Does fuel efficiency pay? Empirical evidence from the drybulk timecharter market revisited

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Abstract

The time charter market for ships represents a classical example of the principal-agent problem, where shipowners can opt to invest in energy efficient ships, yet any savings in fuel expenditures accrue to the charterers. In a competitive and efficient market, ships that have more fuel-efficient designs should, all else equal, obtain a rate premium to reflect the fuel savings. In this paper we investigate empirically the determinants of timecharter rates using a comprehensive panel data set of over 9,100 timecharter fixtures for bulk carriers above 40,000 DWT between January 2001 and January 2016. We test for the presence of an energy efficiency premium using four different definitions of efficiency, while controlling for key macro, ship-specific, and contract-specific variables. Our findings suggest that the "market rate" for a standardised vessel dominates in terms of explanatory power, but that vessel age, fuel prices, place of delivery and DWT also are significant determinants across sizes. We show that the earlier findings on the energy efficiency premium in the literature are not robust when expanding the sample in time and vessel size. Using a substantially longer sample across an entire market cycle, we show that only 14% - 27% of fuel savings are reflected in a higher rate during normal market conditions, while the sign of the relationship flips during market "booms" such that energy inefficient vessels attract a premium. We introduce several explanations as to why there is an apparent market failure and suggest policy measures that could address this issue.

Keywords: Energy efficiency gap; market failure; timecharter rate determinants; drybulk

1. Introduction

Energy efficiency has come to the fore in shipping over the past few years and much has been said on the importance of reduced ship-to-air emissions if the industry is to contribute its share of global emission reductions. As reduced emissions generally go hand in hand with lower fuel consumption and costs, being green is often equivalent to being more profitable, and so this would appear to be one area where shipowners and environmentalists share a common goal. Yet, when theory meets practice, conventions with regards to contractual structure and vessel operation in shipping are often such that the most energy-efficient solutions are not chosen, or that energy efficiency is not rewarded by the market. In the general literature on energy efficiency (see e.g. Sorrel et al, 2004), these barriers are often categorised into a) organisational, b) behavioural and c) economic factors.

Barriers to energy-efficient shipping often fall into the "market failure" category (see, e.g. Rehmatulla et al, 2013, or Acciaro et al, 2013, for a detailed account). A well-known example is the split incentives problem under a voyage charter. Here, any reduction in fuel costs (and emissions) from agreeing to reduce the sailing speed would accrue to the shipowner, while the charterer/cargo owner would be left with longer lead times in the supply chain and the associated increase in trade financing costs. Similarly, the added construction costs of a state-of-the-art energy-efficient newbuilding paid by the owner may not be fully recovered if the vessel is then chartered out on a timecharter where fuel savings accrue to the charterer only (a principal-agent problem).

In this paper we examine whether the principal-agent problem in the timecharter market results in a market failure. Specifically, we assess empirically whether there exists a freight rate premium for energy-efficient drybulk ships that is commensurate with fuel savings. This is important from a policy point of view. The presence of a market failure, in the sense that shipowners do not get sufficiently compensated for building energy-efficient ships, will inhibit innovation and slow down the uptake of new fuel-saving technologies. However, it also has a direct impact on the operational strategies of charterers and shipoperators. If there is no premium for fuel-efficient ships in the timecharter market then the optimal chartering strategy is to always pick the most energy-efficient vessel available, sublet it in the spot market on a voyage charter and pocket the fuel savings. Freight rates in the spot market for voyage charters, measured on a \$/tonne basis, will typically cover all voyage costs for the marginal vessel required to perform transportation, though this lower bound is occasionally breached for low-volume (i.e. backhaul) routes in times of severely depressed freight market conditions (Adland, 2012).

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature, Section 3 presents our chosen panel data variables and regression methodology, Section 4 presents the data and the empirical results and Section 5 contains concluding remarks on policy implications and suggestions for future research.

2. Literature review

The observation that the principal-agent problem can represent a barrier to energy efficiency is well known in the general energy efficiency literature. In this context, the principal-agent problem refers to the observation that the economic benefits of energy conservation do not accrue to the person who is trying to conserve. Blumstein et al (1989) provide an early taxonomy of energy efficiency barriers and argue that they can be classified as: misplaced incentives, lack of information, regulation, market structure (degree of concentration), availability of financing and custom. Similarly, Brown (2001) articulates the barriers to clean energy usage in the US and argues for the presence of large-scale market failures. The principal-agent problem belongs to the category "misplaced incentives" and has been investigated empirically in several market contexts. For instance, Graus and Worrel (2008) estimate the size and the impact of the principal–agent problem for cars provided as a company perk in the Netherlands and find that company cars have higher total higher energy consumption. Vernon and Meier (2012) consider the impact on the US trucking industry and estimate that up to 91% of total trucking fuel consumption is affected by "usage" principal-agent problem, where the driver does not pay fuel costs and lacks incentive for fuel saving operation. Deep-sea shipping is an extremely interesting empirical case within the broader transportation sector as it is generally more transparent and geographically integrated than land-based transportation. Moreover, market intermediaries (shipbrokers) have a long history of collecting and disseminating data on both market transactions and technical vessel details, resulting in the availability of rich datasets where the division of economic benefits due to energy efficiency can be explicitly estimated.

Within the maritime economics literature, our paper belongs to the stream of research that investigates the microeconomic determinants of freight rates. Typically, freight rate data for individual contracts (fixtures) are here regressed against a chosen set of vessel and route-specific characteristics with a view to establish whether certain effects, such as vessel quality premia, are present in the price data. We note that vessels can be chartered on two main types of contracts: voyage charters and timecharters (TC). Under a voyage charter, the shipowner is paid on a $/tonne cargo basis and has to pay all costs, including fuel expenses. Under a timecharter, the shipowner gets paid on a $/day basis for the duration of the hire period, but voyage costs such as fuel expenses are borne by the charterer. The charter type chosen for a vessel at a particular point in time will depend on the policy of the shipowner, the market expectations of owners and charterers, the offers available in the market and the attractiveness of the vessel. Many vessels will operate mainly in the spot market for voyage charters throughout their lifetime. We also note that vessels fixed on a period timecharter often will be re-let in the spot market, and so there is no clear separation between the two sub-markets.

