Implementation Barriers to Low Carbon Shipping

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Abstract

Energy costs represent around 60-70% of operating costs of a ship and with the fuel price soaring to record levels, energy efficiency is once again becoming top of the agenda/priority for many shipping companies. Numerous cost effective energy efficient options/measures (technologies for new and existing ships and operations) have been identified for improving energy efficiency of ships. Analysis from industry leading experts and recognized bodies e.g. Faber et al. (2009), Buhaug et al. (2009), Det Norske Veritas (2009), IMO (2010), has so far shown substantial (e.g. up to 30%) unrealised abatement potential using options that often appear to be cost-negative at current fuel prices. Apart from the shortcomings of the analysis (e.g. risk representation, heterogeneity & hidden costs) failure to realise this potential (the energy efficiency gap) could be attributable to various market barriers and failures. This paper draws on findings of a survey conducted of shipping companies around the issue of barriers in shipping operations and analysis undertaken with the global shipping system model (GloTraM). These findings are used for the analysis of barriers and failures that have been discussed in other sectors and are analysed in the context of the shipping industry.

1. Introduction & Background

It is suggested that "low carbon shipping" describes a transition from the shipping industry's current levels of emissions and emissions intensity, to lower levels. There is still only limited understanding of exactly what the extent of the transition would need to be and how it could be achieved, but to mitigate risks of dangerous climate change and to align with decarbonisation in other sectors of the economy, a reduction in absolute emissions relative to today's by 30-80% is not inconceivable as a longer tem aim (Anderson and Bows, 2009).

In light of that level of ambition, this paper aims to consider what barriers might prevent the implementation of such levels of decarbonisation in the shipping industry. The carbon emissions of the industry can be expressed as the product of transport demand and emissions intensity per unit of transport supply. For the purposes of this paper, we will assume that transport demand is out of scope as a 'lever' to reduce emissions. This paper will therefore concentrate on possible implementation barriers to efforts to lower the carbon intensity (including by lowering the energy intensity) of shipping as a system for the national and international transport of goods and people.

1.1. Assessing the decarbonisation potential of a ship

A key component of the shipping system is the individual ships. A number of options exist for either the increase of energy efficiency or the abatement of CO_2 from ships. These can be either operational measures such as speed reduction, weather routing, etc. or technical measures such as waste heat recovery, air lubrication, etc. (IMO, 2010a) which can be applied to new build ships and in some cases also for retrofit to existing ships. A common method of presenting analysis of the order in which these options might be adopted and the likelihood of investment, particularly for policy work, is the Marginal Abatement Cost Curve (MACC). A MACC is a graph that indicates the marginal cost of emission abatement for varying amounts of emission reduction (Kesicki, 2010). Examples of these for shipping can be found in Faber et al. (2009), Buhaug et al. (2009), IMO (2010), Det Norske Veritas (2009). Besides the inherent shortcomings in MACC analysis (Kesicki, 2010), for shipping it is commonly undertaken with an incomplete representation of costs and little representation of risk (beyond the investment rate of return). The result from the above referenced analyses has so far been the identification of substantial (e.g. up to 30%) unrealised abatement potential using options that often appear to be cost-negative at current fuel prices. Possible explanations for why these options are not taken up or implemented are that either, models for analysis are inadequate for representing costs/benefits of low carbon and energy efficiency investment or the data used are incorrect (i.e. hidden costs, inadequate representation of risk); or other implementation barriers/failures exist which are obstructing the shipping industry's implementation of low carbon such as informational problems, split incentives, access to and cost of capital.

1.2. Defining barriers and the energy efficiency gap

From the MACCs referenced earlier, it can be seen that there are some options that have a negative cost when implemented, meaning they are profitable (i.e. show a positive net present value) which would mean that the option will save money through reduced fuel expenditure over the investment horizon assumed in the modelling. This could be because the majority of these measures are operational measures, which require less capital outlay compared to technical measures featured on the right hand side of the curve. Furthermore these options are operational measures which could in theory also be implemented by charterers with long term time charters. The MACC however does not show current implementation rates of these options, hence there is a need to gauge the actual implementation rates of these within the industry and sectors. Thereafter there is a need to understand why some of these measures were implemented and why some had been not taken up, despite their apparent negative cost i.e. identifying the energy efficiency gap (refer to figure 1, see Blumstein et al., 1980; Hirst and Brown, 1990; Jaffe and Stavins 1994; Sanstad and Howarth, 1994). To meet the above needs a survey of shipping companies was conducted, details of which will be discussed in the later sections.

