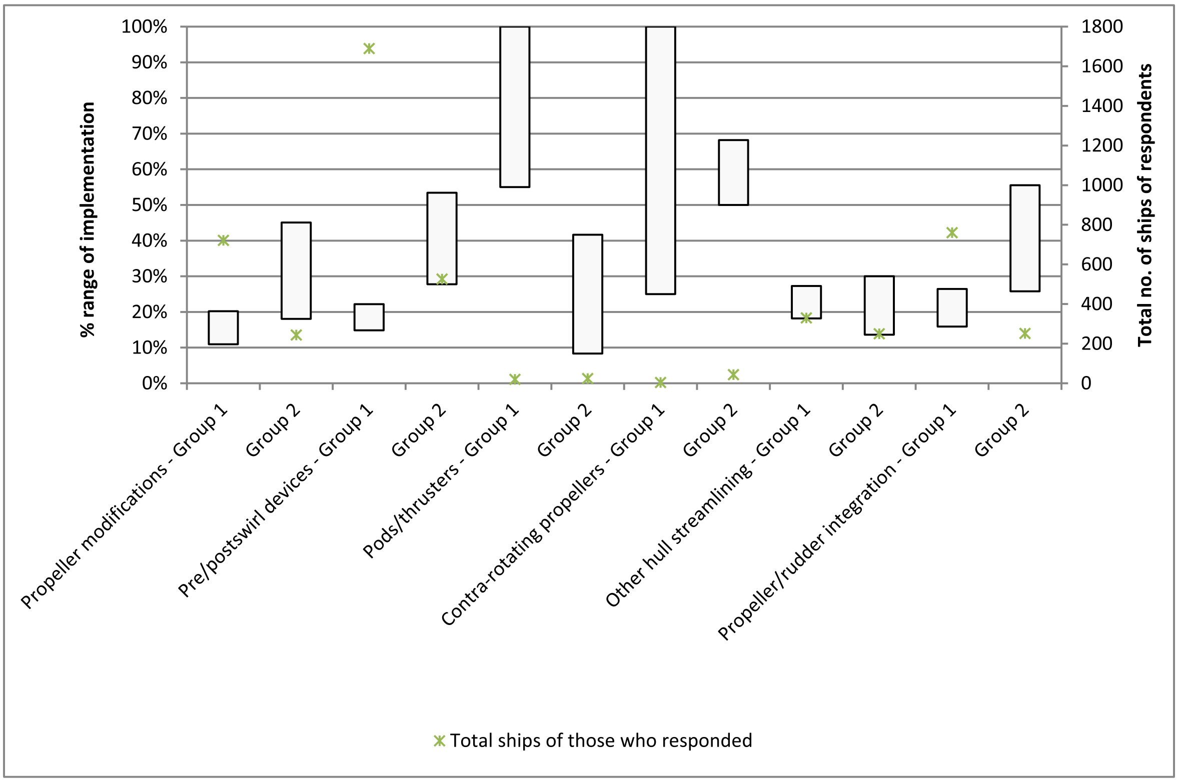

Fig. 5. Implementation of hydrodynamic technologies.

whereas chartering group two had an average implementation range between 37% and 55%.

The following quotes show the 'stated preferences' of the split incentive barrier by the survey respondents. Several survey respondents alluded, without any prompts (i.e. in the additional information section of the survey), to the split incentive among other barriers (e.g. information barrier) as a barrier to implementation. The responses show that split incentives are being perceived as hindrances by the respondents whilst the preceding analysis shows otherwise. One respondent very clearly articulated the split incentive:

"Not beneficial to owners in current time charter market. Charterers purchase fuel" Medium size US drybulk shipowner-operator.

Two of the respondent referred specifically to scrubber installations, which don't come under the scope of reducing GHG emissions, but highlight the regulatory context during which the survey was conducted.

"As vessels are under time charter (and fuel is paid by the charterer), the charterer will only forward a part of the savings to the shipping company after installing a scrubber" Medium size European container line shipowner-operator.

"Did not install scrubbers despite spending close to $100,000 because time charterer would not contribute in any way to the installation cost. Therefore since charterers pay the fuel cost of a time chartered vessel, the charterers wanted us to pay approx. 4 million to fit the scrubber and allow them to use IFO380 instead of diesel fuel which would have saved them the delta between the prices of IFO and MGO but didn't want to pay owners any more to charter hire the ship (Daily Rate)" Medium size US tanker shipowner-operator.

Fig. 7 shows the relationship between the chartering group and the highest implemented technologies broken down by whether they were implemented on newbuilds or retrofitted to existing ships. There isn't a clear relationship between chartering group and whether the technologies are implemented on newbuilds or retrofitted, but when aggregating across the different technologies, the companies in both chartering groups have similar level of implementation for newbuilds, whereas chartering group 1 has higher implementation compared to chartering group 2 for retrofits. This could be due to several reasons. One explanation could be that shipowners, when commissioning newbuilds have incentives to implement the energy efficiency technologies, as the relative extra expenditure during design and newbuild for an energy efficient ship is smaller compared to a retrofit e.g. resulting in higher opportunity costs and loss of earnings if the installation requires drydocking. The lower aggregate implementation in retrofits is also most likely because several the technologies can only be installed whilst on dry-dock, generating a time lag in the implementation. Secondly, newbuilds see a higher uptake of these technologies across both chartering groups, as they are generally offered in 'standardised' energy efficient 'eco' designs or sold as a package and included in the newbuild price (Lloyds List, 2013; BIMCO, 2013). Thirdly, the similar levels of implementation in newbuilds by both chartering groups could be because some newbuilds are commissioned because of future time charters with a known charterer, who is likely also be involved in the decision making during the design and newbuild stage. Finally, the similar levels of implementation across the two chartering groups could also be because of the Phase 1 of the EEDI regulations, which came into force in 2015 and cover the period from 2015 to 2019, which required a 10% reduction in EEDI relative to the EEDI reference line for each ship type and size category.