However, the empirical literature treats the voyage charter and timecharter markets separately, with most research focusing on the former. For instance, Tamvakis (1995) tests whether there is a freight rate premium paid to tanker vessels of lower age, vessels with double-hull construction, or vessels trading to the United States, with mixed results. In a follow-up study, Tamvakis and Thanopoulou (2000) investigate the existence of a two-tier spot freight market in the drybulk freight market on the basis of vessel age, and find no significant age premium in the freight rate. In related work, Strandenes (1999) assesses the potential for a two-tier tanker market to develop based on simulations of a non-linear equilibrium model of the international tanker market. Alizadeh and Talley (2011a, b) broaden the investigation of vessel and contract-specific determinants of tanker and drybulk spot freight rates to include the lead time between the contracting date and loading, as well as macroeconomic proxies representing the market freight rate level and its volatility. Adland et al (2016) show that there exist substantial fixed effects related to the identity of owners, charterers and owner-charterer matches in the pricing of voyage charters in the tanker and drybulk segments.

In the first empirical analysis of period TC determinants, Köhn and Thanopoulou (2011) investigate the presence of a quality premium in the drybulk TC market using Generalised Additive models. Controlling for contract-specific effects such as place of delivery, lead time, charter length, vessel size and fuel consumption, they find strong evidence for the existence of a two-tier dry bulk TC market during the freight market boom years of 2003 – 2007. Agnolucci et al (2014) estimate a microeconomic model for TC rates in the Panamax drybulk market and focus on whether there exists a rate premium for fuel efficiency. They find that a vessel's fuel consumption (relative to the fleet average) is statistically significant, in addition to the traditional determinants of age, DWT and contract lead time.

An important point which has not garnered enough attention in the literature is how to properly account for the impact of the underlying market. As found by Agnolucci et al (2014), models that try to explain the difference between a benchmark "market" rate for a standard vessel and the actual rate obtained for individual fixtures, will generally perform better than models that attempt to explain the "market rate" endogenously. Intuitively, in a perfectly competitive and spatially integrated freight market, the general market condition should indeed dominate in terms of explanatory power. However, panel data consisting of individual period timecharter contracts will comprise a very heterogeneous mix of contractual durations, ranging from about three months to several years, and so the "market rate" is not a unique value at any point in time. Instead, there exists a dynamic relationship between TC freight rates and contract duration - the term structure of freight rates. The term structure of freight rates reflects expectations of mean reversion of the spot freight rate, where short-term TC rates follow the spot freight market closely and long-term TC rates reflect the "asymptotic" average freight rate implied by newbuilding prices (Strandenes, 1984). Koekebakker and Adland (2004) and Adland et al (2007) show that the shapes and dynamics of these freight forward curves can be quite rich and complex, using data for timecharter rates and financial Forward Freight Agreements (FFAs), respectively.

Köhn and Thanopoulou (2011) and Agnolucci et al (2014) effectively ignore this changing relationship between contract duration and the "market rate", with the former study using the Baltic Panamax Index (BPI)[1] spot rate index and the latter using the one-year timecharter rate as the market proxy. Consequently, both market proxies are based on an assumed constant contractual duration, which is at odds with the observed heterogeneity in the sample. Since the real underlying relationship between the market rate and contract duration is not a constant but a non-linear upward- or downward-sloping function, depending on market conditions, this will impose systematic errors in model estimations which can render the empirical results unstable over time and even spurious. Specifically, this simplification will cause the chosen market proxy to explain less of the variations in contract rates than the true market rate and this may affect the statistical significance of the other variables, such as energy efficiency proxies. This is a particular concern since the magnitude of these errors will be correlated with both freight market conditions and the average contract duration, and because both studies relate partly to the 2003 – 2008 period of abnormally strong drybulk freight markets (and therefore strongly downward sloping term structures, on average).

The willingness to pay for energy efficiency is arguably related to both market conditions and contract duration. During periods of very high freight rates, the value of time and carrying capacity (i.e. speed and DWT) will exceed the value of fuel savings and so one would *a priori* not expect energy efficient vessels to obtain a rate premium. Similarly, energy efficiency is likely to matter less for very short durations where the value from entering into the contract relates more to taking advantage of short-term regional freight rate differences than from long-term ship operation as is the case under a long-term period timecharter. Agnolucci et al (2014) specifically suggest that follow-up research should investigate a longer data sample,

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[1] The BPI is an index for the daily spot rate ($/day) in the Panamax market segment as reported by the Baltic Exchange and represents an equal-weighted average of four regional tripcharter rates for trips with duration between 35 and 65 days. For details on the composition and changes over time, see Baltic Exchange (2015).

acknowledging that their 2008 – 2012 sample period was affected by unusual and severe supply-demand imbalances in the drybulk freight market.

In light of the above, the contribution of our paper to the literature is threefold. Firstly, we correctly account for the dynamic term structure of freight rates, allowing us to draw more robust inferences about the impact of the "market proxy" and other contract- and vessel-specific determinants of TC rates. Secondly, while the existing studies on the timecharter market have investigated the Panamax market only (60,000 – 80,000 DWT), we expand to include contracts for all drybulk vessel sizes between Handymax and Capesize (40,000 DWT to 300,000DWT). Thirdly, rather than investigating only short five-year periods we expand the sample in time to include 15 years of public fixtures between January 2001 and January 2016, covering a full freight market cycle. A wider empirical investigation both in time and size segments is crucial in order to ensure robustness of any conclusions. Indeed, the empirical evidence presented herein suggests that the conclusions in the earlier literature are not robust across time and size segments.

