Implementation Barriers to Low Carbon Shipping

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Abstract

Numerous cost effective energy efficient options (technologies for new and existing ships and operations) have been identified for improving energy efficiency of ships or lowering their energy intensity. Analysis from industry leading experts and recognized bodies e.g. Faber et al. (2009), Bauhaug et al. (2009), IMO (2010), Det Norske Veritas (2009), has suggested substantial unrealised abatement potential using options that often appear to be cost-negative at current fuel prices. This paper concentrates on possible implementation barriers to lower the carbon intensity (including by lowering the energy intensity) of shipping using novel multidisciplinary methods. It draws on findings of a survey conducted of shipping companies, content analysis of shipping contracts and barriers modelling in the Global Transport Model (GloTraM). Initial results from these methods suggest the existence of some market barriers and failures that have also been discussed in other sectors and industries.

1. Introduction

It is suggested that reducing global greenhouse gas (GHG) emissions by fifty to eighty percent below 1990 levels by 2050 is necessary to stabilize the climate and avoid dangerous climate change impacts (IPCC, 2007). To avoid dangerous climate change, all the sectors of the global economy will be required to lower their GHG emissions. The shipping sector, through its exhaust emissions, is a major contributing source of several greenhouse gases and non-greenhouse gases. Global transport sector emissions represent around thirteen percent of global CO_2 emissions, of which total shipping CO2 emissions (from international and domestic shipping) accounted for over three percent (1 Giga tonnes) of global CO_2 emissions in 2007 (Buhaug, 2009). At an annual GDP growth rate of around three to four percent, it is estimated that shipping's emissions share will grow by one and half to three times under the business-as-usual scenario (compared to emissions in 2007) by 2050, if the industry is left uncontrolled and in absence of policies (Buhaug, 2009). Moreover, as all other sectors decarbonise, shipping's future CO_2 emissions will represent an even larger share of global CO_2 emissions (Gilbert et al., 2010), estimated to be around twenty five percent of the global CO_2 emissions (CCC, 2011).

The carbon emissions of the industry can be expressed as the product of transport demand (using capacity tonne miles tenm i.e. tonne nautical miles) and transport supply represented by emissions intensity (gCO_2/tenm i.e. grams of CO2 emitted per tonne nautical mile). On the transport supply side there are four options available to reduce emissions from shipping (Buhaug et al., 2009); improving energy efficiency i.e. increasing productivity using same amount of energy, using renewable energy sources (e.g. solar and wind), using fuels with lower carbon content (e.g. liquid natural gas and biofuels) and using emission reduction technologies (e.g through chemical conversion, capture and storage). This paper focuses on the transport supply side and improving energy efficiency as a strategy towards low carbon shipping.

2. Barriers literature

Several studies across a wide range of sectors have empirically shown that cost-effective energy efficiency measures are not always implemented despite the substantial abatement potential, see for example Velthuijsen (1993), Gillissen and Opschoor (1994), Harris (2000), Sorrell et al. (2000), De

Groot et al (2001), UNEP (2006), Zilahy (2004), Rohdin et al (2007), Shi et al (2008), Sordinaou (2008), Thollander and Ottosson (2008), PWC (2009), Schleich and Gruber (2008), Schleich (2009), Hasanbeigi (2009), Trianni et al. (2012), etc.

The barriers debate has gained momentum since the 1980's with the first bibliographical account of barriers by York et al (1978) followed by empirical research by Blumstein et al. (1980), which is then followed by a host of literature, see for example Fisher and Rothkopf (1989), Hirst and Brown (1990), Howarth and Anderson (1993), Sanstad and Howarth (1994), Jaffe and Stavins (1994), Howarth and Winslow (1994), Howarth et al (2000), Brown (2001),Sorrell et al. (2004), Golove and Eto (2006), Thollander et al (2010), Thollander and Palm (2013), etc.

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). An important clarification in the barriers debate (Golove and Eto, 2006) is to differentiate between energy efficiency and economic efficiency. According to Sweeney (1993) "energy efficiency investments should be promoted only to the extent that it improves economic efficiency or increases net social welfare" (Golove and Eto, 2006). This is important in the discussion of low carbon shipping technologies available since some may not lead to economic efficiency but nonetheless are required to meet the higher-level ambitions toward a low carbon industry.

	Decreases energy intensity	**Increases energy intensity**
Increases economic efficiency	A) Energy efficiency	B) Energy enhanced progress
Decreases economic efficiency	C) Not promoted	D) Rejected as undesirable

Table 1: Energy efficiency versus economic efficiency Source: Golove and Eto (2006)

The term 'energy efficiency gap' refers to the difference between the actual lower levels of implementation of energy efficiency measures and the higher level that would appear to be cost-beneficial/effective from the consumers/firms point of view based on techno-economic analysis (Brown, 2001 and Golove and Eto, 2006). Some of the energy efficiency gap can be explained by rational behaviour to market barriers that may not be captured by the techno-economic analysis. If these can be accurately modelled, then the remaining energy efficiency gap can be explained by market failures, as shown in Figure 1.

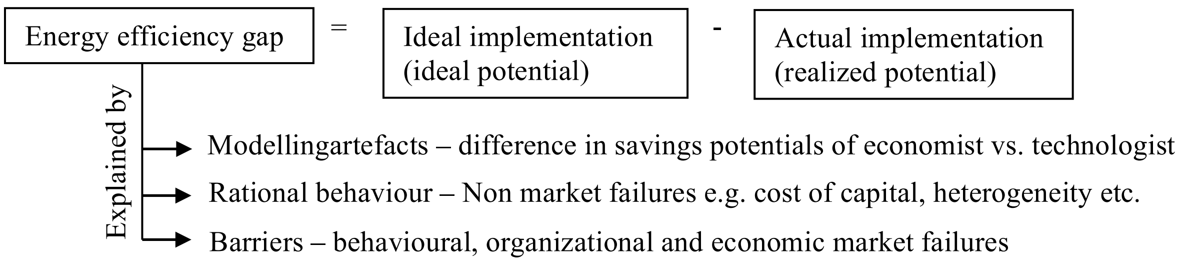

Figure 1: Explaining the energy efficiency gap

Sorrell et al. (2004) also suggest introducing transaction costs and more realistic representation of the decision making process to explain the energy efficiency gap. According to Brown (2001) market barriers are obstacles that are not based on market failures but nonetheless contribute to the slow diffusion and adoption of energy efficient measures. They can therefore be called non market failures, which are defined as "where the organization is behaving rationally given the risk adjusted rate of return on an investment in the existing context of energy, capital and unavoidable 'hidden' costs" (Sorrell et al., 2004, p33). These are real features of the decision making environment, albeit ones which are difficult to incorporate in engineering-economic modelling (Sorrell et al., 2000). 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). The important distinction between general market barriers and market failures is to do with the legitimacy of policy intervention to rectify market failures (Sorrell et al., 2004; Thollander and Palm, 2013). It should be noted however, that the above classification of barriers is not entirely accurate (Thollander and Ottosson, 2008). According to Weber (1997) barriers are unobservable and it is "empirically impossible" to find the true reason for lack of action. Moreover, Blumstein (1980) suggests that the causes of barriers are often interlinked and follow a causal chain. Nonetheless, Sorrell et al. (2000 and 2004) provide a useful framework for investigating barriers to energy efficiency by categorizing them as shown in Figure 2.