Section 3.2 showed that there are relationships between chartering group and firm size, chartering group and sector of operation, and between size of the firm and sector of operation. These relationships suggest that the findings presented in Figs. 3–6 may be confounded due to the size and sector variables. In order to control for these effects, first-order controlled analysis is performed for a set measures

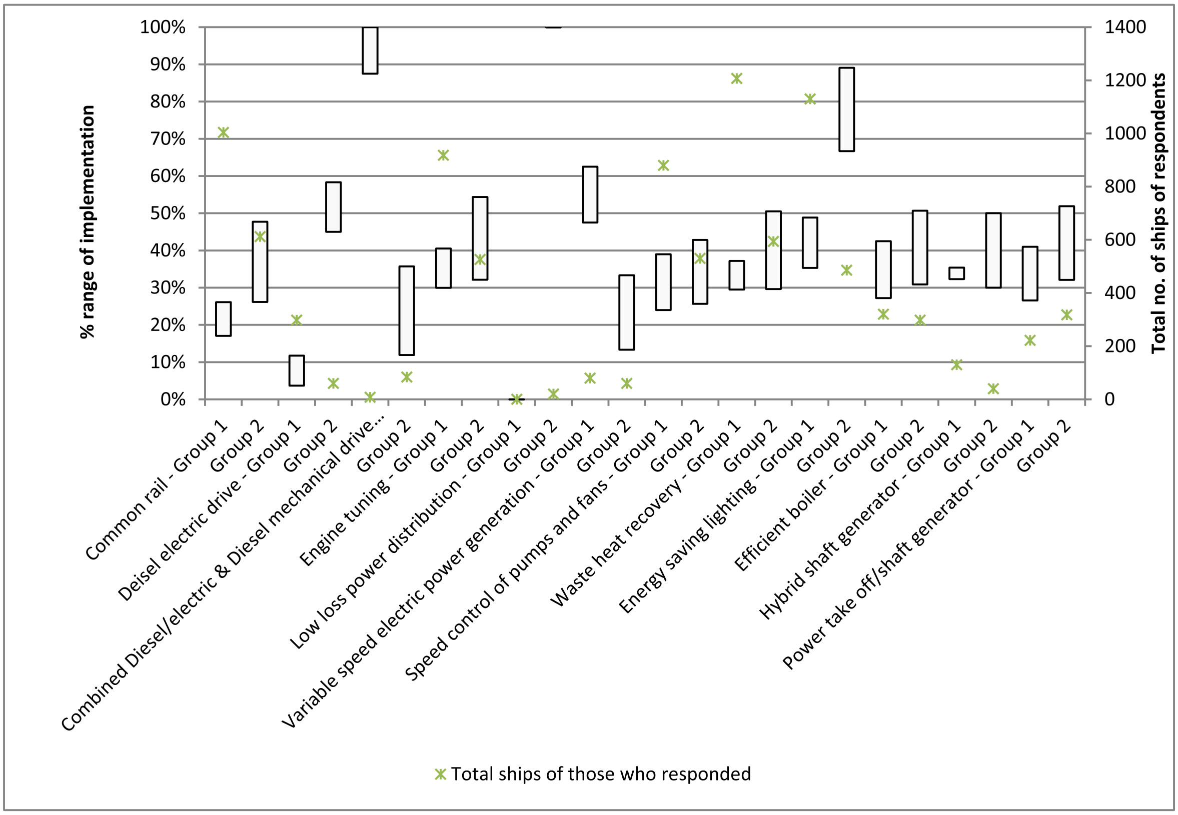

Fig. 6. Implementation of machinery technologies.

(hydrodynamic measures).[5] Fig. 8 and Fig. 9 present the implementation of hydrodynamic measures by size and sector.[6] It can be noted that smaller firms have a higher implementation range of hydrodynamic measures in their fleet relative to medium and large firms, although the absolute number of ships in their fleet may be low. There isn't a clear relationship that can be established for implementation and sector of operation.

Controlling for size and chartering group leads to a reduction of response rates per measure and no clear patterns in implementation can be observed in small and large sized firms (Fig. 10 and Fig. 11). For medium sized firms, where highest number of responses were received, no consistent relationship between implementation of the measures and chartering group is found (Fig. 12). This suggests the size variable is potentially not conflating the effects observed in zero order relationship, despite the underlying correlation in variables. Rehmatulla (2016) shows that on average the hydrodynamic technologies are taken up more in the drybulk sector relative to the tanker sector, for example pre/post swirl devices was implemented between 17% and 33% of 892 tankers compared to 25%–40% of 522 drybulk ships. However, when controlling for sector and chartering group, some opposite patterns can be observed. Fig. 13 shows that when controlling for sector there is a consistently higher range of implementation in chartering group 2 in the wetbulk sector and the opposite is observed in Fig. 14 where chartering group 2 has a lower implementation range in three out of the four measures.[7]

[5] Second-order i.e. controlling for both, size and sector, simultaneously was not performed due to significant reduction in response rates.