3. Methodology

3.1. Choice of variables

Our choice of variables largely follows the literature on microeconomic determinants of freight rates as referenced above, with some new variables added for completeness. In particular, Table 1 below summarizes the variables included in our multiple regression models, grouped in macro, vessel- and contract-specific variables, unit of measurement where applicable, the *a priori* expected sign of the coefficients, as well as their interpretation in the context of our study. We also indicate whether the variables are present in the related studies of Köhn and Thanopoulou (2011) and Agnolucci et al (2014), though these studies may also include other variables which we discard. In particular, we exclude the following macro variables used in Agnolucci et al (2014) on the basis that there is no plausible economic story behind their inclusion: drybulk trade volume, fleet size and commodity price. Given that both global commodity trade and fleet size have been strongly increasing over time, their absolute levels contain no information relevant to the level of the freight rate, which is a stationary process. As an example, according to Clarkson Research (2015), global trade in the major drybulk commodities (iron ore, coal and grain) increased more than threefold between 1989 and 2014 (from 903mt to 2,946mt), yet the one-year Panamax timecharter rates declined from an annual average of \$13,115/day to \$12,035 in the same period[2]. Similarly there is no reason to expect commodity prices to be consistently positively correlated with freight rates over time, as the supply of ships is independent of the

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[2] The reference vessel size increased from 65,000DWT to 75,000DWT in the same period, so the real earnings power per DWT declined even more.

supply of commodities in the short and medium term. Consider, for instance, the case where draught conditions decimate the global grain harvest and volume of international trade, pushing grain prices upwards and freight rates down.

Table 1 – Explanation of independent variables

Independent variable	**Unit**	**Agnolucci**	**Köhn**	**Exp. sign**	**Interpretation**
Macro variables					
Market rate	$/day	x	x	+	Market rate for standardised vessel
Fuel price	$/tonne	x		-	Average Rotterdam/Singapore price for IFO or HFO
Ship variables					
DWT	Tonnes	x	x	+	Deadweight carrying capcity of ship
Age	Years	x	x	-	Age of ship on contract report date
Age_Sq				-	Squared age to capture non-linear effects
Flag_D			x (1)	-	Dummy for black/greylisted Paris MOU flags
Consumption	Tonnes/day	x	x	-	Fuel consumption at design speed
FEI				-	Fuel efficiency index: consumption/(speed*DWT)
EVDI		x		-	Rightship Existing Vessel Design Index
Fexp	$/day	x		-	Difference in daily fuel expenditure to fleet average
Boom_Cons				+	Interaction dummy for Consumption during boom (2)
Boom_FEI				+	Interaction dummy for FEI during boom
Boom_EVDI				+	Interaction dummy for EVDI during boom
Boom_Fexp				+	Interaction dummy for Fexp during boom
Contract variables					
Period	Months		x	0	Duration of timecharter contract (mid-point of min/max)
Forward	Days	x	x	-	Days between report date and delivery (mid-point laycan)
Option_D				+	Dummy for the presence of an extension option
Atlantic_D				+	Dummy for Atlantic Ocean delivery at start of TC

(1) Köhn and Thanopoulou include flag, grain capacity, draught, speed, horsepower and engine type and later drop the variables due to insignificance

(2) We define the boom period as July 2003 through September 2008

For most of the independent variables listed in Table 1 we can be fairly confident about the expected signs of their coefficients, either based on economic arguments or our maritime domain knowledge. Starting with the macro variables, our chosen *market rate* proxy is the term structure of freight rates represented by spot market earnings ("zero" charter duration) and the 6-month, one-year and three-year timecharter rates provided by Clarkson Research (2015). We match the duration of each individual timecharter contract with that of a standardised term structure made by using linear interpolation between the nodes represented by these four timeseries. For contracts with an embedded extension option, the duration is defined as the mid-point between the minimum and maximum duration. Given that the Clarksons data are only available on a weekly (Friday) basis we also match the report date of the individual fixture to the most recent observation point in the time dimension. While more advanced smoothing procedures could be applied both in the time and duration dimension, such as the "maximum smoothness" approach in Koekebakker and Adland (2004), this could also introduce spurious noise or bias in the data and so this approach is not adopted here. Naturally we expect our properly specified market proxy and the contract rate to be highly positively correlated, with a coefficient close to 1. The relationship between the *fuel price* and timecharter rates is not obvious *a priori*, principally because it is the charterer that separately pays for fuel under a timecharter. However, because higher fuel prices will increase the effective transportation cost for the commodity on a $/tonne basis, the most likely outcome is a reduced willingness to pay for vessel hire during times of high fuel prices, i.e. a negative coefficient. In effect, a negative coefficient here would indicate that some of the fuel costs are indirectly passed on to shipowners even under a timecharter.

Considering the ship-specific variables, larger vessels (*DWT*) within a segment should obtain higher TC rates as their bigger cargo-carrying capacity and economies-of-scale effects in voyage costs translate into higher timecharter-equivalent spot earnings ($/day). It is also expected that vessel age (*Age and Age_squared*) has a potentially non-linear negative effect on timecharter rate levels, principally due to age restrictions in certain ports and countries. The flag state of the vessel has often been chosen as a quality indicator (see e.g. Thanopoulou, 1998) and we here include a dummy to reflect whether a flag state is put on the Paris MOU grey/blacklist (*Flag_D*). We also considered the following additional ship-specific variables: vessel speed, engine make, build country, the presence of onboard cranes and engine horsepower. However, these were dropped as they were insignificant across specifications. There is also a risk that build country serves as a proxy for energy efficiency (vessel design), in which case including this variable could affect our statistical inference.