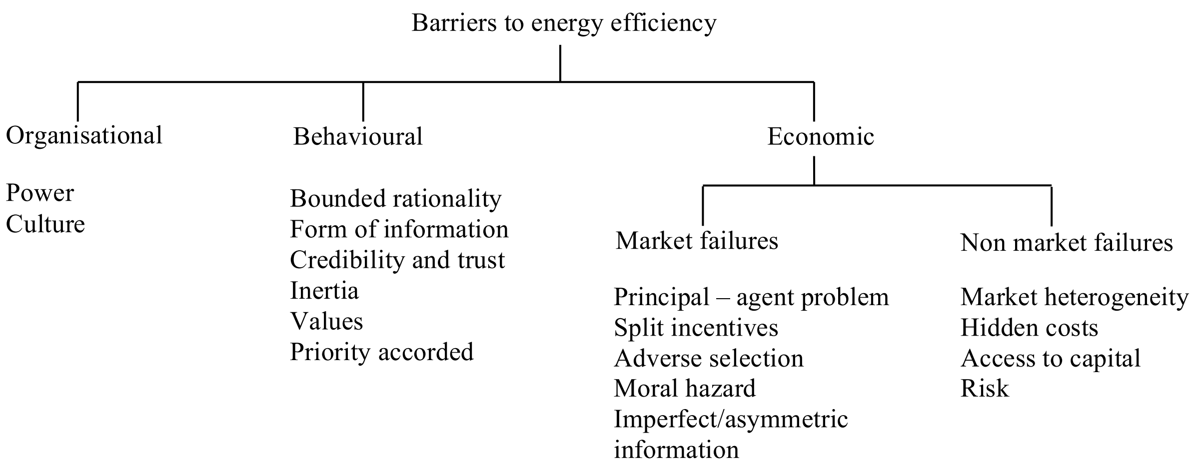

Figure 1: Classification of barriers

2.1. Principal agent problems

Within the context of barriers to energy efficiency, agency theory has been utilized to explain some of the market failures (Levinson and Neimann, 2003, Murtishaw and Sathaye, 2006; Prindle et al. 2006; IEA, 2007; Grauss and Worrell, 2008; Gillingham et al. 2011; Vernon and Meier, 2012). The tenets of agency theory lie under the orthodox economics perspective (Sorrell et al., 2004). The theory aims to create the most efficient contracts for the ubiquitous agency relationship, in which one party (the principal) delegates work to another (the agent), who performs that work (Ross, 1973; cited by Eisenhardt, 1989) or when one individual depends on the action of another (Pratt and Zeckhauser, 1985) and delegates some decision making authority (Jensen and Meckling, 1976). From the perspective of the key stakeholders involved in shipping, the shipowner and the charterer can be seen as being involved in an agency relationship, where the principal i.e. the charterer hires the shipowner as an agent to provide service of carrying goods from A to B (Classification follows Murtishaw and Sathaye (2006), IEA (2007), Vernon and Meier (2008), Veenstra and Dalen (2011). The theory aims to resolve two agency problems that occur as a result of this relationship:

- Problem 1: The desires or the goals of the principal and agent conflict (split incentives problem)
- Problems 2: It is difficult or expensive to verify agent's actions (informational problem)

So, agency theory refers to the economic theory that aims to create most efficient contracts given the assumptions and problems of the agency relationship. Principal agent problems refers to agency theory being applied to the barriers debate, which results in several cases suggesting optimal or sub optimal outcomes. Principal agent problem has been investigated generally through applying a set methodology (IEA, 2007) to quantify the effect of principal agent problem on energy efficiency and energy end use.

2.2. Analysis of shipping's abatement potential

A common method to calculating the techno-economic potential of CO_2 reducing measures and the order in which they may be adopted is through marginal abatement cost curves (MACC). A MACC presents measures to reduce CO_2 emissions in the order of their cost effectiveness, which is calculated using the net present value (NPV) cost per tonne of the carbon reduction measure against the amount of carbon saved. A negative marginal abatement cost means that a measure can be implemented at a net profit to the individual/firm, i.e.to reduce one tonne of $CO_2$the firm/individual pays zero net costs or even makes a profit. MACC's are increasingly being used as a tool in the decision making of climate policies. Several MACC's have been produced for shipping (Buhaug et al., 2009, Faber et al., 2009; DNV, 2009; Eide et al., 2009; Wang et al., 2010) and most feature measures that can be implemented at negative costs.

2.3. Modelling barriers and implementation

Several different types of bottom up models (such as optimization, simulation) have been used to estimate energy demand and emissions for various sector level emissions (e.g. MARKAL, PRIMES etc). Modelling realistic take up of technology through various assumptions is an important feature of these models. Worrell et al. (2004) identify that most bottom up models rely on three factors that affect technology adoption; availability, financial costs and operational decision making. Fleiter et al. (2011) also find that generally very simplistic assumptions through an aggregated approach are used e.g. adjusted higher discount rates to simulate stronger barriers. Very few models such as PRIMES explicitly integrate barriers into the model, but even these fall short of the large range of barriers identified empirically in the literature (Fleiter et al., 2011) as shown in Table 2.

Models	Not explicitly considered	Simple aggregated approach	Explicitly considered by type of barrier					
			Imperfect information	Hidden costs	Access to capital	Risk and uncertainty	Split incentives	Bounded rationality
Accounting:								
-Mure ii	X							
-MED-PRO	X							
-MEAD	X							
-LEAP	X	(X)						
Optimisation:								
-DNE21+	X							
-MARKAL		X						
-AIM		X						
-PRIMES		X				X		
Simulation								
-CEF-NEMS		X						
-ENUSIM		X						
-SAVE		X		X		X		
-POLES		X						
-ISindustry		X						
-LIEF		X						
-CIMS		X		X				

Table 2: Overview of bottom-up models incorporating barriers. Source: Fleiter et al. (2011)

3. Research focus

The research questions that the work informing this paper aims to consider include;

- What are indications from the industry on the implementation of different energy efficiency interventions?
- What are the industry's perceptions of barriers to energy efficiency?
- What are the modelled impacts of different levels of barriers on shipping's take-up of technology?
- What can the combination of survey analysis and modelling tell us about shipping's energy efficiency gap?