[6] The survey covered other sectors and respondents from other sectors could participate, but for the analysis in this section, only firms that were classified as operating most of their fleet (>90%) in wetbulk/tanker, drybulk and container ships. As a result a number of firms which operate a mixed fleet e.g. drybulk and wetbulk are excluded from the analysis in this section.

[7] Results for container sector are not presented because of missing/few responses.

5. Discussion

The results from the foregoing analysis show that firms that have majority of their ships on time charter have a higher implementation of energy efficiency technologies compared to firms that operate ships on the spot charter. The findings suggest that implementation of technical measures is higher when the principal (charterer/shipper) pays for the fuel but is not responsible for energy efficiency investments, referred to as the 'efficiency' problem (Vernon and Meier, 2012) i.e. when the shipowner does not pay for the fuel and therefore may not see the direct benefits of energy efficiency investments. This finding is contrary to that found in the previous studies in the building and transport sector. Murtishaw and Sathaye (2006) and Davis (2009), showed that the efficiency problem was applicable to tenant-landlord problem for large household appliances, where significant capital outlay was required, for example in water heaters, refrigerators and washing machines but not for smaller and easily replaceable appliances by the principal (tenant), for example lighting. Note that other studies in the buildings sector evidence the existence of the 'usage' problem i.e. where energy is included in the contract between the principal and agent (Maruejols and Young, 2011; Levinson and Neimann, 2003), and Rehmatulla and Smith (2015a) show that in most voyage charters this problem exists and is mainly applicable to operational measures. In the trucking sector, Vernon and Meier (2012) show nearly a quarter of trailers are affected by the 'efficiency' problem because owners of rental trailers do not pay for fuel costs and contracts for rentals not only fail to monetize fuel efficiency of trailers but they completely ignore this aspect. It should be noted that Vernon and Meier (2012) was not based on empirical data but provides a first or higher level estimate of the efficiency problem. Using this approach, as a first order approximation or exposure of the problem, it could be inferred that efficiency problems would be pervasive in the drybulk sector as a majority of ships are mainly on time charter, relative to wetbulk and container sector where a high proportion of ships are on voyage or spot charter.

The findings observed in this study can be due to two key reasons, i.

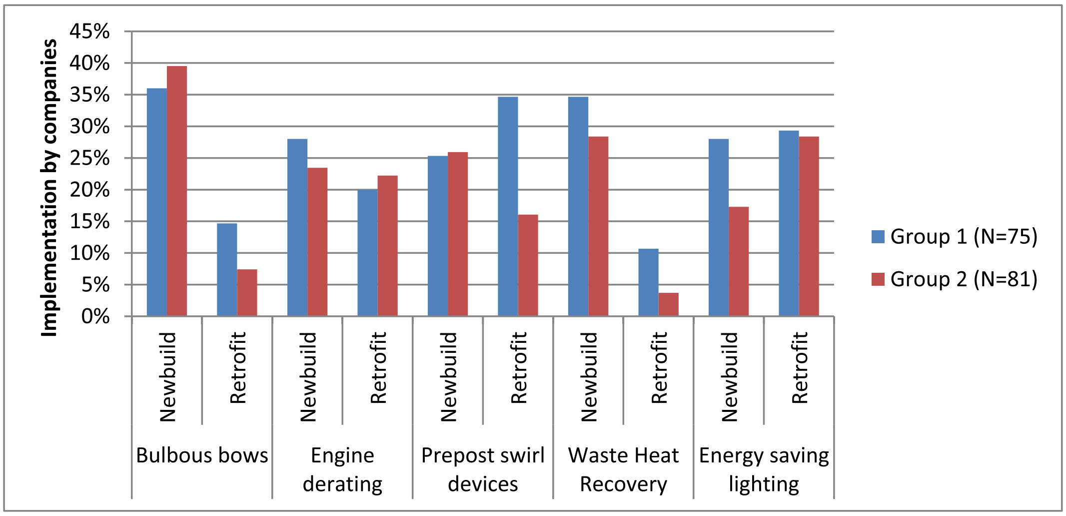

Fig. 7. Relationship of chartering group with implementation during newbuild and retrofit.

Fig. 8. Implementation of hydrodynamic measures by size of the firm.

data or methodological matters ii. market correction for market failures, each of these are discussed further.