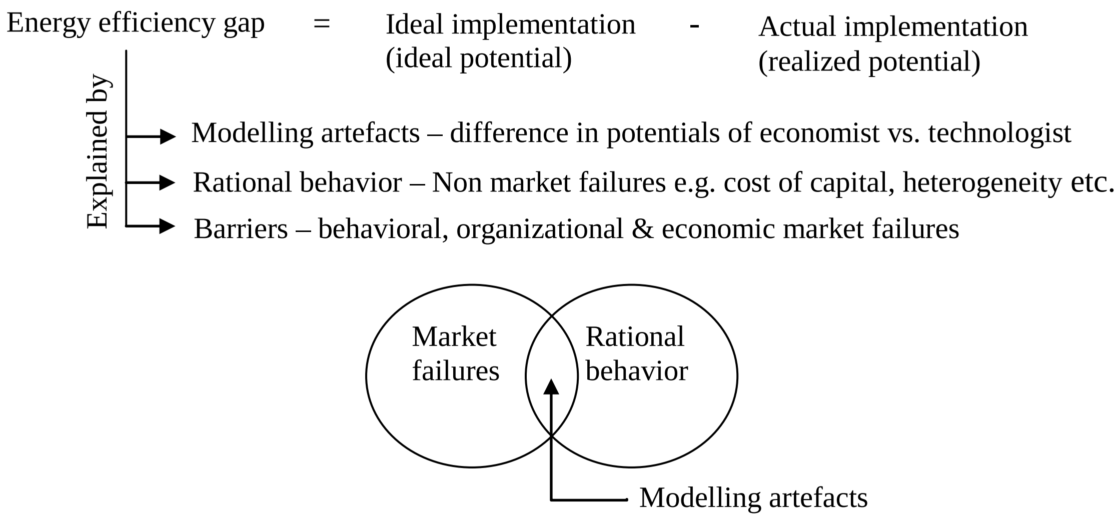

Figure 1. The energy efficiency gap.

A barrier may be defined as a postulated mechanism that inhibits investment in technologies that are both energy efficient and economically efficient (Sorrel et al., 2004). It has been argued that the energy efficiency gap exists due to barriers to energy efficiency (Sorrel et al, 2000; Thollander et al, 2010 etc.). These barriers have been broadly categorised as economic, behavioural and organisational (refer to figure 2) and in practice this typology is not exclusive; each barrier will have economic, behavioural and organisational aspects (Weber, 1997). The focus of this paper is mainly on economic barriers to energy efficiency. Economic barriers to energy efficiency stem from neo-classical economics, which assume individuals and organisations as rational and utility/profit maximising. This approach has been prone to criticism of being unrealistic of actual behaviour (Hodgson, 1988), however it is the most developed and applied approach to understanding the barriers to energy efficiency. Thus, it is possible to gain some insight into the relative significance of economic barriers in shipping, by looking at how this work has been discussed by others in various industries.

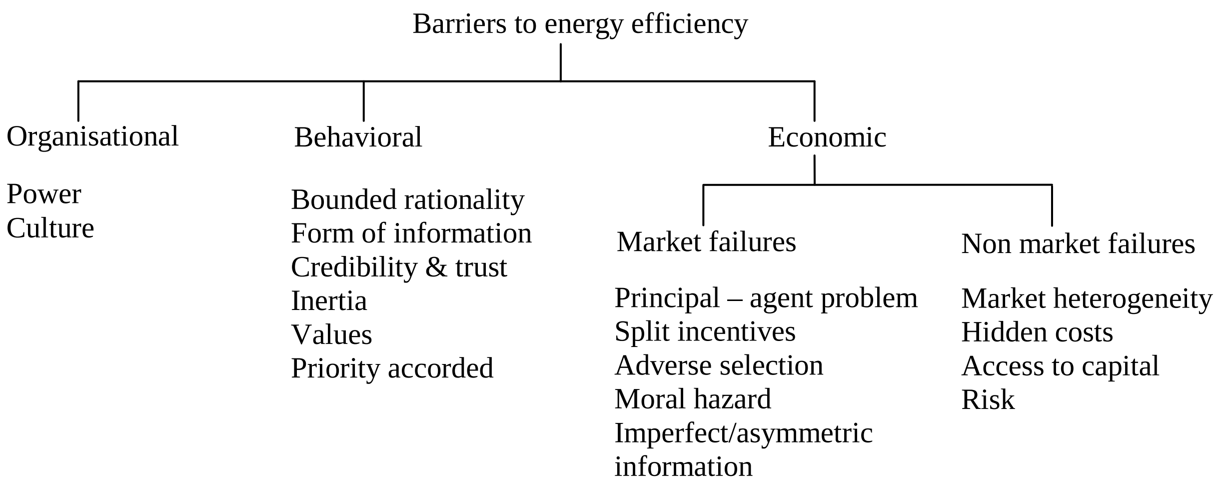

Figure 2. Classification of barriers.

2. Barriers literature in shipping

This section of the paper focuses on economic barriers that are inhibiting the uptake of cost-negative measures in shipping. AEA (2007, 2008), Gordon (2008), Faber et al. (2009), Wang et al. (2010), Hill (2010), Faber et al. (2011), Rehmatulla (2011), Heisman & Tomkins (2011) have discussed in different contexts barriers to implementation of abatement options in shipping.