In answering these research questions, it is beyond the scope of this paper to discuss all of the above barriers. For a general discussion on barriers to energy efficiency refer to Sorrell et al. (2000 and 2004), Brown (2001), Palm and Thollander (2013). For discussion of the above mentioned barriers in context of shipping refer to Rehmatulla and Smith (2012), Rehmatulla (2012), Faber et al. (2011) and Maddox (2012).

4. Principal agent problems in shipping

A market failure which has received particular attention in shipping is the principal agent problem, a common example of this is often referred to as the split-incentive. For a detailed discussion and classification of shipping contracts using the principal agent methodology refer to Rehmatulla (2011). There are two basic forms of contracts (charterparties) for carriage of goods with which the shipowner-operators and charterers contract, namely the voyage charter and time charter. There are other types of contracts but they are not contracts for carriage of goods, for example the bareboat charter is a lease of the vessel to the charterer. Other hybrid forms of charters also exist but they can be reclassified as either voyage or time charter due to the similarities in the cost allocation, examples of these are trip charters which fall into time charter category despite the contract being for a single voyage and Contracts of Affreightment (COA) which fall into the voyage charter category despite the time element (Wilson, 2010; Stopford, 2009).The voyage and time charters allocate or divide the responsibility for capital and running costs (including fuel costs) between a shipowner-operator and charterer as shown in Table 3. The result of this divided responsibility for costs is that both parties could have diverging or conflicting interests to minimize their share of costs at different points in time (e.g. design, operation, sale etc). Table 4 and 5 shows the first step, which identifies where principal agent problems may exist in shipping.

Cost element	**Voyage charter** $/tonne	**Time charter** $/day
Cargo Handling		
Voyage Expenses		
Operating expense		
Capital costs		

Table 3: Cost allocations for carriage of goods contracts in shipping

	End user can chose technology	**End user cannot chose technology**
End user pays energy bill	No principal agent problem. Case 1	Efficiency problem. Case 2
End user does not pay energy bill	Usage and efficiency problem. Case 3	Usage problem. Case 4

Table 4: Transactions from an end-user (principal) perspective Source: IEA (2007)

	Principal selects technology	**Principal cannot select technology**
Principal pays energy bill (direct energy payment)	No principal agent problem. Case 1 Cargo owner operated ships	Efficiency problem. Case 2 Time chartered ships
Principal does not pay energy bill (indirect energy payment)	Usage and efficiency problem. Case 3 N.A	Usage problem. Case 4 Voyage chartered ships

Table 5: Principal agent problems in shipping

The above suggests that there are indications that the specific structure of the shipping markets could be susceptible to market barriers and failures, but to date there has been little work to quantify the consequence of any failures and to test rigorously for their existence. In this paper, the focus is mainly on Case 2 (Table 5), which represents the principal agent efficiency problem that occurs in time chartered ships. In the time charter, the shipowner-operator (classed as an agent providing the service), determines the level of technological energy efficiency, while the time charterer (classed as a principal demanding the service) bears the costs associated with that level of energy efficiency (Agnolucci et al., submitted). The extent of this problems is directly related to how well the charter rate reflects the ships energy efficiency, in other words, to what extent are shipowner-operators rewarded (for an energy efficient ship) through higher time charter rates, as a result of cost savings made by the time charterer. Agnolucci et al., (Submitted) explore this for the drybulk panamax ships and find that X% of the fuel savings are recouped by the shipowner-operators through higher charter rates. This is an important finding for this paper as it will allow for creating scenarios where this figure is reduced or increased.

The following sections of the paper attempt to explain the energy efficiency gap by first estimating the level of implementation using a techno-economic model, then comparing this with the actual implementation derived from a survey method, followed by content analysis of charterparties to examine the observed extent of the principal agent problem.

5. Modelling shipping's market barriers

The model used to analyse the extent to which different market barriers and failures might obstruct energy efficiency in the global fleet is GloTraM, a bottom-up model for estimating the CO_2 emissions trajectories of the shipping industry. The model applies time-domain simulation to calculate evolution over time of the global fleet.The two main drivers of the CO_2 emissions trajectories are:

- the transport demand (e.g. t.nm) over time
- the transport carbon intensity (e.g. gCO_2/t.nm) over time

Transport carbon intensity is a function of the evolution of a fleet's composition (ships) and their technical and operational specifications. These are determined by combining consideration of regulation, economics and technology performance, availability and cost and applying to models of how the fleet evolves both through stock turnover (newbuild and scrappage) and existing fleet management (lay up, retrofit and operation). The choices that are made to determine technical and operational specifications of new build and existing ships are driven by the profit maximization of the ship's owner, and regulatory compliance.

Transport demand and its supply are broken down into a number of component shipping markets. Each shipping market has a specified commodity type and ship type. The ship type is matched to the commodity type and there is not assumed to be any substitution outside of the market. In this paper, for clarity and simplicity, only the dry bulk sector is modeled.

A more complete description of the method can be found in Smith et al. (2013a), and the derivation of the model's baseline input data can be found in Smith et al. (2013b) greater detail on technology modelling can be found in Calleya et al. (2012). The techno-economic evaluation includes a number of assumptions that represent the extent of some of the barriers discussed above. In GloTraM, the principal agent barrier (only split incentives, ignoring informational problems) is represented by the proportion of cost-saving associated with fuel-saving that is passed from the charterer to the owner. This represents only one of the problems that occur in Case 2 as shown in table 5 (PA efficiency problem).

For a time-chartered ship, the revenue of the ship owner comes from the rate that the ship is chartered out on. In GloTraM, that rate is defined as some standard market rate, which is then modified with a premium according to the fuel-cost saving that is achieved by the operator of the ship. The ship owner's annual revenue, R_{own_pa}, is calculated according to:

$$R_{own\_pa} = 365P_{tc\_pd} + B_{tc}\left(R_{vc\_pa} - C_{v\_pa} - 365P_{tc\_pd}\right) \quad (1)$$

Where P_{tc_pd} is the market time-charter day rate, B_{tc} the time charter barrier factor, R_{vc_pa} is the annual voyage charter revenue (effected by the speed that the ship is operated at and the impact on the cargo capacity of any technology interventions), $C_{v_pa}$the annual voyage cost (which will reduce if, all else being equal, the ship becomes more energy efficient.B_{tc} takes a value between 0 and 1, where 0 is a market where there is 100% split-incentive (i.e. no fuel-cost savings are passed back to the owner) and 1 is a perfect market where all cost-savings are passed back to the owner.