Continuing with our variables representing vessel energy efficiency, we formulate four separate proxies in order to check the robustness of any findings of a TC rate premium. Firstly, we consider simply daily fuel consumption (*Consumption*) at the design speed. This variable represents nominal fuel consumption in idealised "flat water" conditions and so the actual fuel consumption in real-life seaway conditions will be higher. Secondly, we define a Fuel Efficiency Index (*FEI*) as follows:

$$FEI = \frac{Consumption}{DWT \cdot Speed \cdot 24} \cdot 10^6 \qquad (1)$$

The FEI effectively measures fuel consumption on a "grams per tonnemile" basis by taking into account the ability of a vessel to produce transportation work (speed and capacity). Thirdly we use the Existing Vessel Design Index (*EVDI*) supplied by Rightship (2016). The EVDI is in principle equivalent to the IMO (2010) Energy Efficiency Design Index (EEDI) but is calculated also for existing ships rather than newbuildings only (from January 1, 2013). Fourthly, the fuel expenditure (*Fexp*) variable measures the deviation in the daily fuel expenditure of a given vessel compared to the average fuel expenditure in the fleet. Thus, this variable takes into account both the prevailing fuel price at the time of the fixture and the difference in daily fuel consumption (tonnes per day). The fuel price here refers to the average of the prevailing spot prices in Rotterdam and Singapore for either intermediate (IFO) or heavy fuel oil (HFO) depending on the fuel type consumed by the particular vessel. We note that our *Fexp* variable is very similar to the "Difference from average fuel expenditure" in Agnolucci et al (2014) such that a comparison of estimated parameters is appropriate.

For all our four energy efficiency variables, a higher reading denotes lower energy efficiency (either higher fuel consumption/expenditure or higher consumption/emissions per tonne mile) and so we expect negative coefficients with regards to the freight rate in the absence of a market failure. Specifically, if energy efficiency is fully rewarded we would expect *Fexp* to have a negative coefficient that is close to -1, that is, all savings in daily fuel expenditure compared to the fleet average are reflected in a reduced daily charter hire. For the fuel efficiency variables we also allow for an interaction dummy for the July 2003 to September 2008 boom period in the drybulk freight market (Boom_Cons, Boom_FEI, Boom_EVDI and Boom_Fexp, respectively). These are included in order to assess the impact of market conditions on the willingness to pay for energy efficiency. Our expectation is that energy efficiency will matter less during very strong markets than during times of low earnings when there is a focus on cost reduction. Our *a priori* expectation is therefore a positive coefficient for these interaction dummies, suggesting a reduced premium for energy efficiency during boom times compared to normal market conditions.

Turning finally to the contract-specific variables we would expect, for instance, that a contract with flexible time of redelivery (*Option_D*) should be more valuable than a contract without this possibility, because a rational charterer will exercise this option only if it has a positive economic value. We would expect most effects of the timecharter duration (*Period*) on contracted freight rates to be picked up by our duration-dependent market proxy, and so this variable is included mainly as a control. The coefficient for the delivery lead time (*Forward*) is expectedly negative as timecharter rates further out on the forward curve will be lower when the term structure is typically downward sloping, as was the case during our sample. Atlantic delivery of the vessel (*Atlantic_D*) is expected to command a premium in the drybulk market. This is because of asymmetric tradeflows where Pacific-bound cargoes dominate, resulting in fronthaul (Atlantic to Pacific) freight rates typically being higher than for the reverse backhaul trade. Thus, timecharters starting in the Atlantic should have a higher value as they include the option to perform the better-paying fronthaul voyage (assuming the common "worldwide redelivery" of the vessel at the end of the timecharter).

3.2. Regression model

To explain the determinants of the period timecharter rate $\mathrm{F_i}$ for fixture i, we estimate various specifications of the following general model:

$$F_i = \alpha_0 + \alpha_1 I_t + \alpha_2 B_t + \sum_j \theta_j R_{i,j} + \sum_j \omega_j S_{i,k} + \varepsilon_i \qquad (2)$$

where F_i is the observed freight rate of the ith fixture (contract) signed at date *t*. Two variables account for macroeconomic market conditions at date *t*: I_t is the calculated "market rate" for a standardized vessel and B_t is the bunker price. $R_{i,j}$ is the set of j contract-specific variables and $\mathrm{S_{i,k}}$ is the set of k ship-specific variables listed in Table 1 above. Finally, ε_i is a random perturbation such that $E(\varepsilon_i) = 0$ and $V(\varepsilon_i) = \sigma^2$.

When estimating Equation 2 we use panel data estimation techniques in lieu of pooled ordinary least squares estimation as the latter does not account for the individual heterogeneity in ships that is constant over time. This omission leads to biased and inconsistent coefficients (Verbeek, 2012). Instead we utilise the random effects (RE) model, which takes into account variation both within and across observational units over time. However, it imposes a strict assumption that the individual unobserved heterogeneity is not correlated with the error term (see, Nickell, 1981; Bartels, 2008; Bell and Jones, 2015, for a detailed discussion). We note that the alternative Fixed Effects model is not appropriate in our case as all our ship-specific variables (with the exception of age) are time-invariant. All our specifications were shown to be prone to heteroskedasticity based on the Breusch-Pagan test (Breusch and Pagan, 1979). Even though this does not bias the results, it impacts the standard errors obtained and thus the efficiency of the estimators. To control for potential heteroscedasticity and serial correlation in the error term we therefore use the cluster-robust (Hubert-White) standard errors (White, 1980). Finally, we tested for multicollinearity by estimating pair-wise correlations between the variables. In the few cases where variables were economically similar but highly correlated (such as measures describing vessel size) the final selection was governed by the specification tests described by Davidson and

Mackinnon (1981). Due to the large number of non-linear combinations, which can lead to ambiguous results (Stock and Watson, 2012), the Davidson-Mackinnon test is preferred over alternative tests which exist in the panel data literature (see, for instance, Ramsey, 1969 or Bierens, 1982).

4. Data and empirical results

We utilize a dataset of 9,136 individual timecharters kindly provided by Clarkson Research Ltd. The sample covers public fixtures between January 2001 and January 2016 for drybulk vessels of 40,000 DWT and upwards and includes all relevant vessel specifications. Weekly (Friday) fuel prices for Rotterdam and Singapore for the same time period were obtained from Clarkson Research (2016) Shipping Intelligence Network.