2.1. Non market failures

As shown above, some of the energy efficiency gap can be explained by rational behaviour. These are real features of the decision making environment, albeit ones which are difficult to incorporate in engineering-economic modelling e.g. MACC (Sorrel et al, 2000). These factors are heterogeneity, hidden costs and risk.

2.1.1. Heterogeneity

Although a technology may be cost-effective on average for a class of users taken in aggregate, the class (e.g. panaxmax container ships, specific routes, commodities), itself, consists of a distribution of owners/operators: some could economically purchase additional efficiency, while others will find the new level of efficiency not cost effective (Sweeney, 1993). This will result in overstating the opportunities for a particular option in a particular sector. Wang et al. (2010) in their MACC analysis report that the cost effectiveness and CO_2 emission reduction potential for each option varies widely as a function of ship type, size and age, for example, the potential for emission reduction through speed reductions for containerships is much greater compared to tankers and bulkers which are relatively slower moving vessels.

2.1.2. Risk

The energy efficiency gap could be as a result of a rational response to risk. According to Sorrel (2000) risk has three dimensions in context of energy efficiency:

- External risk – overall economic trends, fuel price, policy and regulation. This is highly representative of what is being faced by shipping companies especially the latter two. Fuel costs are paramount in the industry and its expectation can shape the investment in energy efficiency. It is important to note how the industry copes with its uncertainty. Faber et al. (2009) show that almost 70% - 90% of the fuel costs are passed on. Future EEDI and MBM for regulation uncertainty.

- Business risk – financing risk and sectoral trends. A major focus for the shipowner is the financing costs of a ship and its repayment (Stopford, 2009). For some shipping markets there are risks that are intertemporal such as development of emission control area (ECA's), use of liquid natural gas (LNG) etc.
- Technical risk – technical performance and unreliability. Technologies are assumed incorrectly to be mature or a risk is perceived that performance may be lower than expected - risk premiums and depreciation are not adequately included in the model. Early investors may be sceptical about the prospects of a technology and demand a premium on return in order to cover the risks of the investment (Faber et al., 2009). When commissioning new builds, if depreciation is faster than expected, due to the adoption of technology (diffusion), which lower costs due to the learning curve, the solvency of the company may be threatened (Faber et al., 2009). So in some cases a ship owner commissioning a new ship would have to compare the risk of having a ship with an innovative design that may depreciate faster than expected with the risk of having a ship with a conventional design but higher operational costs. In such an assessment, the most fuel efficient ship may not always come out best. The same can be said for retrofit technologies as well. All of the above dimensions of risks faced by a business can therefore lead to stringent investment criteria, such as high levels of internal rate of return (IRR) and very short payback periods. In shipping the payback periods tend to be very short (Lloyds List, 2011a) despite the average age of a ship being around 25 years.

2.1.3 Hidden costs

Hidden costs are costs that are hidden to the analyst but not the investing company, resulting in overestimation of the efficiency potential and for shipping perhaps the most cited argument for the efficiency gap. The following costs may not have been included in the MACC for shipping:

- Life cycle costs – hidden costs relating to the energy efficient option's life cycle costs including: identification/search costs, project appraisal costs, commissioning costs, disruption/opportunity costs and additional/specific engineering costs.
- Transactional costs – transaction costs and other unobserved cost items may render apparently cost-effective measures costly. Especially smaller ship owners and operators may experience high transaction costs as they cannot spread the costs of e.g. gathering information over a large number of ships (Faber et al., 2009)
- Commissioning/disruption costs – some measures to reduce emissions require retrofits that can only be installed by temporarily suspending operation. These measures are very costly to implement except at times when operations are halted for other reasons, such as major survey or periodical drydocking. There may therefore be a lag between the time when a measure becomes available and its actual implementation. Retrofits to existing ships such as the installation of wind power, stern flaps, waste heat recovery systems etc. can only be done cost-effectively when a ship undergoes a major overhaul. This causes a time-lag of several years in the implementation of cost effective measures.
- Loss of benefits – reduction in benefits associated with energy efficient options (Nichols, 1994), such as problems with safety, extra maintenance, reliability and service quality. Example of this in shipping are speed reduction and safety, exhaust gas scrubber's reliability and extra maintenance, etc.

2.1.4 Access and costs of capital

Restricted access to capital markets is often considered to be an important barrier to investing in energy efficiency. That is, investments may not be profitable because companies face a high price for capital. As a result, only investments yielding an expected return that exceeds this (high) hurdle rate will be realised (Schleich & Grubber, 2008). Capital rationing is often used within firms as an allocation means for investments, leading to hurdle rates that are much higher than the cost of capital, especially for small projects (Ross, 1986). This leads to competition between projects within a company and may lead to low priority given to energy efficiency. "If improving energy efficiency comes at the cost of forgoing other more cost-effective opportunities (because of capital or labour constraints or because the projects are mutually exclusive alternatives), it would be rational for the firm to give energy efficiency a low priority" (Faber et al., 2009).