The ship owner's annual costs, C_{own_pa}, are calculated as the annual sunk costs, calculated in *ship_cost_data_in*. The voyage costs are assumed to be paid by a charterer and are therefore included in the revenue term. Net Present Value is applied as an assessment of the degree of profitability of a given technology or suite of technologies:

$$NPV = C_0 - \frac{\sum_{t=0}^{T}(R-C)}{(1+d)^T} \quad (2)$$

where C_0 is any additional sunk cost, beyond those of a baseline specification, associated with the chosen retrofit/newbuild specification, d is the cost of capital and T is the time horizon for the investment (both user-specified).

5.1. Model run specification

There are three variables which are used in the model to represent barriers to implementation:

- B_{tc}, the 'barrier factor' for the time-charterer
- d, the discount rate, or cost of capital
- T, the time period over which an investment return is expected

These three variables can be connected back to the fields in Table 2: B_{tc} represents the extent of the split-incentive. d and T in isolation or in combination represent access to capital. Three scenarios are defined in Table 6, capturing a range of possible combinations of these variables.

Scenario	Description	Input values
A	Low impact of split-incentives, cheap long-term capital	B_{tc} = 1, T = 10 years, d = 2%
B	Low impact of split-incentives, expensive short-term capital	B_{tc} = 1, T = 3 years, d = 10%
C	High impact of split-incentives, expensive short-term capital	B_{tc} = 0.25, T = 3 years, d = 10%

Table 6: Scenarios used to define access to capital and split incentive barriers.

Figure 3 presents the fuel price scenario which sets the backdrop to the model run, and is derived in Smith et al. (2013b). There is a change in prices between 2015 and 2020, because the global sulphur limit is anticipated to create a step-change in demand for distillates and consequent higher MDO prices and lower residual fuel prices. The LNG price is based on a forecast of natural gas price, from 2020, and involves a ramp from 2010 to 2020 in order to represent the impact on price of progressively relaxed constraints on availability during this decade. In addition to this evolution of fuel prices, the MARPOL Annex VI SOx and NOx regulations are applied and require compliance, along with the EEDI. There is no carbon price or other MBM included in the scenario.

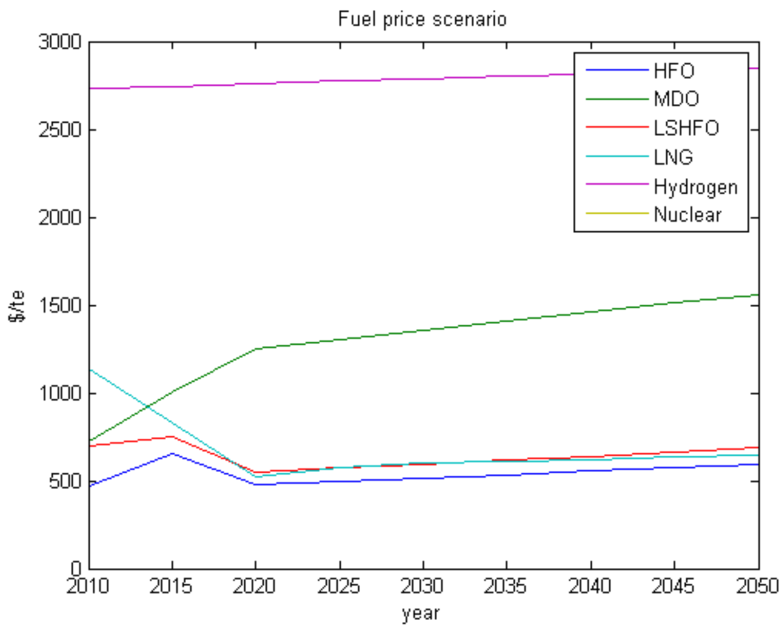

Figure 3: Fuel price scenario for BAU

5.2. Modelling results

5.2.1. Newbuilds

Table 7 and Table 9 describe the technical and operational specifications of the average newbuild for two different size categories of bulk carrier, for each of the three scenarios defined above. This focus is applied because the two size categories are responsible for the greatest share of emissions from the total dry bulk fleet (which represents 20% of CO_2 emissions of the shipping sector), and limiting to the display of two ship sizes simplifies the presentation of results. Table 8 and Table 10 list the take-up of a number of technology and operational measures from the LCS dataset (providing information on cost and performance for approximately 50 abatement and energy efficiency options).

A number of conclusions can be drawn from the output datasets:

- All scenarios involve the take-up of LNG by 2050, the smaller ship size takes up LNG in both scenario A and B in 2015, whereas the larger ship type only sees a competitive advantage for LNG in 2015 in scenario A.
- As expected, Scenario A results in the largest take-up of energy efficiency measures. In most cases, larger amounts of technology take-up results in smaller engine powers, although for the smaller ship, in Scenario A, in both 2015 and 2050, the optimum design speed is higher than the design speed in Scenarios B and C. This higher design speed outweighs the power reduction created by the greater take-up of technology, resulting in a higher installed power than Scenario B.
- In all scenarios and both ship sizes, operating speeds are higher in 2050 than they are in 2015 (despite the design speed being the same). This is because the cost per kWh of energy is lower in 2050 than 2015, both when comparing HFO with LNG (because of similar cost per tonne of the fuel, and a lower sfc of the LNG engine relative to a 2-stroke), and when comparing LNG or MDO with LNG (mainly driven by lower cost per tonne of fuel.
- In all years and both ship sizes, taking the interaction of both speed, fuel, machinery and abatement/efficiency technology into account, the EEDI of a newbuild ship follows the hierarchy of the three barriers scenarios (e.g. Scenario A has the lowest EEDI).
- Whilst strict comparison is difficult with three ‘point’ scenarios, it appears to be the case that for the ranges of values used in Scenarios A, B and C, the EEDI is at least as sensitive to the access to capital barrier (A vs. B) , as it is to the split-incentive barrier (B vs. C).

- With reducing EEDI, comes increasing operating speed. This phenomenon was also observed in a related, but simpler study Smith (2013), and was found to be because of two effects: the cost burden of 'speeding-up' of technologically more efficient ships is lower than less technologically efficient ships, and the increased capital cost of a technologically more efficient ship creates an incentive to increase speed.