Table 2 below contains the descriptive statistics for our variables by size segment. We can notice the "economies of scale" effect in energy efficiency, where fuel consumption increases less than proportionately with vessel size (DWT), leading to declining FEI and EVDI averages with increasing size. Regarding contract specifications, Capesize vessels tend to be fixed further ahead (Forward, days) and for longer time periods (Period, months) than the smaller sizes. The Pacific Ocean clearly dominates as the place of delivery, with Atlantic delivery constituting between 18% and 27% of all contracts. Importantly, we note that the difference between the calculated "market rate" and the average contract rate is very low, already highlighting how individual contract and vessel factors are not likely to add much explanatory power.

Table 2 – Descriptive statistics

	Capesize			Panamax			Handymax		
	Average	Std.Dev.	No_obs	Average	Std. Dev.	No_obs	Average	Std. Dev.	No_obs
Contract rate	43851	38212	1494	28633	20928	5720	23805	15772	1922
Market_rate	47573	40264	1494	28738	20491	5720	24250	16020	1922
Fuel price	373.66	172.60	1494	378.68	171.11	5720	422.46	167.45	1922
DWT	168612	14004	1494	74608	4293	5720	51740	4595	1922
Age	7.6	6.2	1494	7.2	5.3	5720	6.2	5.1	1922
Flag_D	2.1%		1494	1.2%	0.0%	5720	1.1%		1922
Consumption	55.3	7.5	1221	33.5	3.8	5060	29.8	3.5	1576
FEI	0.969	0.105	1219	1.336	0.139	5057	1.708	0.194	1576
Fuel_exp	381.24	3003.57	1221	78.33	1569.78	5060	106.52	1450.60	1576
Period	10.3	7.7	1494	8.1	6.0	5720	7.0	5.2	1922
Forward	21.0	34.7	1494	12.9	24.8	5720	9.3	20.8	1922
Atlantic_D	18%		1494	24%		5720	27%		1922
Option_D	78%		1494	88%		5720	83%		1922

Table 3 below shows the results of the estimations of our various model specifications for the Panamax sector (60,000DWT – 100,000DWT). We note that all models are of linear instead of logarithmic specification as logarithmic models were both less efficient and harder to interpret. Encouragingly, the estimates conform extremely well to our *a priori* expectations based on economic theory, and are highly stable both with regards to magnitude and signs across model specifications.

Table 3 – Panamax sector results

Contract rate as dependent var	1	2	3	4	5	6	7	8	9
Macro-variables									
Market_rate	1.011	1.006	1.006	1.008	1.005	0.988	0.991	0.994	1.005
	0.004	*0.003*	*0.003*	*0.003*	*0.003*	*0.004*	*0.004*	*0.004*	*0.003*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fuel price	-3.437	-2.297	-2.323	-2.241	-2.283	-1.230	-1.418	-1.386	-2.216
	0.251	*0.308*	*0.309*	*0.270*	*0.309*	*0.319*	*0.322*	*0.279*	*0.307*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Ship-specific variables									
DWT		0.116	0.098	0.062	0.114	0.126	0.104	0.067	0.113
		0.020	*0.019*	*0.014*	*0.020*	*0.020*	*0.019*	*0.015*	*0.020*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age		256.16	253.63	268.80	258.79	270.55	264.12	273.71	272.20
		31.45	*31.52*	*28.20*	*30.53*	*31.21*	*31.38*	*28.09*	*30.65*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age_Sq		-23.58	-23.30	-25.18	-23.85	-24.00	-23.64	-25.27	-24.57
		1.72	*1.73*	*1.59*	*1.66*	*1.72*	*1.73*	*1.59*	*1.67*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Flag_D		314.7	329.2	260.0	314.2	268.8	294.9	248.9	310.8
		427.3	*437.3*	*371.3*	*425.0*	*446.5*	*457.6*	*388.2*	*423.5*
		(0.461)	(0.452)	(0.484)	(0.460)	(0.547)	(0.519)	(0.521)	(0.463)
Consumption		-37.68				-50.74			
		14.03				*14.23*			
		(0.007)				(0.000)			
Boom_Cons						30.50			
						3.44			
						(0.000)			
FEI			-1186				-1509		
			366				*372*		
			(0.001)				(0.000)		
Boom_FEI							648.8		
							84.3		
							(0.000)		
EVDI				-8.61				-93.53	
				42.50				*41.78*	

				(0.839)				(0.025)	
Boom_EVDI								188.33 *23.48* (0.000)	
Fuel_exp					-0.093 *0.035* (0.007)				-0.141 *0.032* (0.000)
Boom_Fuel_exp									0.215 *0.089* (0.016)
Contract-specific variables									
Atlantic_D		2686 *124* (0.000)	2686 *124* (0.000)	2774 *120* (0.000)	2687 *124* (0.000)	2682 *125* (0.000)	2682 *125* (0.000)	2773 *120* (0.000)	2691 *124* (0.000)
Forward		-12.9 *4.3* (0.003)	-12.9 *4.3* (0.003)	-12.3 *4.3* (0.004)	-12.9 *4.3* (0.003)	-13.3 *4.2* (0.002)	-13.2 *4.2* (0.002)	-12.6 *4.2* (0.003)	-13.1 *4.3* (0.002)
Period		-30.2 *10.6* (0.004)	-30.1 *10.6* (0.005)	-31.1 *10.1* (0.002)	-30.2 *10.6* (0.004)	-38.2 *10.5* (0.000)	-37.1 *10.5* (0.000)	-37.8 *10.0* (0.000)	-30.1 *10.5* (0.004)
Option_D		-447.6 *164.8* (0.007)	-446.6 *164.8* (0.007)	-451.8 *162.3* (0.005)	-445.3 *164.9* (0.007)	-424.8 *165.5* (0.010)	-428.4 *165.6* (0.010)	-429.3 *162.3* (0.008)	-443.2 *164.7* (0.007)
CONSTANT	634 *137* (0.000)	-6601 *1401* (0.000)	-4935 *1492* (0.001)	-3887 *1119* (0.001)	-7742 *1492* (0.000)	-7309 *1402* (0.000)	-5335 *1502* (0.000)	-4192 *1120* (0.000)	-7683 *1503* (0.000)
N. Of obs	5696	5037	5034	5696	5037	5037	5034	5696	5037
Overall R^2	0.972	0.980	0.980	0.981	0.980	0.981	0.981	0.981	0.980
VIF test	2.51	28.94	25.07	11.49	9.14	27.57	24.08	11.48	8.63

* numbers in *italic* are robust std. errors; numbers is brackets ( ) are p-values.