If the above rational responses can be incorporated and accurately represented in models and still show existence of apparent cost-negative options that were not being employed, it could then be concluded that additional implementation barriers existed. One could then say that there is a gap between the potential reduction achievable and current state, which could be explained by market failures.

2.2. Market failures

A market failure occurs when the requirements for efficient or optimal allocation of resources through well-functioning markets are violated, which leads to incomplete markets, imperfect competition, imperfect and asymmetric information. The latter two are more important and relevant in context of explaining the energy efficiency gap (Sorrel, 2004).

2.2.1. Informational problems

Informational problems taking different forms are the principal source of market failures that account for the energy efficiency gap (Huntington et al, 1994). According to Golove & Eto (1996) this falls into three categories; lack of information, cost of obtaining information and accuracy of information. These could occur because information has a public good attribute leading to information being under supplied or those who have information have strategic reasons to manipulate it in order to inflate its value. This is very relevant to the barriers faced by shipping companies. Generally the MACC modelling in shipping utilises manufacturer data on costs and savings that may be biased/optimistic e.g. Wang et al. (2010) use data derived from an engine manufacturer's brochure. Faber et al. (2011) showed that respondents cited lack of trusted data on measures from an independent third party as an important barrier to implementation. Several initiatives have begun to bring more information, create transparency and decrease the information asymmetry between charterers and shipowners, suppliers and buyers, examples of which include Carbon War Rooms shipping efficiency index and Fathom shipping's Ctech website. Stern and Aronson (1984) argue that even when provided with information (via labelling) establishing the cost effectiveness of such purchases, consumers are wary and mistrustful because of past experience with advertised misinformation. Faber et al. (2009, 2011) and Wang et al. (2010) suggest that even the Energy Efficiency Design Index (EEDI) will allow for gaming, and as such may not remove the information barrier.

2.2.2. Split incentives/principal-agent problems

These problems refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information (IEA, 2007). One example is misplaced or split incentives which occur when the costs and benefits of energy efficiency accrue to different agents (Blumstein, 1980; Fisher & Rothkopf, 1989). In shipping, split incentives are likely to occur due to the different types of charter (and the divided responsibility for fuel costs) existing between shipowners and charterers (Wang et al, 2010, Rehmatulla (2011). Ship owners who invest in fuel efficiency improving measures cannot, in general, recoup their investment, unless they operate their own ships or have long term agreements with charterers and also because neither charter rates nor second hand prices of ships reflect the economic benefit of its fuel efficiency due to informational problems (Faber et al, 2009, 2011; Lloyds list, 2011b). The shipowner may have relevant information on the costs and benefits of an energy efficiency investment, but may also find it difficult to convey to the other party (Jaffe & Stavins, 1994). If there were no informational problems and incentives were aligned then the parties would be able to enter into contracts to share the costs and benefits of the investment. However sometimes this may be outweighed by the transaction costs involved hence investment is likely to be forgone despite potential advantages to both parties (Sorrell et al., 2004).

3. Summary of existing research and a problem statement

The existing literature therefore reveals two key findings:

- Market barriers and failures, particularly the concept of an efficiency gap, appear to be a common feature of a number of markets which could be considered to be similar to shipping.
- There are indications that the specific structure of the shipping markets could be susceptible to market barriers, but to date there has been little work to quantify the consequence of any failures and to test rigorously for their existence.

Therefore, to develop the knowledge of shipping's low carbon implementation barriers beyond the existing literature, this paper will first examine how different investment parameters might affect the uptake of energy efficiency technology, and then use the results of a survey of shipping stakeholders to investigate the levels of uptake of low carbon initiatives. The results will also be used to discuss differences in uptake between sectors of the shipping markets and to hypothesise about what this might tell us about the incidence of some of the classical market barriers and failures.

4. GloTraM modelling of barriers to low carbon shipping

GloTraM is a model of the shipping system that can be used to estimate the take-up of different technologies and the consequence that these would have on the emissions from the shipping industry. A general overview of the model's components can be found in Smith et al. (2011), greater detail on technology modelling can be found in Calleya et al. (2011).

The model uses a techno-economic evaluation of a range of different technologies to identify the specification of newbuild ships, the potential for any retrofits and the consequences of these changes to the global fleet of ships to the annual fuel consumption, emissions and costs of shipping. The techno-economic evaluation includes a number of assumptions that represent the extent of some of the barriers discussed above. Therefore the model can be used to explore the consequence of some of the classical barriers to the technical specification of ships and the emissions from the sector. Those barriers include:

- Access to capital, as represented by the return on investment period and the WACC (weighted average cost of capital)
- Time window to recoup savings. or return period for investment
- The principle-agent problem, represented by the proportion of cost-saving associated with fuel-saving, that is passed from the charterer to the owner

4.1. Investment appraisal method

It is not possible to explain all the detail in this paper so only detail on the evaluation of the economic benefit of an intervention is described here. For the example analysed here, it is assumed that there are two stakeholders, one (A) who bears the capital and operating costs of the ship and another (B) who bears the voyage (fuel) costs. This could be considered to be typical of a time-charter arrangement but may also be present in the stakeholder chain behind a voyage charter.