Some of the higher implementation by firms whose ships are on time charter can be explained by the underlying or confounding variable, mainly the sector variable, as shown earlier in section ý4 and because of the relationship between size and sector, it can be expected that implementation may also impacted by size of the firm. Connecting the first order approximation of the prevalence of the efficiency problem aforementioned, the controlled analysis for the sector variable shows that in the drybulk sector there was much lower implementation relative to the wetbulk sector for ships that were on time charter in those sectors. One possible explanation for the higher implementation of hydrodynamic measures on ships in time charter in the wetbulk sector could be that it enables shipowners to differentiate their vessels compared to their competition, although the focus historically has been on safety (Poulsen et al., 2015) and analysis mainly on voyage charterers, showing ships are favoured strongly for location relative to energy efficiency (Parker, 2014). Second, the number of energy efficiency technologies implemented can be relayed relatively easily to the charterer or brokers to 'display' energy efficiency to win potential charter contracts compared to relaying the actual or observed energy efficiency due to the complex monitoring systems required to isolate the effects of energy efficiency. Third, higher implementation of hydrodynamic measures on ships in time charter in the wetbulk sector could be because of the higher bargaining power of charterers, where economic conditions characterised by low capacity utilisation, give the charterers a stronger bargaining power (Karakitsos and Varnavides, 2014) and the market composition, characterised by very few customers, typically oil majors, who govern and drive the sectors priorities (Poulsen et al., 2015). The wetbulk sector is characterised as unipolar, in terms of being highly-driven by buyers (oil majors) (Poulsen et al., 2015), whereas the drybulk sector is characterised with many buyers and many suppliers of transport, leading to perfect competition (Stopford, 2009).

There are also other variables that have not been controlled for in the analysis, including the chartering 'in' ratio and or ownership of vessels, and it is possible that this could have an impact on implementation. The

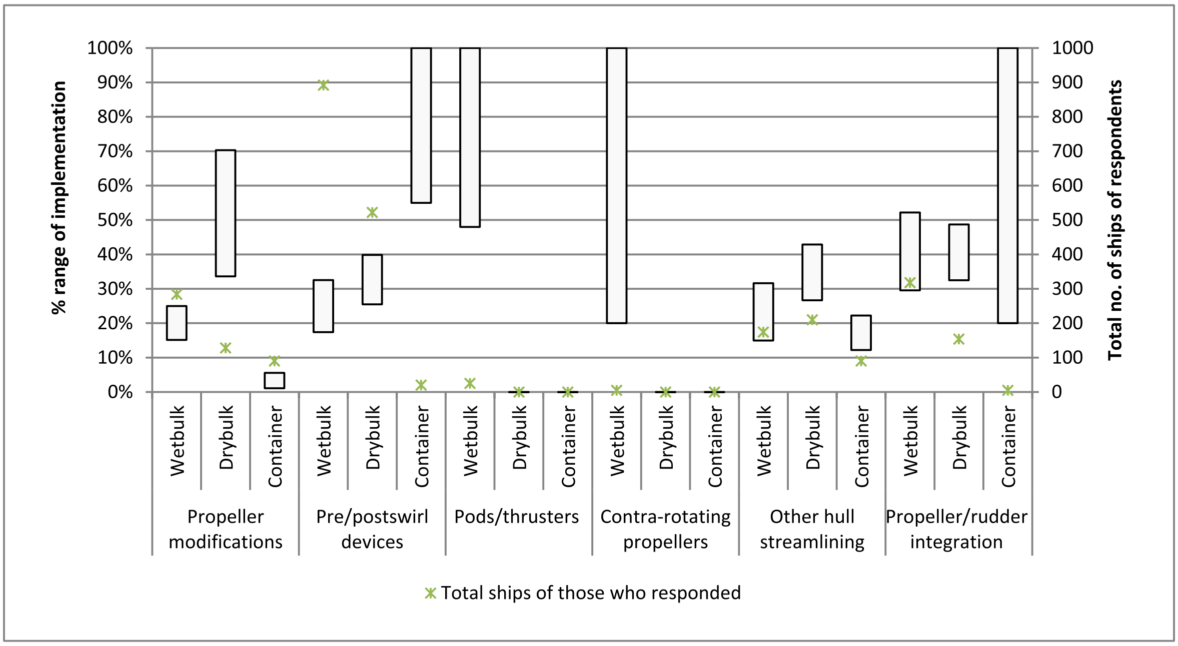

Fig. 9. Implementation of hydrodynamic measures by sector of operation.