As expected, the market rate proxy dominates in terms of explanatory power, with the basic macroeconomic specification (1) providing an R^2 of 0.97, with both the fuel price and the market rate being significant at the 99.9% level of confidence. The Atlantic delivery premium, in the order of $2,700/day, is also clearly present in the data. As for vessel age, the estimated second-order polynomial relationship is such that, all else equal, a brand new vessel will command a slight premium of about $250/day, declining sharply to a $5,400/day discount for a 15-year old vessel. The only counter-intuitive result in Table 3 is a negative coefficient for the Option dummy, suggesting that timecharters with a flexible time of redelivery of the vessel come with a discount. While we are aware that most shipping industry practitioners would consider such options as being "given away for free", suggesting statistical insignificance, it is difficult to explain why TC extension options should result in a *lower* TC rate.

If we focus finally on our chosen energy efficiency measures, a number of interesting inferences can be made from the above results. Firstly, all our energy efficiency variables have the expected negative sign for the sample as a whole, though the EVDI not significantly so. Secondly, all the interaction dummies for energy efficiency during the boom period are positive. This is also as expected, and illustrates how there is a lower willingness to pay for energy efficiency during strong freight markets. As an example, the estimated parameters for Fexp are -0.093 for the sample as a whole, or -0.141 during normal markets and 0.074 during boom markets if we distinguish by market conditions. The observation that the total coefficient for the boom period is actually positive for the *EVDI* and *Fexp* variables is tantamount to saying that less energy efficient ships commanded a premium during the boom. This could be related to "high powered" vessels being more attractive when freight rates (and, thus, the value of time) are high, due to the ability of maintaining high operational speeds also in real seaway conditions.

In other to check the robustness of the above findings, Tables 4 and 5 show the estimates for the larger Capesize vessels (100,000DWT+) and smaller Handymax vessels, respectively. Starting with Capesizes, we can once again see the dominance of the "market rate" in determining the level for individual fixtures, albeit with the simple macroeconomic model having a somewhat lower R^2 of 0.949.

Table 4 – Capesize sector results

	1	2	3	4	5	6	7	8	9
Macro-variables									
Market_rate	0.925	0.940	0.940	0.942	0.941	0.933	0.942	0.938	0.938
	0.011	*0.010*	*0.010*	*0.009*	*0.009*	*0.012*	*0.012*	*0.011*	*0.009*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fuel price	-4.679	-5.482	-5.196	-5.763	-5.822	-4.703	-5.427	-5.383	-2.865
	1.049	*1.398*	*1.365*	*1.257*	*1.492*	*1.321*	*1.316*	*1.169*	*1.240*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.021)
Ship variables									
DWT		0.198	0.217	0.202	0.197	0.198	0.217	0.202	0.180
		0.034	*0.031*	*0.030*	*0.031*	*0.034*	*0.031*	*0.030*	*0.029*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age		562.93	555.03	452.34	571.89	559.30	556.43	446.86	627.86
		184.78	*187.40*	*168.30*	*187.39*	*183.80*	*187.85*	*168.09*	*175.79*
		(0.002)	(0.003)	(0.007)	(0.002)	(0.002)	(0.003)	(0.008)	(0.000)
Age_Sq		-48.95	-49.21	-45.19	-48.70	-48.87	-49.23	-44.99	-50.27
		10.06	*10.14*	*9.64*	*10.23*	*10.02*	*10.15*	*9.63*	*9.58*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Flag_D		-4809	-4943	-3387	-4882	-4802	-4940	-3390	-3386
		2035	*2055*	*2428*	*2017*	*2052*	*2050*	*2435*	*2125*
		(0.018)	(0.016)	(0.163)	(0.015)	(0.019)	(0.016)	(0.164)	(0.111)
Consumption		55.21				48.55			
		50.96				*51.60*			
		(0.279)				(0.347)			
Boom_Cons						14.86			

						11.13 (0.182)			
FEI			3434 *3096* (0.267)				3584 *3122* (0.251)		
Boom_FEI							-269.4 *587.9* (0.647)		
EVDI				4.17 *206.83* (0.984)				-45.77 *198.37* (0.818)	
Boom_EVDI								99.20 *123.79* (0.423)	
Fuel_exp					0.197 *0.114* (0.083)				-0.271 *0.085* (0.002)
Boom_Fuel_exp									1.499 *0.206* (0.000)
Contract variables									
Atlantic_D		3729 *573* (0.000)	3727 *572* (0.000)	3715 *525* (0.000)	3696 *574* (0.000)	3770 *570* (0.000)	3712 *570* (0.000)	3740 *524* (0.000)	3767 *540* (0.000)
Forward		-34.0 *10.9* (0.002)	-34.1 *10.9* (0.002)	-34.1 *10.1* (0.001)	-34.0 *10.8* (0.002)	-34.4 *10.8* (0.002)	-34.0 *11.0* (0.002)	-34.3 *10.1* (0.001)	-32.8 *9.6* (0.001)
Period		67.1 *36.0* (0.063)	65.4 *36.1* (0.070)	46.6 *32.9* (0.157)	70.3 *36.1* (0.052)	60.8 *35.5* (0.087)	67.4 *35.7* (0.059)	43.4 *32.7* (0.183)	80.6 *35.2* (0.022)
Option_D		419.8 *634.0* (0.508)	357.1 *637.4* (0.575)	-78.4 *566.4* (0.890)	470.3 *631.3* (0.456)	444.7 *637.8* (0.486)	348.5 *638.7* (0.585)	-56.7 *568.8* (0.921)	246.3 *608.1* (0.685)
CONSTANT	1038 *641* (0.105)	-35758 *5217* (0.000)	-39216 *6390* (0.000)	-32475 *5364* (0.000)	-32856 *5372* (0.000)	-35654 *5201* (0.000)	-39278 *6381* (0.000)	-32434 *5353* (0.000)	-30797 *4945* (0.000)
VIF test	2.07	26.23	18.19	10.71	9.27	24.99	17.56	10.73	8.74
N. Of obs	1488	1215	1213	1488	1215	1215	1213	1488	1215
Overall R^2	0.949	0.971	0.971	0.971	0.971	0.971	0.971	0.971	0.973

* numbers in *italic* are robust std. errors; numbers is brackets ( ) are p-values.