	Main fuel		P_me		V_des		V_op		EEDI	
Scenario	2015	2050	2015	2050	2015	2050	2015	2050	2015	2050
A	LNG	LNG	4344	4334	12.9	12.9	10.9	11.5	4.81	4.80
B	LNG	LNG	4290	4223	12.4	12.4	10.4	11.1	4.88	4.88
C	MDO	LNG	4335	4335	12.4	12.4	9.7	11.0	6.69	5.00

Table 7: technical and operational specifications of the average newbuid dry bulk carrier in the 10-40,000 dwt size range.

Scenario	2015	2050
A	Prop section optimization, propeller upgrade, rudder bulb, autopilot upgrade, trim and ballast optimization, prop hull optimization, skeg optimization, stator fins, air lubrication	Prop section optimization, propeller upgrade, rudder bulb, autopilot upgrade, trim and ballast optimization, prop hull optimization, skeg optimization, stator fins, air lubrication
B	Prop section optimization, autopilot upgrade, trim and ballast optimization, stator fins	Prop section optimization, autopilot upgrade, trim and ballast optimization, stator fins
C	Trim and ballast optimization, autopilot upgrade	Trim and ballast optimisation

Table 8: take-up of technical and operational measures of the average newbuild dry bulk carrier in the 10-40,000 dwt size range.

	Main fuel		P_me		V_des		V_op		EEDI	
Scenario	2015	2050	2015	2050	2015	2050	2015	2050	2015	2050
A	LNG	LNG	6947	6946	12.9	12.9	10.5	12.1	2.88	2.88
B	HFO	LNG	7465	7345	12.9	12.9	10.4	11.0	3.83	3.03
C	HFO	LNG	7540	7540	12.9	12.9	10.2	11.0	3.87	3.10

Table 9: Technical and operational specifications of the average newbuild dry bulk carrier in the 50-100,000 dwt size range

Scenario	2015	2050
A	Prop section optimization, rudder bulb, energy saving lighting, autopilot upgrade, trim and ballast optimization, prop hull optimization, skeg optimization, stator fins, air lubrication	Prop section optimization, rudder bulb, energy saving lighting, autopilot upgrade, trim and ballast optimization, prop hull optimization, skeg optimization, stator fins, air lubrication
B	Prop section optimization, autopilot upgrade, trim and ballast optimization, air lubrication	Prop section optimization, autopilot upgrade, trim and ballast optimization, stator fins
C	Trim and ballast optimisation	Trim and ballast optimisation

Table 10**Error! Reference source not found.**: take-up of technical and operational measures of the average newbuild dry bulk carrier in the 50-100,000 dwt size range.

5.5.2. Aggregate fleet

In addition to assessing the specifications of newbuild ships, GloTraM incorporates the newbuild stock at each time-step and carries over the existing fleet (retrofitting and changing operational parameters such as speed, as required). The combined newbuild and existing fleets have an overall weighted average specification which demonstrates the net consequence of the fleet turnover. GloTraM uses the stock data with an activity (routing) model and trade data in order to calculate emissions. Table 11 contains all three scenario's results at these aggregate levels, for the year 2050. Ships are assumed to be scrapped at the age of thirty, so by 2050 all ships in GloTraM have been built in the time-steps since the start of the model (none of the baseline stock are left). These results show that despite the large magnitude difference in the impact of the three scenarios on EEDI shown in Section 5.2.1 (particularly in 2015), the consequence on average EEOI and emissions in 2050 is small (1.5 – 3% on the magnitudes of these figures). The explanation for this is the GloTraM resolved take-back of the technological efficiency advantage with higher operating speeds and therefore lower operational efficiency.

Scenario	2050		
	Average EEOI size 3 fleet, gCO_2/t.nm	Average EEOI size 5 fleet, gCO_2/t.nm	Annual emissions (all dry bulk), million tonnes
A	9.7	5.6	4.48×10^8
B	9.9	5.7	4.54×10^8
C	10.1	5.8	4.37×10^8

Table 11: Take-up of technical and operational measures of the average newbuild dry bulk carrier in both drybulk size ranges.

The extent to which this outcome is a feature of the algoithms used in GloTraM and the extent to which it is expected market behavior depends on the way speeds are set in the industry. This is dependent on the flexibility provided in charterparties and the transparency with which information allowing both owner and operator to trade off lower ship speeds with fuel cost savings and higher inventory costs can be undertaken. Some information in Smith et al. (2013) can corroborate the current model used in GloTraM, but as is discussed in Section 6, this model is a simplification and may need further development to increase its realism. If barriers prevent freedom in setting speeds that maximize profits and the sharing of benefits fairly, then the differential in the outcomes in Table 11 are expected to be higher.

6. Survey and Charter-party analysis

In order to explain the energy efficiency gap, both modelled and actual level of implementation of measures is required. The preceding section attempted to model the implementation of measures as accurately as possible by considering the impact that certain barriers may have on implementation. Actual levels of implementation are required so that the difference between the most realistic modelling and observed can be compared, and if there is still a difference between the two, then it could suggest market failures could be impeding implementation. A carefully considered online survey was used to assess the actual uptake of energy efficient operational interventions that were perceived to be cost-effective/cost negative for shipping and to obtain views on barriers to their implementation. A stratified sampling approach was taken so as to represent the different variables (sector, size and region), which other similar studies in shipping have lacked. Further details on the design considerations of the survey can be found in Rehmatulla (forthcoming). The total number of respondents was 170, which consisted of 120 almost complete (90% item response) responses and 50 partially completed responses. In order to be representative and to make generalizations 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).

The principal agent problem in other sectors (e.g. buildings residential and commercial) has been represented by assessing the proportion of properties that are owner-occupied and those that are rented. The principal agent problem in shipping could be represented using the chartering ratio/level of a shipping company as shown in table 12. Table 12 can also be regrouped in to two chartering groups, one representing respondents with majority of their fleet chartered out voyage (i.e. combining group 1 and 3) and another group representing respondents with majority of the fleet chartered out time (i.e. combining group 2 and 4). These groups can be said to be reflecting the cases presented in Table 4 and 5 in section 4 of this paper.