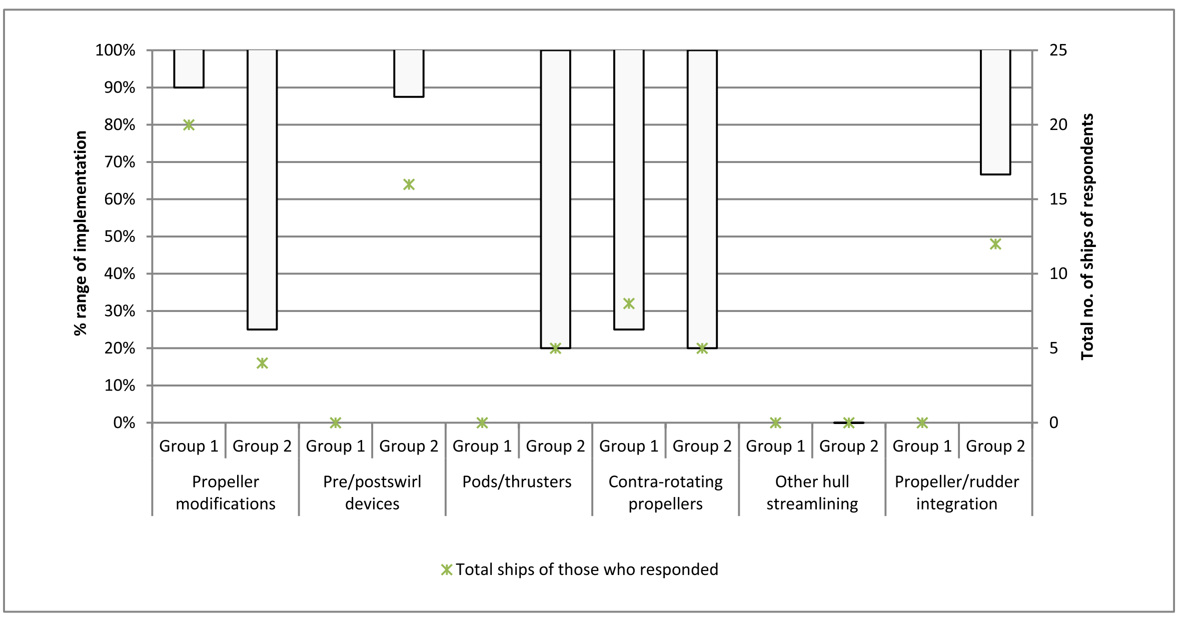

Fig. 10. Implementation of hydrodynamic measures by chartering group in small sized firms.

logic to use only chartering 'out' ratio (i.e. on spot and time) is because it determines the fuel consumption at point of use. Both, Murtishaw and Sathaye (2006) and Davis (2009) rely on large government administered national surveys, enabling them to have a large data set to enable multiple controls to estimate the efficiency effects of split incentives compared to Vernon and Meier (2012), which corroborates a number of data sources to estimate the efficiency problem in the trucking or transport sector and therefore in respect to data, encounters similar challenges as this paper's analysis, making it difficult to differentiate the exact impact of the split incentives efficiency problem.

Another argument to explain the results observed is centred around the shipping market's ability to correct or overcome to some extent the split incentive efficiency problem. The higher implementation in time chartered ships could suggest that there is economic incentive to invest in energy efficiency. This could be as a result of a number of factors, there may be sufficient premium obtained through higher time charter rates, higher utilisation through preference by charterers to charter efficient ships or in the cases where the charterer is investing, there is sufficient return on investment (shorter payback, higher net present value etc.). These factors can also explain why Parker and Prakash (2015) find that energy efficient ships are more likely to be allocated to the time charter. Anecdotal evidence (Lloyds List, 2012; Lloyds List, 2013) suggests that energy efficient ships may be benefitting from higher utilisation. Prakash et al. (2016), using the Rightship GHG rating as a proxy for energy efficiency, show that little to no evidence of a preference for ships with better GHG Ratings is detected in time charter rates in the period 2005–2015, ceteris paribus. Furthermore, using Automatic Identification System (AIS) data, they find that there isn't a significant difference observed in terms of productivity (time spent loaded and number of loaded voyages, for example) for ships with better

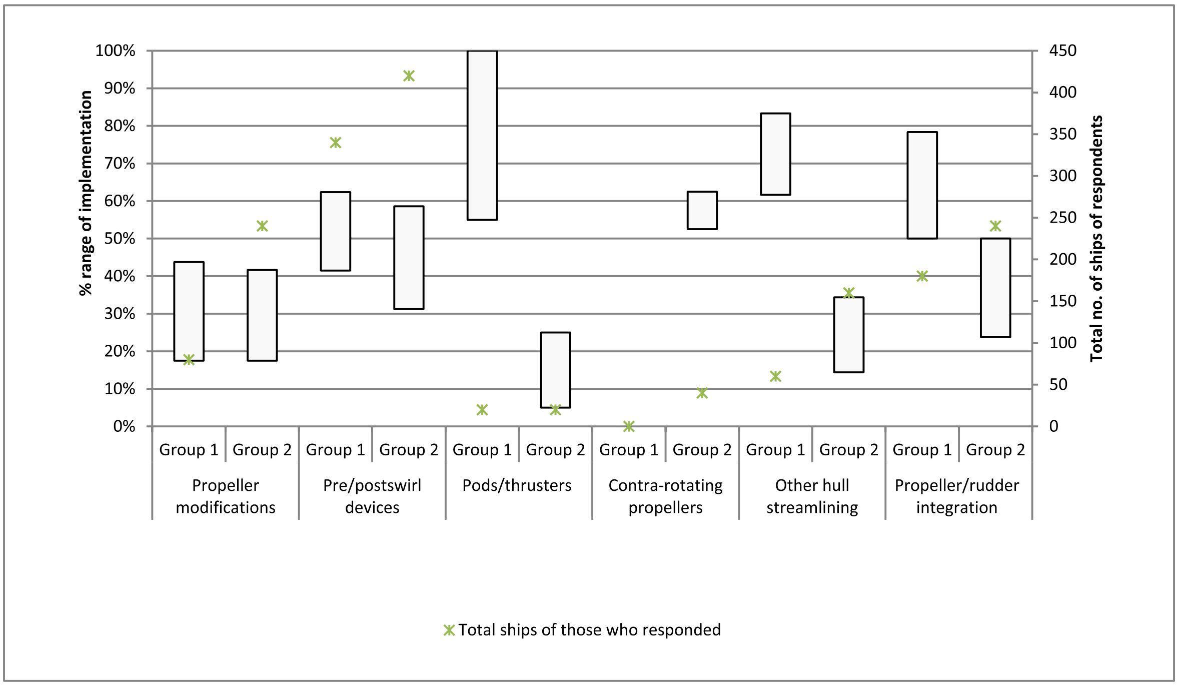

Fig. 11. Implementation of hydrodynamic measures by chartering group in medium sized firms.