Vessel age has a similar non-linear effect as for Panamax vessels, with brand new vessels earning about $600/day more than the market rate, declining to an approximately $11,000/day discount for a 15-year old Capesize, all else being equal. Interestingly, despite only 2% of the fuxtures being related to a black- or greylisted flag under the Paris MOU, most specifications suggest that these vessels must offer a significant discount of nearly $5,000/day in the timecharter market. The Atlantic premium (around $3,700/day) is highly significant for all specifications, as is the discount for forward delivery. Timecharter duration (Period) is now broadly insignificant, which is the expected result as long as the market rate proxy takes the changing shape of the term structure of freight rates properly into account. In other words, any dependence on the length of the period should be embedded in the “market rate” data. There is no significant value of having an embedded extension option.

Importantly, no measure of energy efficiency is a significant determinant of the TC rate for the sample as a whole. When we account separately for the “boom” period, *Fexp* has a coefficient of -0.271 during normal market conditions and a total coefficient of 1.229 during “boom” conditions. This is a more exaggerated pattern that what we could observe for the smaller Panamaxes, and again it is evident that the willingness to pay for energy efficiency is closely related to the freight market cycle. In the case of Capesize vessels, there clearly is a substantial energy efficiency premium during normal market conditions, with approximately 27% of fuel savings being reflected in higher TC rates for individual fixtures. However, during boom times, this relationship falls apart and seemingly energy-inefficient vessels obtain higher rates. We expect that this is only an indication that other, revenue enhancing, vessel specifications are more important in times of very strong freight markets, such as high engine power and vessel speed.

Finally, Table 5 shows the estimated results for the Handymax sector. The market rate, fuel price and DWT remain highly significant determinants across specifications. There is a significant non-linear age effect such that a 15-year old vessel offers, on average, a $3,100/day discount in the market. The flag state effect is present also here, with black-or greylisted flags attracting a $1,500/day discount, all else equal. Of the contract-specific variables, only the Atlantic delivery premium (approx. $3,100/day) is consistently significant. Turning to our energy-efficiency variables, the results are qualitatively very similar as for the other sizes, although lacking in statistical significance in many cases. Specifically, all estimated boom parameters are positive, showing the same relationship between market condition and energy efficiency as observed for the other classes. Focusing on the *Fexp* variable, we observe that 21.6% of fuel savings are reflected in a higher TC rate during normal market conditions, with the total coefficient again switching sign during boom times (reflecting a premium for fuel-inefficient tonnage).

Table 5 – Handymax sector results

	1	2	3	4	5	6	7	8	9
Macro variables									
Market_rate	0.964	0.977	0.977	0.979	0.977	0.960	0.968	0.965	0.977
	0.009	*0.008*	*0.008*	*0.008*	*0.009*	*0.010*	*0.010*	*0.009*	*0.009*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fuel price	0.148	-2.406	-2.403	-2.332	-2.363	-1.598	-1.991	-1.717	-2.150
	0.423	*0.538*	*0.538*	*0.451*	*0.541*	*0.529*	*0.526*	*0.457*	*0.548*
	(0.727)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.000)	(0.000)	(0.000)

Ship variables									
DWT		0.000	0.191	0.192	0.215	0.229	0.199	0.204	0.209
		0.000	*0.035*	*0.028*	*0.034*	*0.036*	*0.036*	*0.029*	*0.035*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age		78.87	75.42	101.35	76.16	94.15	82.06	110.28	73.49
		55.75	*56.16*	*47.93*	*55.39*	*55.79*	*56.45*	*47.60*	*55.53*
		(0.157)	(0.179)	(0.034)	(0.169)	(0.091)	(0.146)	(0.021)	(0.186)
Age_Sq		-13.76	-13.53	-14.55	-13.78	-13.90	-13.55	-14.52	-13.75
		2.90	*2.93*	*2.71*	*2.88*	*2.91*	*2.95*	*2.71*	*2.89*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Flag_D		-1483	-1478	-1636	-1449	-1536	-1516	-1682	-1388
		733	*727*	*764*	*742*	*686*	*701*	*711*	*762*
		(0.043)	(0.042)	(0.032)	(0.051)	(0.025)	(0.031)	(0.018)	(0.069)
Consumption		-32.46				-46.84			
		30.85				*31.73*			
		(0.293)				(0.140)			
Boom_Cons						29.21			
						8.01			
						(0.000)			
FEI			-637				-771		
			440				*448*		
			(0.148)				(0.085)		
Boom_FEI							270.5		
							131.0		
							(0.039)		
EVDI				83.64				27.72	
				69.08				*67.43*	
				(0.226)				(0.681)	
Boom_EVDI								161.06	
								48.34	
								(0.001)	
Fuel_exp					-0.116				-0.216
					0.081				*0.069*
					(0.151)				(0.002)
Boom_Fuel_exp									0.301
									0.201
									(0.134)
Contract variables									
Atlantic_D		3157	3158	3042	3157	3151	3151	3037	3163
		253	*253*	*215*	*253*	*255*	*255*	*216*	*253*
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Forward		-2.5	-2.5	1.5	-2.4	-3.1	-2.8	1.3	-2.2
		5.2	*5.2*	*5.4*	*5.2*	*5.2*	*5.2*	*5.4*	*5.2*
		(0.629)	(0.638)	(0.776)	(0.639)	(0.555)	(0.595)	(0.815)	(0.667)
Period		-26.1	-26.1	-27.1	-26.4	-40.0	-33.4	-39.8	-26.1
		19.5	*19.5*	*20.1*	*19.5*	*20.2*	*20.0*	*20.5*	*19.4*
		(0.181)	(0.180)	(0.176)	(0.175)	(0.048)	(0.095)	(0.052)	(0.177)
Option_D		-323.4	-320.2	-361.9	-325.1	-413.4	-369.6	-456.6	-277.8
		251.0	*251.1*	*267.3*	*250.5*	*251.4*	*253.3*	*267.0*	*248.4*
		(0.198)	(0.202)	(0.176)	(0.194)	(0.100)	(0.145)	(0.087)	(0.264)
CONSTANT	322	-8871	-7630	-9271	-9894	-9482	-7921	-9711	-9660
	289	*1956*	*2223*	*1606*	*1895*	*2042*	*2275*	*1634*	*1953*
	(0.265)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