If everything else remains constant, the consequence of an investment in energy efficiency (or low carbon) technology is an increase in A's costs (higher capital and maintenance costs), and a decrease in B's costs (lower fuel costs). The extent to which this cost saving is passed from B to A is a representation of the extent of a market barrier associated with this principle agent problem and a key determinant of the investment strategy that A should apply in order to maximise their profits. The cost pass through is quantified in a factor in GloTraM that takes a value between 0 and 1. If the latter, the entire cost-saving is passed from B to A, if 0.5 then 50% of the saving is passed from B to A and 50% retained as B's profit and if 0, 100% is retained as B's profit.

4.2. Run specifications

For the purpose of investigating the sensitivity of low carbon shipping to a variety of market barriers, five runs of the model were performed during the period 2010-2025. The following scenario details were held constant for all runs:

- EEDI regulation
- Compliance with SOx, NOx and ballast water regulations as per IMO MARPOL Annex VI regulations for global limits, no application of ECA regulation.
- No MBM, carbon price etc.
- IEO reference oil price used to derive fuel prices
- Long-run averages for time-charter prices, held constant in time
- Main engine and fuel choice limited to conventional diesel engines, heavy fuel oil and marine diesel oil.
- Technology performance and cost data, as described in Day (2012).

In all instances, the design speed was held constant and the operating speed of the ship was matched to the design speed. Whilst it is recognised that this may not be reflective of all of the flexibility owners have in choosing the design speed of a ship and that operators have in choosing voyage speeds, these were held constant to control the scenario experiment. The results are therefore a comparison of, ceteris paribus, levels of technology uptake as a function of some key investment parameters.

The investment parameters that were varied and their specifications were as shown in Table 1.

Table 1. Values for the investment parameters used in scenarios A to E.

Run	Cost savings pass through from operator to owner / %	WACC for owner / %	Return on investment period for owner / years
A	100	10	3
B	100	10	20
C	100	2	20
D	50	10	3
E	25	10	3

There is no publicly available data listing the combination of these investment parameters that best represents different owners and operators in the shipping industry. The values chosen were chosen so that they spanned some of the likely values. Perhaps scenario D could be suggested to be closest to reality for operators of ocean going merchant shipping, but all the parameters are likely to vary significantly between firms and the specifics of the contract(s) under which the ship is being operated. Therefore, these should not be considered as definitive of the range of parameters used in the sector, but illustrators of sensitivity.

4.3. Results

The results from the runs specified in Table 1 can be seen in Figure 3. Only two examples are presented, corresponding to a large tanker (VLCC) and a large containership. The results presented show the model estimated forecast of the attained EEDI by newbuild designs from 2010 to 2025. The trends are approximately similar for all ship sizes, but because of variations in revenue, capital costs, operating costs and performance and cost data between ships of different size and type, the results are not exactly the same. In all cases, the upper limit of the EEDI trajectories is represented by the EEDI regulation's required EEDI value in each of the years (it progresses from 10% baseline reduction in 2015 to 30% baseline reduction in 2025). The constraints on design speed and machinery specification mean that the only source of energy efficiency improvement is technology. The range of technology options available are not all compatible with each other and the maximum feasible improvement of EEDI is 40%. This sets a lower bound on the curves, which is reached in both instances in 2015 for the most favourable investment parameter scenario.

Scenario D (estimated to be BAU) is shown to follow the required EEDI values closely for both the ship types studied. There is little discrepancy between E and D – perhaps more would be seen if the constraint on achieving a maximum EEDI were relaxed. Scenario A shows a significant departure to D and E for the case of the container ship, but the greatest discrepancy is shown when the return on investment period is significantly extended. There is little discrepancy between scenarios B and C which differentiate from each other solely on cost of capital. That discrepancy is more marked in the instance of tankers, which is consistent with the general trend in the results that imply that in A,B and C, a greater amount of decarbonisation is achievable for the containership than the tanker given the same set of investment parameters.