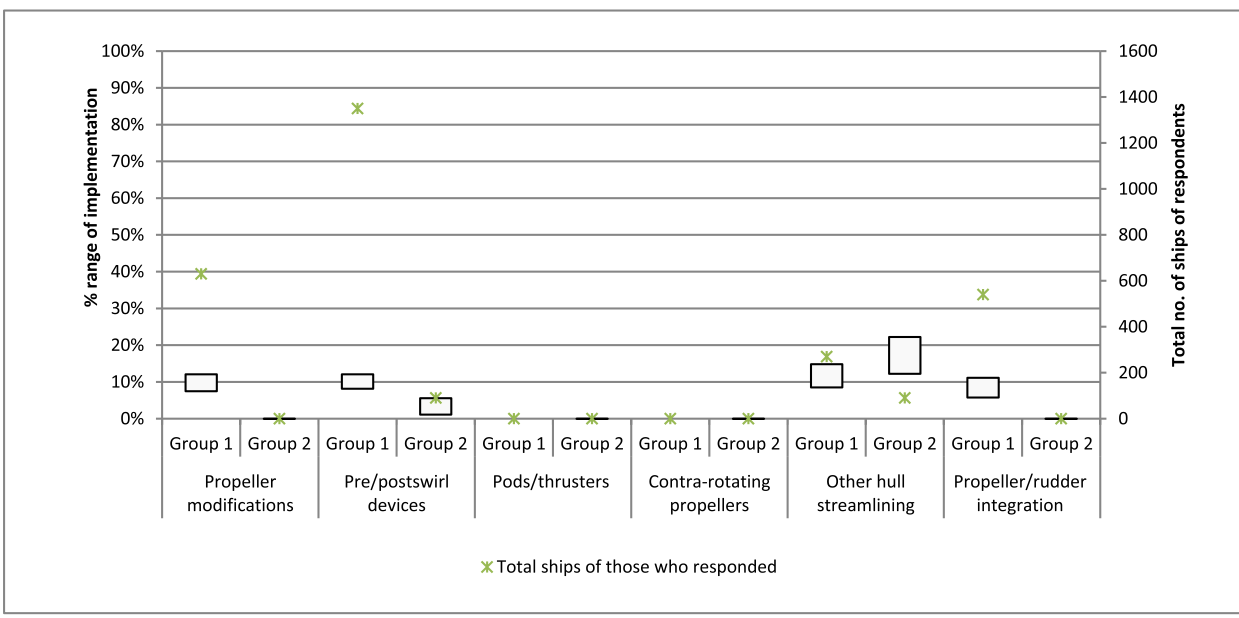

Fig. 12. Implementation of hydrodynamic measures by chartering group in large firms.

GHG Ratings. The findings from Prakash et al. (2016) corroborate with that of Agnolucci et al. (2014) and Adland et al. (2017) who find only up half and up to a quarter of fuel savings, respectively, are reflected in a higher charter rate in different market conditions in the drybulk market. This is important because it shows that despite higher implementation of energy efficiency technologies, the market is to some extent rewarding energy efficient ships either through premiums or higher utilisation, assuming that the proxies used in this study (implementation of energy efficiency technologies) and other studies (energy efficiency design index or it's variants) are good representations of energy efficiency. The shipowner and charterer may jointly participate in technical upgrades and the benefits (financial i.e. cost savings and higher premiums) are equally shared when a ship is on time charter. Examples of this can be found in Rehmatulla et al. (2017a). Some notable examples include Hammonia Reederei (shipowner) and Intermarine (charterer) retrofitting three ships with multiple technologies (optimized bulbous bows, rudder optimisation and high performance hull coating) achieving 25% fuel savings per ship (Fathom C-Tech, 2016). The key to this collaboration is the agreement by Intermarine to pay Hammonia a premium on the daily time charter rate through a retrofit clause in the charter party. The clause enables fuel savings to be split between the parties, as well as locking in a long-term time charter for Hammonia. Examples such as these to overcome the split incentives are less standardised in shipping (and other transport modes) compared to other sectors, such as the buildings (residential and commercial), where access to capital, informational problems and the split incentives are tackled through various