Group	Description	Survey Indicator	N
1 – Case 4	Majority of the fleet is owned and majority of the fleet is chartered out on voyage charter.	> 50% owned and > 50% chartered out on voyage	21
2 – Case 2	Majority of the fleet is owned and majority of the fleet is chartered out on time charter.	>50% owned and > 50% chartered out on time	21
3 – Case 4	Management company with majority of its managed fleet out on voyage charter.	>50% chartered out on voyage	9
4 - Case 2	Management company with majority of its managed fleet out on time charter.	>50% chartered out on time	20

Table 12: Grouping the chartering ratio and survey respondents

Most studies (e.g. Murtishaw and Sathaye, 2006; IEA, 2007; Vernon and Meier, 2012, etc) focus on technical energy efficiency and show that the principal agent efficiency problem exists, since the technical efficiency levels of different cases differ significantly. However, there is a problem when investigating operational efficiency, since only one study to date has investigated how implementation of operational measures is affected by the principal agent problem. Maruejols and Young (2011) suggest that split incentives impact some aspects of occupant behaviour, such as households that do not pay directly for their energy opting for increased thermal comfort and being less sensitive to whether or not somebody is at home and the severity of the climate when deciding on temperature settings, thus being operationally inefficient compared to households that pay for their energy. Most of the above studies for example hypothesize that households on rental market (with no energy included) will have lower implementation of technical measures, which has been confirmed by many studies. It is important to extend this original hypothesis to investigate that rental households (with no energy included rents) may have better operational efficiency, based on the principal agent incentives. Conversely, households on rental markets (with energy included in rents) will have higher implementation of technical measures but may suffer from lower implementation of operational measures. The key here is the end user's/tenant's (principals) incentives to conserve energy. Whilst operational efficiency in households or other sectors may not be as important, it certainly is in the case of shipping. Smith et al (2013) show that there is a wide range of operational efficiencies for different ship types, suggesting a greater potential for energy efficiency or CO2 reduction through these measures.

Figure 4 below shows the zero order relationships (uncontrolled) between the implementation of five operational measures and chartering group. It can be seen that there exists to some extent a relationship between the chartering group and three operational measures. For example for the speed reduction measure it can seen that group one and three (fleet mainly chartered out voyage) had lower implementation compared group two and four (fleet mainly chartered out on time). The same could be said for weather routing measure and to some extent for fuel consumption monitoring measure. This suggests that operational measures may not be susceptible to the principal agent problem and this is because the charterer has operational control or command as well as the incentive to save fuel which is under their account, switching the time charter (from case 2) to case 1 of table 4 for operational measures. Controlling the above relationships for sector strengthens the relationship further and statistically significantly for the drybulk sector for both measures. For autopilot adjustment and trim draft optimization (measures that were suggested to have been taken up in the modelling), the relationships are not consistent and do not show similar pattern of association compared to the other operational measures with chartering group.

A separate study by Smith et al. (2013) assessed the operational efficiency of ships using satellite automatic identification system (AIS). Comparing operational energy efficiency of ships on voyage and time charter shows that there isn't a significant difference between the operational efficiency of ships on the different types of charter (appendix). Statistical significance could not be achieved due to the aggressive filtering of ships that occur only on time charter throughout the whole year thus have not been sublet on the voyage charter nor have entered the voyage charter market when not on time charter, resulting in very small sample.