N. Of obs	1918	1574	1574	1918	1574	1574	1574	1918	1574
Overall R^2	1	1	1	1	1	1	1	1	1
VIF test	2.480	25.200	19.440	11.440	8.720	24.630	19.380	11.640	8.220

* numbers in *italic* are robust std. errors; numbers is brackets ( ) are p-values.

5. Concluding remarks

There are some important takeaways from the methodology and empirical results presented in this paper. Firstly, we have shown that, when properly implemented, the "market rate" will dominate any ship- or contract-specific variables in the determination of the freight rate for individual period timecharters. While not directly comparable due to the smaller sample, Köhn and Thanopoulou (2011) use the spot rate as their market variable and report that their market-only model has an R^2 of 0.789. Indeed, even our basic macroeconomic model for the Panamax sector has higher explanatory power than any of the more comprehensive specifications presented in Agnolucci et al (2014). The point to make here is not about explanatory power *per se*, but that failure to account for the full term structure dynamics in the literature means that the estimates for the remaining contract- and vessel-specific variables are not robust.

Secondly, we have shown that the findings in the literature of an energy efficiency premium are not robust with regards to expanding the historical sample throughout a full freight market cycle. We find, across drybulk vessel sizes, that the extent to which fuel savings are reflected in higher TC freight rates depends on the state of the freight market. During normal freight market conditions (i.e. outside the 2003 – 2008 boom), we find that between 14% (Panamax) and 27% (Capesize) of fuel savings are reflected in a higher TC rate, Our estimates are, thus, substantially lower than the approx. 40% reported for Panamax vessels for the period 2008-2012 by Agnolucci et al (2014). More importantly, however, this relationship breaks down during the 2003 – 2008 freight market boom, when it is the fuel-*inefficient* vessels that instead attract a rate premium.

Is this sufficient evidence to claim that a market failure exists? Our results certainly suggest that there is a very low reward for building fuel efficient vessels for chartering out in the timecharter market during normal market conditions and, worse, with energy-efficient vessels being penalised during boom times as charterers presumably focus on revenue-enhancing vessel attributes such as speed and engine power. Of course, the latter observation reflects entirely rational economic behaviour, as the value of time far exceeds any fuel savings during times of very high freight rates. Still, the low degree to which fuel savings accrue to shipowners even during normal markets is concerning. Within the framework of Blumstein et al (1980), we can structure the possible reasons for a market failure as follows:

Lack of information: The relative fuel efficiency within a fleet of vessels operating in real-life dynamic sea conditions is actually very hard to measure. If the expected fuel savings are hard to estimate, it may be reasonable that it is not priced highly by the market. There is also the related problem of asymmetric information, where only the vessel owners have a fair idea of real-life operational performance but typically only have to warrant a vessel's service speed and consumption.

Market structure: The drybulk freight market is generally taken as a textbook example of a perfectly competitive market. However, Adland et al (2016) show, in the case of the voyage charter market, that certain large drybulk charterers have pricing power. If relationships matter, or if charterers have a degree of market power over a large number of competing shipowners, then this makes it less likely that they have to pay a premium for energy-efficient ships.

The above discussion also points to a possible policy solution: standardised and mandatory systems for the collection and dissemination of vessel data on energy efficiency (i.e. principally real-world data for fuel consumption as a function of vessel speeds). Thus far such initiatives have been voluntary and organised by non-profit organizations such as Rightship. Yet, in the broader context of emission monitoring, supranational organizations such as the EU and IMO have the opportunity and incentive to mandate the collection and distribution of such vessel-specific data in international regulations. This would also alleviate the problems related to asymmetric and incomplete information on the real energy efficiency of the global fleet.

One criticism against our study could be that we have relied on nominal (design) values for speed and fuel consumption when, in practice, what matters is the real fuel consumption based on real sailing speeds and seaway conditions. Moreover, at least since the 2009 financial crisis, most ships have been sailing with reduced speeds, so-called slow-steaming. This is obviously a choice based on data availability, as real-life fuel consumption numbers (e.g. noon log reports) are not available on a scale that would enable a meaningful study. Secondly, we note that because fuel consumption is roughly a cubic function of speed, reduced sailing speeds will only have led to a lower variance in fuel consumption across the fleet and, consequently, made the "no fuel efficiency premium" even harder to reject statistically. As a related point, we acknowledge that if all timechartered vessels tend to be of high quality, then this selection bias will have an impact on our findings.

Finally, we note that the market can reward energy efficient designs through other channels than the charter rate premium investigated here For instance, it is likely that fuel efficient vessels achieve better utilisation by being "first picks" if they are re-let on the spot market and therefore have less idle time and higher average earnings. As we do not have detailed operational data on a ship-by-ship basis we are unable to assess whether this is indeed the case, though this is a very interesting avenue of future research.

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