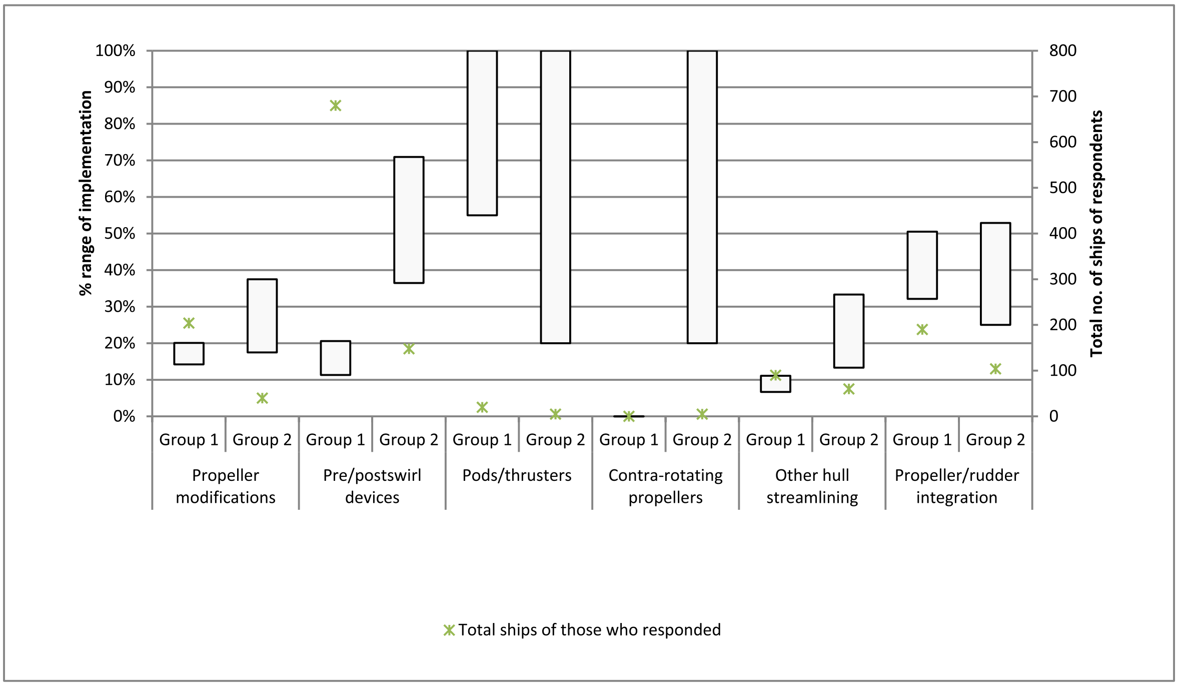

Fig. 13. Implementation of hydrodynamic measures by chartering group in wetbulk sector.

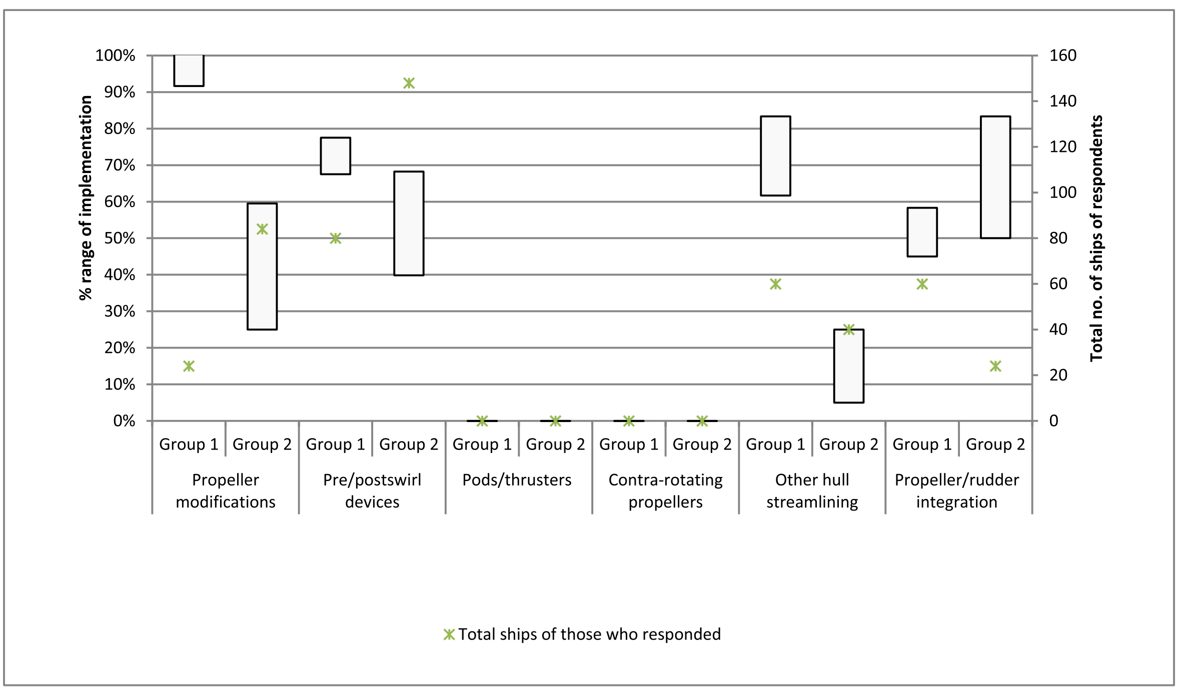

Fig. 14. Implementation of hydrodynamic measures by chartering group in drybulk sector.

mechanisms (Bird and Hernandez, 2012). The evidence presented in this study also suggests that when looking at the relationship between chartering group and implementation, it is important not only to control for firm level variables (e.g. size, sector, location) but also ship level attributes that could introduce bias in the results, these include whether the measure was retrofitted or for newbuild, the ship size and ship age.

6. Conclusions and policy implications

The paper aimed to assess the extent to which the split incentives may be impacting the uptake of energy efficiency technologies, which are a necessary first step to enable shipping to transition towards a low and zero carbon future. The analysis of existing literature in the shipping sector shows that studies have mainly focused only on the general level of implementation and have not considered how the implementation can be different under the split incentive proposition elucidated in other sectors. When using the chartering ratio as a proxy to measure the split incentive in shipping, the preliminary results suggests that firms that have majority of their ships on time charter (i.e. don't directly observe the energy price signal but may potentially receive an energy efficiency premium) have a higher implementation of energy efficiency technologies compared to firms that operate ships on the spot charter (i.e. directly observe the price signal). This is in contrast with the 'efficiency' problem postulated by Murtishaw and Sathaye (2006). Two primary reasons for these findings are discussed. To some extent the findings could be due to the effect that confounding variables, especially sector, have on the implementation of measures. Another argument to explain the results observed is centred around the extent to which the shipping market is correcting or overcoming the split incentive efficiency problem.