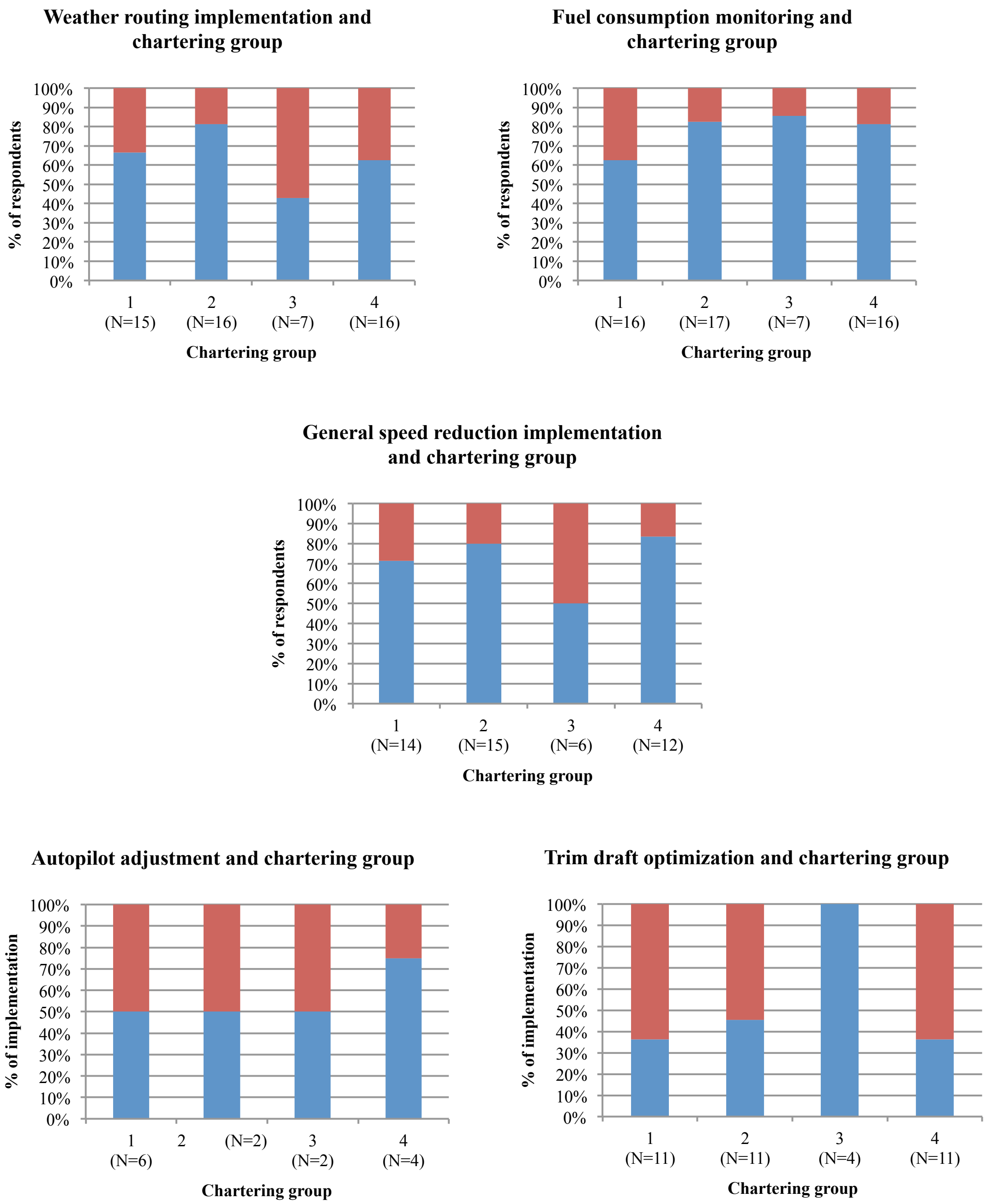

Figure 4: Implementation of operational measures by chartering group

Possible explanation for the speed reduction measure relationship could be found in the charterparties. A detailed content analysis of thirty voyage and time standard form charterparties (Rehmatulla, forthcoming) highlighted interesting corroborative findings to the survey results. Close reading of the charterparties revealed that there were different express obligations of utmost despatch, which are consequently coded into four categories under the goal conflict proposition of the agency theory. The different categories discussed above belonged to specific sectors, for example the lack of express mention of reasonable despatch was only found in general form charterparties (used for trades for which no specifically approved form is in force) e.g. Gencon makes no mention utmost despatch for the loading or discharging leg. The difference between the bulk and container sector can be explained by the use of bill of ladings, where liner bill of ladings e.g. Conlinebill 2000, permit the owner/operator to slow steam. These results are consistent with the survey findings, which reflect the perception of respondents in those sectors, where almost 80% of drybulk and wetbulk sector perceived standard utmost dispatch clauses as a significant barrier to speed reduction compared to around 60% of respondents in the container sector.

There was also clear difference in the voyage charterparties of the different sectors for other factors such as place of tendering Notice of Readiness (NOR) and timing of NOR, wetbulk charterparties generally were found to be port charters whereas most drybulk charterparties were observed to be berth charterparties. Similarly, for NOR times, there were clear sectoral differences in the charterparties. Wetbulk charterparties had no specific times in which NOR has to be tendered whereas in contrast majority of the drybulk and general charterparties had specific times in which shipowners had to tender NOR. It is believed that all three; utmost dispatch clauses, place of NOR and timing of NOR would affect the implementation of speed reduction measure in the voyage charter. Table 13 below summarizes the results of the charterparty content analysis of 19 voyage charterparties.

Voyage charterparty	Utmost despatch to load port	Utmost despatch to discharge ports	ETA/ERL	Specific NOR times	Specific NOR place
BIMCHEMVOY	✓	✓ through B/L	✓	×	×
INTERTANKVOY	✓	✓ through B/L	✓	×	×
ASBATANKVOY	✓	✓ through B/L	✓	×	×
BEEPEEVOY 4	Stated speed	Stated speed	✓	×	×
SHELLVOY 6	✓ + stated speed	Stated speed	✓	×	×
COALOREVOY	×	✓	✓	×	✓
OREVOY	×	✓ or reduced speed	✓	×	✓
NIPPONORE	✓	✓	✓	User	✓
POLCOLVOY	×	✓	✓	✓	×
SYNACOMEX	✓	✓	✓	✓	✓
BHPBVOY03	✓	✓	✓	User	✓
NIPPONCOAL	✓	✓	✓	User	✓
NUBALTWOOD	✓	✓ through B/L	✓	✓	×
RIO DOCE ORE	✓	✓	✓		
AMWELSH	✓	✓	✓	✓	✓
GRAINCON	✓	✓	✓	✓	✓
GENCON	×	×	✓	✓	✓
SCANCON	×	×	✓	✓	✓
NUVOY	×	✓ or reduced speed	✓	User	User

Table 13: Charterparty clauses affecting implementation of speed reduction in voyage charters

7. Discussion and concluding remarks

The barrier factor used in the modelling in Section 5, represents case 2 of the principal agent matrix i.e. the efficiency PA problem, which proposes that the technical efficiency of the ship will be lower due to shipowner being responsible for capital costs and time charterer responsible for voyage (including fuel costs). Incentives can be aligned if the shipowner-operator can recoup the investment in energy efficiency through higher charter rates for the savings in energy made by the charterer. The modelling results show that when 100% of the fuel savings are passed back to shipowners through higher charter rates, it results in a greater number of measures being implemented (for both ship sizes and periods), consequently resulting in higher technical efficiency (EEDI). On the other hand, in the scenario where only some of the fuel savings are recouped by shipowners, only two operational measures seem to be implemented (neither influencing EEDI). This suggests that, for the typical values of cost and benefit of technologies which are frequently proposed for increasing shipping's energy efficiency, the resultant technical efficiency is likely to be dependent on the level of the principal agent problem, i.e. if shipowners deem that savings cannot be recouped they may not invest in the technical efficiency of the ship.

Operational efficiency measures were implemented in all of the three modelled time charter scenarios and the survey results also suggested that they were implemented more when ships were chartered out on time charter. This seems to suggest that operational measures may not be affected by the principal agent problem to the same extent as technical measures. Perhaps the reason to this is that the principal i.e. the charterer would rather implement operational measures in a time charter, one of the reasons for this being energy efficiency information is difficult to observe (similar to credence goods) and to monetize during the contracting process. Similarly the shipowner's implementation of operational measures in the scenario with least savings passed through (Scenario C), suggests that it may be easier to portray savings from operational measures.

The speed reduction measure (or slow-steaming) is commonly suggested to have the highest fuel saving potential and under the current market conditions it would be envisaged that it would be implemented to the highest levels but the survey results show otherwise. On average it was implemented by around 65%-70% of the respondents and breaking this down by chartering group shows that general speed reduction implementation is higher in ships under time charter than ships under voyage charter. Satellite AIS data also confirms this finding, as not all ships were operating at lower speeds compared to the design speed. Possible explanations to the lack of uptake can be obtained from the results of the modelling, which suggest that with reduction in EEDI mainly in scenario A and B, operating speed increases due to a lightening of the cost burden of 'speeding-up' of technologically more efficient ships, increased capital costs, and the use of speed for a competitive advantage.

Modelling suggests that when there are no time charter split incentives (scenario A/B where 100% of savings recouped), ship speed and EEOI should increase, whereas survey results suggest that speed decreases in time charter because it has higher implementation compared to voyage charter, this apparent contradiction and speed's important influence on transport efficiency implies the need for further work.

The presence of these barriers and the potential effects forecast by the modelling outcomes create complexity for policy makers. On the one hand, the presence of market barriers incentivises the use of command and control regulation to enforce minimum energy efficiency requirements (e.g. EEDI), as an industry with significant market barriers is unlikely to respond efficiently to market stimuli such as carbon price. However, if the market barriers only have a moderate effect on technology take-up, the outcome of the wrong type of command and control regulation could be perverse (see speed increases) and result in little or no measurable influence on carbon emissions. The data (survey results, AIS analysis and modelling) that has been used to date to draw inferences is, we believe, some of the best available data. However, uncertainty remains and given the significance of the issues that are being addressed and the risk of creating unnecessary burden on the shipping industry with in effective regulation, further work would appear to be required. The advent of an IMO (ideally) or EU MRV will hopefully go some way to improving the quality of the data available for assessing the system dynamics of the industry.