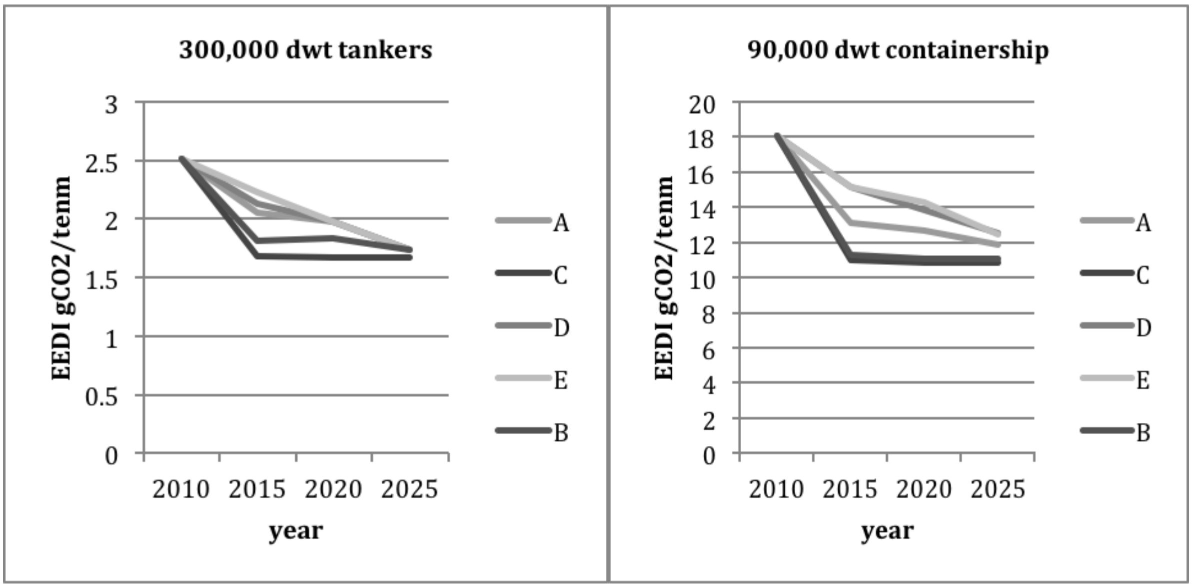

Figure 3. Results from scenario runs for newbuild EEDI in each year.

5. Results from Survey

A survey was used to assess the uptake of a number of cost-effective/cost negative and energy efficient operational measures within the shipping industry. The survey was able to provide a general indication of what measures are implemented in each of the shipping sectors and shed light on why some measures were not undertaken or seemed unattractive for investment (Rehmatulla, 2012).

5.1. Survey design

The unit of analysis/target population were global shipping companies with more than 5 ships which consisted of shipowners, ship owner-operators, ship management company & shipping division major charterers/cargo owners in the wetbulk, drybulk & container sectors only. These were recruited from Clarksons Shipping Information Network (SIN) database of shipowners. It is believed that this is the most comprehensive list of the target population. However, upon comparison with other online databases such as World Shipping Directory slight under coverage of companies was noted. Effort was made to merge the frames to cover accurately the target population. A stratified sampling approach was taken so as to represent the different variables of interest to the survey. A company with 90% of its fleet belonging to a sector would be placed in the respective sector category and when the fleet composition falls below 90% for one sector, the company is placed under the mixed sector. The total number of companies that responded was 170, which consisted of 120 almost complete (90% item response) responses and 50 partially completed responses, making the response rate for large and medium companies just over 15% (90/600) (80% of total stratified sample required) and 50% of the sample required for small companies. In order to be representative and to make generalisations i.e. reach statistically overall significant results with a confidence level of 90% and margin of error interval of +/-15% or +/-20%, each stratum required a minimum number of responses, presented in Rehmatulla (2012). Due to a level of non-response there may be a presence of systematic biases (i.e. those who responded are significantly unlike those who failed to. However because of scarcity of information on this subject area, even such low response rate may be able to provide useful information, hence the decision to publish the results as is, without any weightings and inferences to the population.

5.2. Implementation of measures

Respondents were first asked to select the top five operational measures that they believe have the highest potential in reducing fuel consumption. Fuel consumption monitoring, general speed reduction and weather routing were cited as measures that have the highest potential. The follow up question asked whether they have considered/implemented the measure they believed had the highest potential. From figure 4 it can be seen that even measures that were cited as having the highest potential have actual implementation rate of around 70%. On average across all the measures the implementation rate is around 50%. This clearly shows that despite the negative costs, ease of implementation and short payback period of most operational measures (Wang et al., 2010), some measures still do not see 90-100% implementation. Many MACC studies assume that measures with negative costs would have been fully implemented or would have been or will be implemented under a certain fuel price. How much of this gap between the potential and actual be explained by rational responses & market failures?