6.1. Limitations and future work

The disconnect between the theoretical hypothesis and empirical findings could be to some extent due to the limitations of the study. The data that have been used to draw the above inferences are believed to be the best available data on implementation of energy efficiency technologies. Whilst every effort was made to reduce or remove biases stemming from errors (both sampling and non-sampling errors), there may be other influences that could potentially distort the results. An example of this is market artefacts, given that the survey was conducted at a period of depressed oil prices — the lowest ever since the economic crisis — that has the effect of increasing the payback period of various energy efficiency technologies. It was also a period in which new regulations in shipping came into force e.g. stringent emission control area limits and higher standards for newly built ships, Energy Efficiency Design Index (EEDI) Phase 1 required a 10% reduction in the design efficiency of new ships compared reference line for each ship type and size category. Employing a longitudinal study will to an extent be able to track implementation over a longer period.

The chartering ratio as a proxy for the split incentive uses the 'chartering out' strategy of the companies. This approach ignores the various alternatives to 'chartering in' a ship, i.e. the ship may be a bareboat chartered or an even long-term time chartered ship that is sub-chartered on the spot market. The survey was also not able to detect sub-chartering beyond the respondent company. Various combinations of chartering-in and subletting may occur in shipping and therefore the implementation may be 'masked' due to these. Furthermore, the results presented in this paper do not control for other test variables, at the company level such as regional location, and at the ship level e.g. age of ships and size of ships, which can potentially lead to spurious relationships between chartering group and implementation of a measure. To overcome these limitations, a triangulation approach, using a case study method is being deployed in a forthcoming study. The case studies of a few selected companies delve further into the drivers and barriers to implementation of the energy efficiency technologies in the organisation. Further data to corroborate the findings has also been obtained from some of the technology providers, see for example Bonello and Lelliot (2017) and it is also possilbe to examine impact of subletting on implementation using fixtures data where vessel details are provided in the case studies.

Looking only at the number of technologies implemented implies that every technology has an equal cost-benefit, for example, a shipowner may have implemented three technologies to a vessel on time charter, which may have cost in total only a tenth of one technology implemented by another firm on a vessel spot charter—or may only save a tenth in fuel cost compared to the one implemented on spot charter. Further work could therefore include relative cost (or expected fuel savings) of the technologies, to estimate the total impact of technologies on energy efficiency of ships.

The allocation of ships by shipowners to the time charter market and spot charter market is dependent on the market conditions and the shipowners and charterers risk bearing level (Stopford, 2009). There is some evidence as to how liquid the shipping markets are (Pirrong, 1993). Thus, sector-specific rigidity and contractual preferences outweigh the likelihood of vessels being speculatively switched onto the different contracts. Nonetheless, if the markets were assumed to be liquid then further work would need to control for the temporal nature of the charter markets by estimating the amount of time spent by ship in each type of charter. Another approach could be to conduct longitudinal surveys that account for market conditions, such as those found in the buildings sector (English Housing Survey in the UK, Residential Energy Consumption Survey in the US).

6.2. Policy implications

Acknowledging the significant advancement in data that has been gathered on implementation of technologies, limitations and proposals for further work, this paper suggests that split incentive efficiency problem is technology and sector specific, and it may well be dynamic, with its pervasiveness varying over time and the 'efficiency' principal-agent problem is to some extent being corrected for in the market. Policy intervention may not be required to address the split incentive directly, given the market is to some extent already correcting for or overcoming this problem. However, one area where policy intervention may be required is the lack of information or information asymmetry related to, for example, the fuel savings of the technologies or efficiency of ships in general, both of which are closely linked to or can exacerbate the split incentive problem. In shipping, this is a problem for both technical and operational energy efficiency, due to lack of publicly available verified data for new ships and operational energy efficiency for existing ships. The current IMO EEDI database not capture the technologies that have been implemented to meet the EEDI requirements and the ship details have been fully anonymised, therefore not allowing for meaningful interpretation or corroboration with other data sources. The advent of a Monitoring Reporting and Verification (MRV) at the global level through the IMO – Data Collection System and at the regional level through EU Monitoring Reporting and Verification under Regulation 2015/757 and as amended by Delegated Regulation (2016)/2071, is to some extent going to improve the information on operational energy efficiency of ships, if designed correctly i.e. portray the best estimate of operational CO_2 intensity. However, currently, both MRV schemes are sub-optimal. The IMO Data Collection System only requires shipowners to report design capacity instead of actual cargo carried or capacity utilisation and is not disclosed publicly, whilst the EU MRV scheme, though is a relatively more accurate representation of operational energy efficiency, because of its regional nature it will lack global coverage and therefore some shipping markets will continue to face the information problems that could lead to split incentives.

CRediT authorship contribution statement

Nishatabbas Rehmatulla: Conceptualization, Methodology, Formal analysis, Writing - original draft, Project administration. **Tristan Smith:** Conceptualization, Writing - review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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