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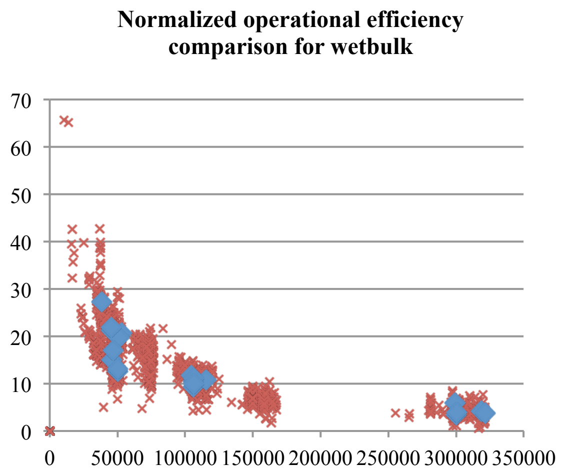
10. Appendix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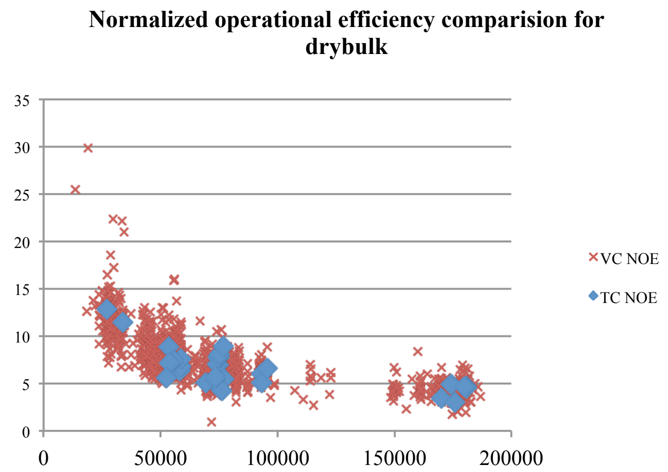
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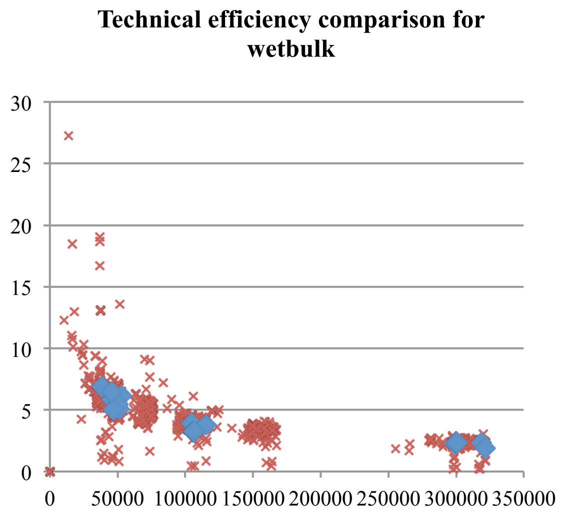
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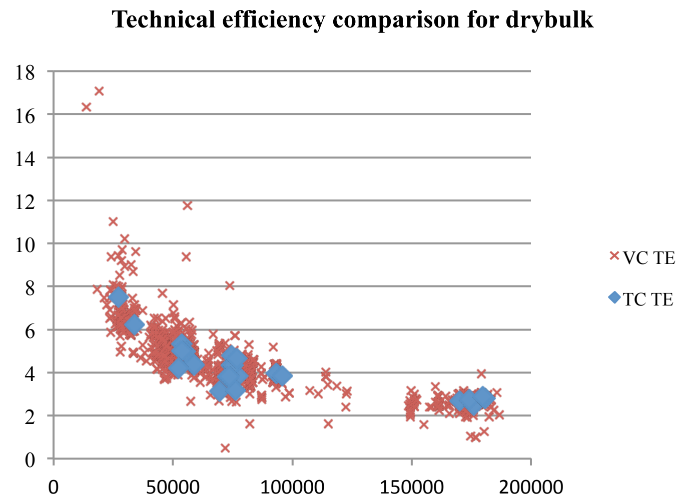
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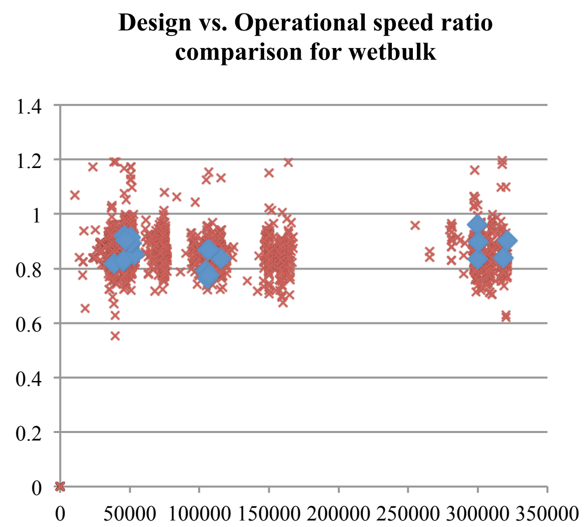
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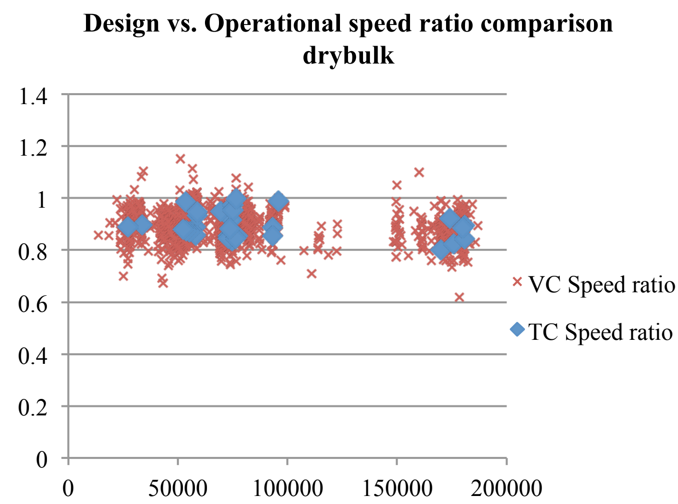
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