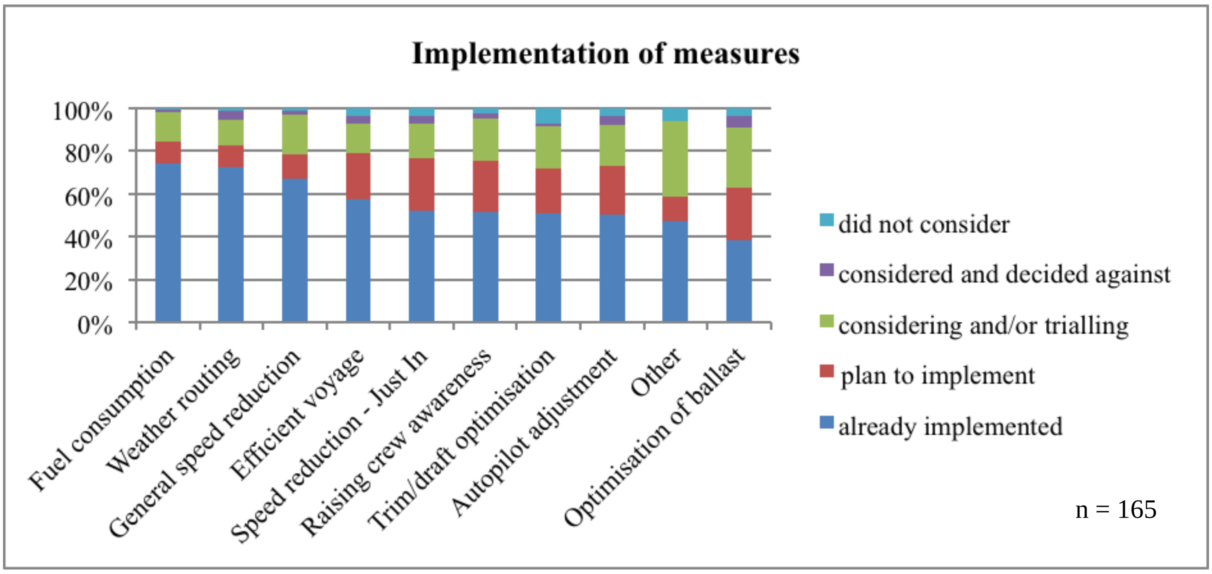

Figure 4. Implementation of operational measures believed to have highest potential.

5.3. non market failures

Some of the gap in the implementation could be explained by rational behaviour of the firms as explained in section 2.1. We apply the concept of heterogeneity (a particular technology may be cost effective on average, but not in all cases) and see how size of the firm and the sector it operates in affects the implementation of measures. There was found to be a difference between the overall implementation rates for each of the sectors, however zero order (without controlling other variables) bivariate relationships (crosstabulations/chi-square) between each measure's implementation and its association with a sector showed that in general there was some relationship between the two. Multivariate regression analysis shows that neither of the variables (sector and size) are good at explaining the implementation of the measures.

Table 2. Results from the statistical testing of homogeneity in the survey respondents.

Measure	Sector		Size		Multivariate analysis	
	Phi/Cramers V	Significance	Phi/Cramers V	Significance	R^2	Significance
Weather Routing	0.305	0.151	0.117	0.557	0.1	0.3
General speed reduction	0.283	0.24	0.178	0.266	0.11	0.25
Fuel consumption monitoring	0.213	0.536	0.189	0.208	0.08	0.45

Hidden costs, access to capital and risk perception are also cogent reasons for why some shipping companies do not implement measures and these can be easily misrepresented in techno-economic modelling approaches, resulting in overestimation of savings potential. The respondents were asked why they believed the measures they had not selected initially had lower potential for fuel savings. Lack of access to capital and additional costs related to the measures fared very low in the responses to this question (Rehmatulla, 2012), although, lack of access to capital and additional costs had perfectly negative correlation with size of the company.

5.4. Market failures

In general the most pertinent barrier across all measures that were not selected (i.e. seemed to have lower fuel saving potential) were lack of reliable information on cost and savings, difficultly in implementing under some types of charter, lack of direct control over operations & materiality of savings, i.e. measures may be ignored by decision-makers due to their limited impact (AEA, 2008) (these, represented on average 50% of barriers cited for any given measure). Analysing this in greater detail, it can be seen that there were specific barriers for each of the measures. Lack or reliable information on cost and savings affects the potential for weather routing, autopilot adjustment, trim/draft optimisation and raising crew awareness & training. Weather routing and autopilot adjustment are mature technologies (Wang et al., 2010) for which it would be expected that such information is readily and reliably available. For a breakdown of most cited barriers per measure refer to Rehmatulla (2012). There wasn't a clear relationship between informational problems cited and size of companies. For the survey, indicators of split incentives market failure were; the chartering ratio of the company, which asked respondents the % of the fleet that is owned, chartered in and out under the different types of charter and perception of the barrier which had three categories; savings cannot be fully recouped, difficult to implement under some types of charter and lack of direct control over operations. Companies were divided into six groups to reflect company structure and chartering ratio e.g. group 1 is a company that owns majority (>50%) of the fleet and charters out majority (>50%) of the fleet in spot market. Controlling for sector results in much larger effect size but at the same time significance values increase, because of smaller sample after controlling, e.g. general speed reduction and group correlation is 0.627 almost doubling after controlling for sector with p value of .215. The table below only shows zero order relationships between implementation of measures and group.

Table 4. Results of correlation by group of different operational measures

Measure	Group		Multivariate analysis	
	Phi/Cramers V	Significance	R^2	Significance
Weather Routing	.287	.394	.08	.42
General speed reduction	.363	.154	.13	.15
Fuel consumption monitoring	.284	.369	.08	.38
Raising crew awareness	.485	.086	.23	.08

5.5. Barriers to onboard energy efficiency: Crew training

The discussion above has been focused on the measures that can reduce CO_2 emissions. However, it is important to look at the whole shipping system and this includes understanding how the ship is actually operated and whether this may increase or decrease the potential of CO_2 reduction measures. In an article in sustainable shipping, Germany-based SkySails said winning support from ships' crews is crucial in developing towing kites as a tool to cut bunker consumption. "*One of our main goals now is to have the system accepted by the crews*" (Sustainable Shipping, 2011), highlighting the importance of crew in delivering the required fuel savings. To that end, a survey was developed to quantify the need for energy efficiency crew training schemes and to support the development of a low carbon strategy for shipping (Banks, 2011). Over 300 responses were collected from six groups of crews such as companies engaged in shipping and training. The results show that the crew are generally aware of the CO_2 dimension in shipping with 76% responding that they were aware of the effects of CO_2 emissions, however very little of this knowledge was gained through maritime education and training. It was acknowledged by the respondents that there was a good scope of reducing CO_2 emissions by making changes to onboard crewing processes, such as through creation of incentive structures, focussed guidelines, etc. In shipping, under the time charter where fuel is paid by the charterer, there is no direct control over the use of fuel as crewing/manning is on the account of the shipowner, which may result in split incentives and moral hazards (actions of crew unobservable to the charterer). Almost half of the respondents have made little or no effort to make improvement to energy efficiency. To address this, some companies have already begun incentivising crews by paying bonuses based on fuel savings (Sustainable Shipping, 2012). Over half of the respondents supported the notion that a reward scheme would affect the effort they make for energy efficiency improvements. From the previous survey analysis, it can be seen that raising crew awareness had a strong relationship with the chartering group and that the chartering group explained almost a quarter of the level of implementation (R^2), both the results being almost significant, implying split incentives are significantly affecting crew energy efficiency training.

6. Concluding remarks

This paper attempts to take a broad perspective on the subject of the implementation barriers that could impede shipping's transition to a lower carbon modus operandi. Given the extensive evidence for an efficiency gap that is presented for other sectors of the economy (Sections 1 and 2), it seems hard to imagine that a gap is not also present in the shipping industry. Indeed the results of the survey presented in Section 5 show implementation of around 70% of measures with high fuel saving potential and an average implementation rate across all the operational measures examined to be 50%, under the assumption that 100% of the operational measures could be considered by classical analysis to be termed "cost-effective" this supports the hypothesis that an efficiency gap might exist for shipping too.

In order address the question: if an efficiency gap exists, what might its significance be? a study was undertaken using GloTraM. This quantified the energy efficiency of newbuild ships over the period 2010 to 2025 under a range of assumptions for the investment parameters used as input parameters to the model. The study showed that under certain investment circumstances, a maximum impact on energy efficiency (in this instance a reduction of EEDI by approximately 40%) could be reached in 2015, whereas with several of the range of scenarios considered the newbuild's energy efficiency would be 'pegged' to the level defined in the EEDI reduction trajectories.

Given the evidence for the existence of an efficiency gap, the next challenge is to estimate which market barriers or failures might be most likely to be responsible. Detailed analysis of the survey data can provide some insight to this. The fact that a greater implementation percentage is attributable to the measures perceived to have the highest fuel saving implies either that agents were behaving rationally or that there may be barriers that result in the lack of uptake (i.e. it appears to refute the hypothesis that there are modelling artefacts that exist that have not been taken into account).

The statistical analysis found that non market failures (mainly heterogeneity & access/cost of capital) were not obvious explanations for the patterns of uptake of individual operational measures for the population studied, however extrapolating this conclusion to the whole fleet could not be fully justified due to the size of the sample. On the other hand, market failures (mainly split incentives through grouping by chartering ratio) were found to be correlated to the implementation of individual measures, which supports the hypothesis that they are a plausible explanation for the efficiency gap. The survey of onboard energy efficiency appears to further support the hypothesis that a significant principal-agent/split incentive market failure exists, as over half the survey respondents had made little or no effort to improve energy efficiency.

Further work is clearly beneficial in a number of areas. GloTraM could be used to consider the retrofit as well as the newbuild sectors of the shipping industry. Results from such analysis could then be combined in order to explore the impacts of different levels of market barriers on the emissions of the sector and not just the specifications of the fleet. The survey that has been conducted to understand the implementation scale and behaviours around operational measures could be extended to include technical measures and could also be increased in its sample size.

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